Root Cause Analysis and Troubleshooting Techniques

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Abstract
Troubleshooting is a fundamental technique that everyone should acquire. It is rooted in the various techniques collectively referred to as cause–effect analysis (root cause analysis or RCA) but with significant differences. Both utilize cause–effect relationships as the key to finding solutions. However, troubleshooting is usually more short-term oriented, focusing on what is wrong (where and how), while RCA is more long-term oriented, focusing on why (for long-term solutions). The intent of this article is to clarify some common points of confusion, including the true meaning of root cause and RCA, the difference between RCA and troubleshooting, and techniques and tools for RCA and troubleshooting.

INTRODUCTION
The term “root cause” is frequently used in our professional life, and occasionally in our social and personal lives as well. “Have you found the root cause yet?” is a common question we hear people ask. We care about it because when we run into problems, we believe that identifying and addressing root cause will help us resolve the problem more effectively and/or thoroughly.

Given that root cause analysis (RCA) is an old subject, somewhat familiar to many people, one might assume that they would generally have a clear mind on it. Yet, surprisingly, this is often not the case. RCA frequently tops the list of tools people want to learn more about. Many professionals do not feel confident about it and want to see some light shed upon it.

This article summarizes and expands upon a series of publications[1–3] on the subject, and will address the following topics:

• The true meaning of root cause
• The true meaning of RCA
• Techniques to find the leverage point for high return on investment (ROI)
• The difference between RCA and troubleshooting
• Techniques generic for RCA
• Techniques unique for troubleshooting

There are several concepts introduced in this publication that make it unique. Some are simple and powerful, yet not widely known.

• Root Cause: There is NO true root cause in an absolute sense. So-called root cause is what is subjectively chosen to serve in that role. This subjectivity is the source of conflict and confusion about the best strategy and criteria to apply to consistently achieve high-quality RCA outcomes.
• RCA: The purpose of RCA is not to find the “true” root cause per se, since there is none. The purpose of RCA is to find the leverage point that maximizes ROI. There are some unique techniques to help differentiate the potential “root causes” so that one can set priority to actions.
• Troubleshooting: There are strong connections as well as differences between RCA and Troubleshooting. Both rely on cause–effect relationships to find answers. The difference is that RCA is more long-term oriented (focusing on why), while troubleshooting is more short-term oriented for quick turnaround, (focusing on what, where, and how). Focusing on RCA when the need is troubleshooting diminishes ROI, which can cause frustrations, while focusing on troubleshooting when the need is RCA reduces the long-term effectiveness.
• Techniques: There are a series of generic techniques from simple to complex to span the whole spectrum of RCA need. Meantime, there are some unique techniques that are especially suitable for troubleshooting. Is/Is Not Comparative Analysis, Relationship Diagram, and Fault Tree Analysis (FTA) are some examples. FTA is similar to RCA using a root cause tree (RCT) but the goals are different. FTA is focused on troubleshooting to identify what, where, and how; RCT is focused on identifying why, for long-term solutions. The outcomes between the two can be quite different.

THE TRUE MEANING OF ROOT CAUSE
There are a lot of publications and programs explaining tools/methods to do RCA, yet very few of them explain...
or explore the true meaning of root cause. The term “root cause” appears to be simple but is quite misleading and confusing.

Many people who use the term “root cause” are unaware of the larger context of this concept. When asked what root cause means to them, some typical responses are: “It is what is really happening”; “it is the one thing that causes everything else”; “it is the switch that when flipped, turns the light on,” etc. Better yet, “it is the originator of the problem.”

With these types of descriptions, many people imply that there is one specific thing that is the originator of the problem, and that this origin is somewhat “absolute,” meaning unconditional and not relative. This “absolute” originator is what people usually consider as the root cause.

The books on RCA often fail to give clear descriptions of the concept of root cause. For example, although RCA is a must-have tool category, most Six Sigma books only explain the specific tools themselves without exploring the true meaning of “root cause.” Even the encyclopedic quality book, *Juran Quality Handbook*,[4] does not have an entry for root cause. One exception is the *Six Sigma Black Belt Handbook*, by McCarty et al.,[5] which provides a list of tenets that “underpin the belief that root causes can be fixed to improve processes,” citing that “they are must-be accepted beliefs” for Six Sigma to reliably succeed. This is a rare case.

**Concept of Chain of Causation**

Although not many quality or Six Sigma books go very far in exploring the true meaning of “root cause,” the nature of the cause–effect relationship and “root cause” have been widely explored at the philosophical level throughout human history, outside the technology and engineering arena. Some discussions of these subjects can be traced back to the Aristotle and Socrates era. The following argument is widely recognized in the philosophical world: “The nature of a cause–effect relationship forms an infinite chain of causation. Any event is both a cause and an effect at the same time. It is an effect of its upstream events and a cause of its downstream events. One can continue to identify causes to the causes without ending. The only way to force an end to the chain is to attribute the cause to ‘God’ or God’s creation, although this doesn’t provide any practical help in solving a given problem.”

A possible explanation of why nobody touches upon the true meaning of root cause is that god’s creation belongs to the religious, nonscientific world. Some people do recognize the infinite nature of causation, but do not want to cross the line between science and religion. This amounts to a kind of taboo. The rest of the majority simply do not know.

God’s creation was formally attributed as the ultimate end of the chain of causation through the introduction of teleological causality in the Hegelian dialectic. Alexa- 

Spiekin provided a good summary of the concept of the infinite chain of causation in his *Dialectical Materialism*.[6]

An important feature of causality is the continuity of the cause–effect connection. The chain of causal connections has neither beginning nor end. It is never broken. It extends eternally from one link to another. And no one can say where this chain began or where it ends. It is as infinite as the universe itself. There can be neither any first (that is to say, causeless) cause nor any final (i.e., inconsequential) effect. If we were to admit the existence of a first cause we should break the law of the conservation of matter and motion. And any attempt to find an “absolutely first” or “absolutely final” cause is a futile occupation, which psychologically assumes a belief in miracles.

To summarize the philosophy of the infinite chain of causation (or causality) again, there is no fixed, absolute “true” root cause per se. The so-called root cause in practice is something subjectively chosen to serve in the “root cause” role. It is a moving target. RCA is not about finding the “true” root cause; it is about how to select the one out of many that benefits the objective the most.

Although this concept is well established in the philosophical world and is self-evident when people are truly objective, it is not widely recognized in the engineering world. In fact, it was somewhat shocking to many people when they were first exposed to this concept. Dean L. Gano helped introduce the concept to the engineering world with his book, *Apollo Root Cause Analysis—A New Way Of Thinking*. Fig. 1 illustrates an example used in that book. As easily seen, the chain can go on and on with no ending. He designated Chapter 2 to introduce the chain of causation concept. Yet, he warned, “because this book challenges conventional wisdom, it may not validate your existing belief system.”

**Cause–Effect Network**

Although individual cause–effect relationships form chains of causation, a single chain of causation can
hardly provide a complete picture of the cause–effect relationship. In reality, a single effect may have multiple causes jointly affecting it, thus forming multiple trailing chains; so may a cause have multiple effects in parallel. A collection of multiple parallel chains may merge and/or split, forming a cause–effect network, infinite at both ends. In this case, a specific problem event is simply a knot in the network. There are some techniques to deal with cause–effect networks, which will be discussed in later sections of this article.

THE TRUE MEANING OF RCA

With the infinite chain of causation concept in mind, one of the major challenges for people is how to know when and where to stop “drilling down” and conclude that they have reached a “root cause” out of the infinite layers of cause and effect. This is the wisdom that differentiates an adult from a 2 year old, and an expert from a novice.

Many articles in the quality literature highlight one key goal of RCA, which is to identify and eliminate the noncritical causes out of many likely causes. In order to do that, one needs to study the strength of the cause–effect relations, deselecting the weak ones, while keeping the ones with high impact. While this is one of the interests of cause–effect analysis, it is insufficient.

The clue resides in the typical business mindset. The ultimate goal of RCA should be to select something that yields high ROI, that is, high return with low cost. That is how most businesses make decisions. It is also how people apply RCA, often subconsciously and without realizing it. Thus, in practice, RCA is about ROI calculation, intentionally or unintentionally. Although ROI calculation may not be openly claimed or recognized as a key goal when performing RCA, it is likely what going through people’s minds, perhaps subconsciously, when choosing root cause. The noncritical causes usually do not generate high ROI. Much can be said about the ROI mindset. ROI has two main dimensions, cost and return, as shown in Fig. 2. The ideal is to achieve low cost and high return simultaneously but this is not always possible. Ultimately, the ratio of return to cost is the deciding factor, the higher the better.

Fig. 3 shows a framework depicting the relationship of problem-cause-effect-solution. It is revised from Wessel’s 98. According to this framework, a problem is shown along with its causes and effects and the two types of solution approaches. Solutions aimed at mitigating the effects are adaptive or reactive in nature; while those aimed at the causes are corrective and preventive in nature. The general idea is to shift attention to the cause side when possible, since preventive solutions are usually (but not always) associated with higher return. When people apply this approach, the original cause will become the new problem (or focus), which has new cause(s) and associated new solutions. This drives the continuous shift of attention to the new cause(s), which is the focus of the 5-Why’s technique. Note that during this continuous process, solutions that were corrective or preventive become adaptive or reactive now, as causes become effects of their own causes. This highlights the fact that roles are relative and are moving targets. Without ROI in mind, it is hard to decide when to stop the chase.

Although it is generally true that the cause side solutions are usually associated with higher returns, there are certainly exceptions. Importantly, the costs associated with the cause side solutions are usually higher too and at least some cost components are always higher. This is usually not recognized by people, resulting in the major fallacy of thinking the deeper the better, as well as in the common dilemma of not knowing when to stop. In contrast, people are frequently stuck with short-term solutions without understanding the deeper causes for the problem. The truth is that deeper is not necessarily better, and
choosing when to stop is much easier if people are conscious of the costs and returns.

To better understand this mentality, let us take a look at the cost structure of RCA. The cost of a solution (solution cost) has at least two components—the cost to search for the cause and solution (research cost), and the cost to implement the solution (implementation cost). The research cost will always go higher the deeper we go, while implementation cost may vary significantly. The trick is to find a solution that has significantly lower implementation cost, to offset the research cost and get a low solution cost overall:

\[
\text{Solution cost} = \text{research cost} + \text{implementation cost}
\]

When a cause has a low solution cost and high return, it is a good candidate to serve as the root cause. Yet research is a risky business and before the right cause is found, everything is unknown. It requires experience, functional expertise, intuition, and, sometimes, belief to succeed. Because of this, in many cases people do not want to or can not afford to take the risk. They will settle on less fundamental causes, at least to keep the research cost low.

ROI assessment can be internal (self), external (customer), short-term, or long-term oriented. The results can be very different. These differences tend to be overlooked. In many cases, short-term solutions are chosen due to cost constraints. Also, ROI may change over time, as does root cause. To make the fix long-lasting and organizationally sustainable, all parties’ (stakeholders’) interests need to be considered and balanced. Because of these inherent differences, many CAPA (corrective and preventive action)-like action plans ask for both short-term and long-term solutions.

TECHNIQUES TO FIND THE LEVERAGE POINT FOR HIGH ROI

There are three keys to help identify high ROI solutions. They are:

1. The Leverage Point Principle
2. The Pareto Principle (80–20 rule)
3. The Span of Control/Sphere of Influence Principle

Generally speaking, it is much more rewarding to focus on the causes that have high leverage or high frequency and are within the span of control. These causes should be the first to be considered as the root causes.

The leverage point refers to the causes that cost less to fix but affect more, with higher impact. The Pareto principle has a similar intent. A handful of “vital few” has greater impact than the “trivial many.” That is the mindset of the 80–20 rule—80% of problems are caused by 20% of causes. It is easy to see how the leverage point and Pareto principles affect ROI. But it may be harder to see the link between the span of control and ROI.

Regarding span of control, people’s influence can be roughly grouped into three zones as shown in Fig. 4. At the center is a core area within which people have full control. It is called the span of control. Outside the central core area, people have some influence but not full control. It is called the sphere of influence. Outside the sphere of influence is the area over which people have no influence whatsoever. The span of control/sphere of influence principle prescribes that people should operate within the span of control as much as possible. If it is not possible, people should try to operate within the sphere of influence while always avoiding operation outside of it. The point behind this mindset is that the causes within the span of control usually provide the highest leverage or ROI and the zone outside the sphere of influence gives no leverage and no ROI at all.

In practice, the span of control principle can be used to identify where to stop drilling-down the chain of causation and to select the preferred root causes to work on. Ideally, the root causes should be situated within the span of control; at worst, within the sphere of influence. If all of the causes that may interact with each other are within the span of control, usually it is safe to stop drilling-down the chain (s) and to treat them as the root causes. By the same token, if a cause is outside the sphere of influence, it is also a good indication to stop drilling, because working beyond that generates no returns. That is not to say that people should always give up in this case, because the influence boundaries may be expandable. The focus then needs to be shifted to expanding the influence boundaries to enclose the cause outside the sphere of influence. In practice, the
sphere of influence is frequently the dominating factor in root cause selection.

One engineer with a strong engineering mindset had a hard time adopting the span of control mindset. He made the following counter argument: “When you lose your key at night, you look for it where it is most likely to be at, not limiting yourself only to where you can see, e.g., under the street lights, etc. If it’s likely to be in the dark area, you need to look in the dark area.” This is a typical outside-of-influence scenario. In this case, the most rewarding action is to expand the sphere of influence by bringing in flashlights to assist in the search.

Case Studies of Root Cause Concept Applications

Two famous RCA cases, the Jefferson Memorial Preservation and the John Snow Cholera Breakout Investigation, can be used to demonstrate how the three keys have been used intuitively or unintentionally to help investigators land on root causes that generate high ROI. After the two case studies, Six Sigma trainees who enter the program confused always walk away enlightened and excited, dealing with RCA with newfound confidence. The Quality Minutes video produced by Juran Institute contains some brief video clips for the two cases. The study here is from a specific angle, looking for clues for the three keys.

Case 1: Jefferson Memorial preservation case

Here is the synopsis for the case:

The U. S. Park Service noticed that the Jefferson Memorial monument deteriorated faster than other monuments. They investigated the problem with the “5-Why’s” and formed a chain of causation:

- Why does it deteriorate faster? Because it gets washed more frequently.
- Why is it washed more frequently? Because it has more bird droppings.
- Why more bird droppings? Because more birds are attracted to the monument.
- Why more birds? Because there are more fat spiders in and around the monument.
- Why more spiders? Because there are more midgets flying in and around the monument in the evening.
- Why more midgets? Because the monument illumination attracts more midgets.

The list can keep going, on and on. Multiple events at various stages can be declared as the root causes and, thus, various solutions can be sought after, to break the chain of causation. For example, people can treat the bird droppings as the root cause and focus on their removal or prevention through alternative measures, such as coating the surface of the monument with water-resistant coatings, etc. Or, they can focus on the removal and prevention of spider infestations caused by the presence of midgets, through pesticizing spiders. Or, they can try different lighting features, such as color, intensity, location, and pattern, to make it less attractive to midgets, etc. The solution chosen by the Park Service was to turn on the lighting one hour later in the evening. This simple act allegedly reduced 90% of the bird-dropping problem.

A lot can be said about this simple yet magical solution. The biggest advantage of it over others is really the high ROI, although the people who selected it may not realize it that way. The illumination, in this case, is not the absolute originator of the problem, but it is both a high leverage point and fully within the span of control of the park service, and, therefore, is a wonderful choice of root cause.

Worth noting is the common observation that ROI is usually a concern of the private sector. The public sector, that is, government functions, usually is not as sensitive to and motivated by ROI. The same is generally true for scientific research. Scientists usually are inclined to seek and identify more fundamental level causes. In this case study, it is very likely that researchers would try to have a better understanding of why and how this particular site is more attractive to midgets. This knowledge may lead to ways to alter lighting features to reduce the attraction. They might even attempt to change the midgets themselves to reduce their attraction to the light. While this approach may be more scientific, it may not provide as high ROI and may be outside the span of control of the Park Service. Taking into consideration all three criteria, leverage point, Pareto principle, and, especially, the span of control, the solution of choice, delaying the lighting by 1 hour, is a clear winner.

Case 2: 1854 London cholera epidemic case

There was a famous cholera breakout in 1854, London, where 127 people died in three days. Dr. John Snow, a preeminent physician then, and a legendary figure in the history of public health, closely monitored the breakout and made a breakthrough observation. He was able to trace the source of the breakout back to a particular water pump on Broad Street, using his famous Snow Map (a concentration map, see Fig. 5). Because of this, he was able to contain the breakout by removing the handle of the pump. “For his persistent efforts to determine how cholera was spread and for the statistical mapping methods he initiated, John Snow is widely
considered to be the father of modern epidemiology”—
citation from *Old News* by Vachon.\(^9\)

“He found out that the addresses of the cholera epidemic victims clustered around the Broad Street pump. He found out through interviews that the great majority of the victims had used the Broad Street pump as their source of drinking water. While Dr. Snow did not know what had caused the epidemic in the first place, he was able to succeed in persuading the local community leaders (parish guardians) to remove the pump handle. The epidemic ended immediately!” For people who want to know more details about John Snow and this famous breakout, the Department of Epidemiology of (University of California, Los Angeles) has a wonderful, dedicated webpage for it: http://www.ph.ucla.edu/epi/snow.html.

Interestingly, at that time, people had no idea about cholera. Dr. Snow examined the water under a microscope and found that it contained “white, flocculent particles.” He suspected it was the cause, but nobody believed him and he moved no further. He was only able to isolate the source without understanding of what it really is. Another scientist from the same era, Italian scientist Filippo Pacini, was credited as the discoverer of cholera. So, clearly, Snow was not anywhere close to identifying the true “root cause” of cholera. Yet, he was able to get a handle on the problem, literally, the handle of the pump, which is the high leverage point of the breakout. The pump handle is a good visual illustration of what the leverage point is really about. Fig 6 shows what now stand on London’s Broadwick Street (then Broad Street), the John Snow Memorial and Pub. Note that the pump is without its handle.

**Fig. 5** The snow map.

**Fig. 6** John snow memorial and pub on Broadwick Street, London.
It is worth noting that the fundamental root cause of the cholera breakout went beyond the cholera itself. The poor living conditions of that Soho neighborhood of London were the more fundamental cause of the series of breakouts there. The following is a description from *Soho—A History of London’s Most Colourful Neighborhood* by Summers[10]: “By the middle of the 19th century, Soho had become an insanitary place of cow-sheds, animal droppings, slaughterhouses, grease-boiling dens, and primitive, decaying sewers. And underneath the floorboards of the overcrowded cellars lurked something even worse—a fetid sea of cesspits as old as the houses, and many of which had never been drained. It was only a matter of time before this hidden festering time-bomb exploded.”

In fact, the 1854 breakout was not the only breakout, nor the first. There was a series of cholera breakouts starting in 1831. Reports show that nothing was done about the living conditions there 1 year after the famous 1854 breakout. So if Dr. Snow was to concentrate on the more fundamental root causes of the problem, it would be beyond his sphere of influence as a physician. It would not be a choice with high ROI, at least no quick returns for the breakout. Even for the choice of removing the pump handle, he still needed to expand his sphere of influence through persuasion of the local community leaders (parish guardians) to adopt the idea.

**POPULAR RCA TOOLS AND GENERIC TROUBLESHOOTING TECHNIQUES**

This section introduces selected tools to cover the whole spectrum of generic RCA need. It also introduces a unique practice and technique: a weighting system, to differentiate and prioritize potential root causes. It prevents loss of focus over many equally important causes.

Although many tools can be used to identify root causes, the following five are some of the most popular ones that cover the whole spectrum from simple to complex. The five popular tools are (from simple to complex):

- **Is/is not comparative analysis.**
- **5-Why’s**—Good for digging deep, yet with narrow focus.
- **Fishbone Diagram (Cause–Effect Diagram)**—Good for investigating broadly, yet not too deeply, the causes for a single effect.
- **RCT**—A tree structure diagram that begins with undesirable effects (UDEs) and drills down to root causes. It is a combination of the Fishbone and the 5-Why’s and allows studying the interactions among causes.
- **Cause and effect matrix (X–Y matrix)**—Used to quantify and prioritize the impacts of a group of causes (X’s) on a group of effects (Y’s) through a numerical ranking. It is originally intended to handle multiple effects.

Some of the tools are so popular that most people are familiar with them, for example, the 5-Why’s and the Fishbone. The following discussion will focus on highlighting some aspects that are usually overlooked.

**Is/Is Not Comparative Analysis**

Is/is not analysis is a comparative analysis method. It has not been formally classified as a cause–effect analysis tool. But, it can certainly provide insight into the details of what’s happening, and it has frequently been used to investigate root causes when the cause–effect relationships are broad but not deep.

Fig. 7 (a) shows a sample template for is/is not analysis. There are fancier versions for this, but the key components are the same. They generally focus on the six “WH’s”: What, Why, How, Where, When and Who, the basic dimensions to identify and describe things. These basic things appear to be simple but allow people to zoom in on the problem to get visibility and clarity on details. As shown in Fig. 7 (b), by this method, the problem can be quickly narrowed in on and defined in clear relief by a process of segregation, or, to put it another way, by dividing and conquering.

Some firms use is/is not exclusively as the primary problem solving tool. They have standardized the descriptions into eight categories and added additional components such as brief sections for potential causes and cause testing. The eight categories are as follows:

1. What items have the problem?
2. What’s wrong with the item?
3. Where was the item located?
4. Where was the problem located?
5. When was the problem first noticed?
6. How does the problem repeat?
7. When in the process or lifecycle was the problem seen?
8. How big is the problem?

Many people like this tool a lot after the first exposure, since it is straightforward and intuitive, not high-tech, yet very effective in discovering and organizing a lot of details. Some organizations consider it the first step in every RCA effort.
The 5-Why’s technique is good for digging deep, yet with narrow focus. The 5-Why’s is essential to develop the chain of causation, as illustrated in Fig. 1, and is a no-brainer to most people. Again, what might be unclear to many people is what has been discussed earlier, how to decide when and where to put an end to the chain.

**Fishbone Diagram (Cause–Effect Diagram, Ishikawa Diagram)**

Fishbone is good for investigating broad, yet not too deep, causes for a single effect. This is a popular tool, very good for investigating a large number of causes. A major limitation is that the relationships among the causes are not readily seen and interactions among them will be missing. To identify and diagram interactions requires RCT tools.

One problem many people have with this tool is that it will identify a bunch of causes or potential root causes. People may get lost regarding what to focus on in the next step. Thus, prioritizing the causes becomes a needed step. Sometimes people use a cause–effect matrix to formally do that. But, in this application, the matrix only uses single output criteria for the evaluation, which is not what the matrix was originally designed for.

One unique practice is to do the evaluation and prioritization right on the fishbone diagram. This is an extra value-added step. This technique employs a unique weighting system to reflect the ROI mindset in the assessment. As shown in Fig. 8, the weighting system has two dimensions, opportunity, which represents returns, and controllability, which represents costs. The
assessment can be done either categorically or numerically. Certainly, more or different criteria can be used for this assessment, such as those used in FMEA (Failure Mode and Effect Analysis): severity and frequency, etc. But opportunity and controllability are among the ones having the most leverage. This practice can help in clarifying and visualizing the focus of the next step in problem solving. Causes with high opportunity and within the span of control get the highest priority. An additional value-added practice is to highlight high priority items in red or circle them.

The fishbone diagram can be linked to the affinity diagram. The affinity diagram is used for open-minded brainstorming using post-it notes to capture ideas, one per note, then grouping the free-flowing ideas into categories by physically moving around and reorganizing the post-its. While the fishbone is more rigidly structured, usually having recommended categories to go by (as shown in Fig. 9), the affinity diagram is less structured, more free-flowing, not constrained by pre-set categories, and is a better format to use during the brainstorming stage. Fundamentally, the two diagrams are the same. The biggest advantage of the affinity diagram is the flexibility to regroup ideas to create better, more relevant categories. When no categories are prescribed or pre-selected, sometimes people create an affinity diagram first, and then turn it into a fishbone diagram.

RCT

RCT is a tree-structured diagram that begins with UDEs and drills down to root causes. In a way, RCT is a combination of the fishbone diagram and the 5-Why’s, which facilitates both broad and deep analysis. The way they are combined also allows studying the interactions among causes.

RCT is the most sophisticated and complex method of cause–effect analysis. Similar tools with mutations include FTA, event tree analysis, current/future reality tree, etc. RCT can be presented in a formal or less formal format. Fig. 10 shows a formal tree structure, a
fault tree. In this case, formal notations (called gates) are used to show the relationships. But this is not always needed. When the relationship is simple, like an “or” relationship, for example, no gate is necessary.

The biggest advantage of this tool is that it can study and present the interrelationships among causes. The most common relationship is the “or” relationship, meaning either cause A or B alone can lead to effect C. Sometimes the relationship is an “and,” meaning causes A and B together are needed to produce effect C. Other relationships may occur as well, although they are hardly used. For example, one cause A may have multiple standalone effects, B and/or C. Sometimes, multiple causes need to occur in sequence to generate an effect. Sometimes the “or” relationship is exclusive. Sometimes some causes are conditional. All of the relationships, although many are not commonly used, can be captured as shown in Table 1. The RCT format provides sufficient flexibility to allow people to study and present all of these types of relationships.

To make the tree focused and concise, it is advisable to focus on UDEs for each event/cause. The key points are:

- UDEs are negative on their own merit
- No further explanation is needed on why
- Effects are negative at face value

Table 1  Formal notation for various relationships

<table>
<thead>
<tr>
<th><strong>AND Gate</strong></th>
<th>Any higher level event that is a result of lower level events</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OR Gate</strong></td>
<td>The lowest level event. The limiting resolution in our analysis.</td>
</tr>
<tr>
<td><strong>Event</strong></td>
<td>If any input event occurs, the output event will occur</td>
</tr>
<tr>
<td><strong>Priority AND Gate</strong></td>
<td>Output event occurs if all events occur in the right order from left to right</td>
</tr>
<tr>
<td><strong>Exclusive OR Gate</strong></td>
<td>Output event occurs if one, but not both of the two input events occurs</td>
</tr>
<tr>
<td><strong>Inhibit Gate</strong></td>
<td>Input produces output when conditional event occurs</td>
</tr>
<tr>
<td><strong>Conditional Event</strong></td>
<td>Used with inhibit gate</td>
</tr>
</tbody>
</table>

Fig. 10  RCA example.
There are actually multiple approaches for doing this.

1. **Top-down approaches**
   - Complete fishbone first. If further analysis is needed, turn the bone structure 90 degrees counterclockwise to form the initial tree, study the (and, or) relationship among the existing causes, and then expand from there.
   - Perform mind mapping to generate ideas, study relationships among items, consolidate items, and rearrange them in tree structure. Fig. 11 shows an example mind map. It is equivalent to a free-flow RCT, without showing the relationships.
   - Perform 5-Whys on each of the first layer causes; repeat “horizontally” to exhaust all possible first layer causes and form multiple chains in parallel; study the relationship across the chains and consolidate when needed; repeat the same process at each layer.

2. **Bottom-up approach**
   - Complete affinity diagram to generate and organize ideas. Connect and consolidate groups into tree structure.

One limitation with top-down approaches is that when the tree is directly drawn on paper, it is difficult and inefficient to make changes, especially when rearranging relationships. It is strongly recommended to use post-it notes to capture events/causes to avoid this problem. Alternatively, a bottom-up approach has some advantages. It allows generating and capturing thoughts without restriction prior to putting them in order.

Once again, the decision of when and where to stop drilling down is a common concern when using this tool. The sphere of influence criterion can help assess ROI. The point where a cause crosses a control boundary (i.e., the sphere of influence or span of control) is generally a good place to stop.

In the spirit of continuous improvement, it is acceptable to customize tools to incorporate more useful information that may help analysis. Besides generating the traditional cause–effect relationships, another thing that can be done is to differentiate and group the causes through the previously described weighting system and color coding. An example is shown in Fig. 12. With this type of notation, readers can quickly and easily identify in the diagram the key causes to be focused on in the next step. Those highlighted with the letters “H” and “C” and colored in red are the ones that should be further explored first. They are highlighted by circling them as well. Most applications in practice miss this type of value-added assessment and information.
Fig. 12 Example of RCT with weighting categories.

Table 2 Example of cause–effect matrix

<table>
<thead>
<tr>
<th>Rating of Importance to Customer</th>
<th>10</th>
<th>9</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROCESSES</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>----</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Effort</td>
<td>8</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Commonality</td>
<td>8</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Yield (accuracy)</td>
<td>8</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Change Implementation</td>
<td>8</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>252</td>
<td>264</td>
<td>237</td>
</tr>
<tr>
<td>%</td>
<td>11.36%</td>
<td>11.90%</td>
<td>10.69%</td>
</tr>
</tbody>
</table>

1. Customer Input
2. Equipment Specs
3. Bill of Materials
4. # of Revisions
5. Label Documentation
6. Drawings
7. Pre Meeting
8. Ownership
9. Approval Cycles
10. Delays

What is the cause of the corrosion problem? 
- Customer suffered a corrosion problem, meantime they tested a surge of sulfate with our product. They suspect it is the primary contributor and demand for the root cause and control.
### Table 3: Example of cause–effect matrix with objective scores

<table>
<thead>
<tr>
<th>Input Variables - Materials</th>
<th># of Adjustment Entry/Total</th>
<th>Added Quantity/Total</th>
<th>Subtracted Quantity/Total</th>
<th>Added S/Total</th>
<th>Subtracted S/Total</th>
<th>Added Quantity/Consumption</th>
<th>Subtracted Quantity/Consumption</th>
<th>Added S/Consumption</th>
<th>Subtracted S/Consumption</th>
<th>Rank Without Consumption Info</th>
<th>Rank by Subtracted $</th>
<th>Overall Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>830R25</td>
<td>0.001</td>
<td>0.000</td>
<td>0.001</td>
<td>0.000</td>
<td>0.027</td>
<td>0.138</td>
<td>-2.840</td>
<td>-2.840</td>
<td>11</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>225-7500-0585-03</td>
<td>0.007</td>
<td>0.020</td>
<td>0.037</td>
<td>0.003</td>
<td>0.013</td>
<td>0.102</td>
<td>0.028</td>
<td>-2.317</td>
<td>0.357</td>
<td>0.316</td>
<td>28</td>
<td>17</td>
</tr>
<tr>
<td>001638-01-006154</td>
<td>0.004</td>
<td>0.000</td>
<td>0.003</td>
<td>0.042</td>
<td>0.076</td>
<td>0.358</td>
<td>-0.036</td>
<td>0.011</td>
<td>-0.036</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>4002-5973-02-01</td>
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<td>0.004</td>
<td>0.010</td>
<td>0.008</td>
<td>0.108</td>
<td>0.183</td>
<td>-0.157</td>
<td>0.015</td>
<td>-0.209</td>
<td>15</td>
<td>15</td>
<td>15</td>
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<tr>
<td>004448-8105-0100-01</td>
<td>0.012</td>
<td>0.009</td>
<td>0.000</td>
<td>0.067</td>
<td>0.206</td>
<td>0.564</td>
<td>0.564</td>
<td>0.000</td>
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<td>403</td>
<td>8</td>
</tr>
<tr>
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<td>0.009</td>
<td>0.034</td>
<td>0.005</td>
<td>0.013</td>
<td>0.117</td>
<td>-0.135</td>
<td>0.071</td>
<td>-0.135</td>
<td>13</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>FKG-782-01-009871</td>
<td>0.003</td>
<td>0.024</td>
<td>0.017</td>
<td>0.008</td>
<td>0.044</td>
<td>0.258</td>
<td>-0.092</td>
<td>0.258</td>
<td>-0.092</td>
<td>30</td>
<td>52</td>
<td>10</td>
</tr>
<tr>
<td>01-009644-17C0-9700-7036-01</td>
<td>0.018</td>
<td>0.052</td>
<td>0.000</td>
<td>0.014</td>
<td>0.069</td>
<td>0.570</td>
<td>0.569</td>
<td>0.000</td>
<td>0.559</td>
<td>32</td>
<td>403</td>
<td>11</td>
</tr>
<tr>
<td>PKG-782-01-0098971</td>
<td>0.002</td>
<td>0.002</td>
<td>0.005</td>
<td>0.018</td>
<td>0.221</td>
<td>0.072</td>
<td>-0.083</td>
<td>0.071</td>
<td>-0.084</td>
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<td>3</td>
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<tr>
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<td>0.001</td>
<td>0.006</td>
<td>0.017</td>
<td>0.103</td>
<td>0.047</td>
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<td>17</td>
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<td>0.003</td>
<td>0.005</td>
<td>0.015</td>
<td>0.020</td>
<td>0.152</td>
<td>0.037</td>
<td>-0.070</td>
<td>0.073</td>
<td>-0.070</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>01-01854-01-021524</td>
<td>0.001</td>
<td>0.001</td>
<td>0.003</td>
<td>0.008</td>
<td>0.016</td>
<td>0.079</td>
<td>-0.095</td>
<td>0.047</td>
<td>-0.095</td>
<td>25</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>01-021554-01-009897</td>
<td>0.003</td>
<td>0.002</td>
<td>0.008</td>
<td>0.003</td>
<td>0.011</td>
<td>0.076</td>
<td>-0.076</td>
<td>0.029</td>
<td>-0.077</td>
<td>27</td>
<td>21</td>
<td>20</td>
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<tr>
<td>01-021554</td>
<td>0.001</td>
<td>0.000</td>
<td>0.002</td>
<td>0.001</td>
<td>0.012</td>
<td>0.069</td>
<td>0.013</td>
<td>-0.073</td>
<td>0.014</td>
<td>-0.087</td>
<td>31</td>
<td>19</td>
</tr>
</tbody>
</table>
**Cause and Effect Matrix (X–Y Matrix)**

X–Y matrix is primarily used to quantify and prioritize the impacts of a group of causes (input variables, X’s) on a group of effects (output variables, Y’s) through numerical ranking. This tool was originally intended to handle multiple effects. Because of this, the X–Y matrix is a tool that can be used to analyze and evaluate the relationships in a cause–effect network.

As shown in Table 2, a typical X–Y matrix lists input variables (X, causes) to the left and output variables (Y, effects) at the top. It contains two sets of numerical evaluations: the impact of individual X’s on individual Y’s in the middle part of the matrix and the weight or importance of individual Y’s on the top part of the matrix. The final score, shown in the “total” column, is the weighted summation (“sumproduct” function in Excel) of the individual impact multiplied by weight for each X. It represents the impact of an individual X on all Y’s overall.

Most of the time the impact scores are subjective, but they may, in some cases, be objective as well. Table 3 shows a unique example of objective scores, where impacts are the % contribution of each of the X’s (materials) to specific Y’s ($, quantities, or # of entries). They are all based on actual values.

Some people like to use the X–Y matrix to formally prioritize the causes generated by the fishbone, as a separate step. Unfortunately, even when people perform this additional step, they do not necessarily connect the output explicitly to ROI. Also, using the matrix for a single criterion (i.e., single Y) evaluation defeats the original intent of the matrix structure.

X–Y matrix represents one of three major scoring schemas existing for multivariate-multi-response scenarios, typically in matrix format. The other two are the schema used for FMEA and the original Pugh matrix. The weighted summation schema is widely used in many forms with mutations. For example, the core of quality function deployment, also called house of quality (HOQ), is built around the X–Y matrix. Just the layout is transposed, outputs listed to the left and inputs listed on the top.

**Tools Specifically Good For Trouble Shooting**

As mentioned earlier, there are strong connections as well as differences between RCA and troubleshooting. They both rely on cause–effect relationships to find solutions. The difference is that RCA is more useful for the pursuit of long-term gains, while troubleshooting is more useful for quick, short-term solutions. Troubleshooting usually focuses on what is wrong (specifically where or how), while RCA usually focus on why it is wrong. To perform RCA when the need is troubleshooting dilutes both efficiency and effectiveness, which can bring frustration to the pursuit of a practical solution. While all of the discussions on identifying root causes
remain valid here, it is important to remember that the ROI for troubleshooting is short-term oriented.

There are some unique techniques that are especially good for troubleshooting. Three tools are typically handy as examples:

- Is/is not comparative analysis
- Relationship diagram
- FTA

Is/is not comparative analysis has already been discussed in depth. The important point is that the purpose of this analysis is not to go deep. It is well-suited to the pursuit of short-term, quick-fix solutions.

Fig. 13 shows an example of a relationship diagram. In this case, the effects of molding factors upon each other are shown. This tool graphically shows the interconnections and interactions between all related parties. With the arrows shown, one can trace back to the origination side and forward to the receiving side. The party that has more arrows going out is likely to be at the upstream origination side; the ones having more arrows going in are more likely to be at the downstream receiving side. The tool was originally used by law enforcement to investigate crimes. Because it is quite effective in zooming in on suspects, it was adopted for other uses, typically investigation-related.

FTA and RCT analysis are performed similarly, but they have different goals. FTA aims at troubleshooting to determine what, where, and how to find short-term solutions; RCT aims at why, to find long-term solutions. With these different goals, the outcomes may be quite different. A typical FTA for troubleshooting purposes may focus on the decomposition or breakdown of the product or object only, from assembly to sub-assembly, to components. The idea is that if we can verify a certain subset (e.g., sub-assembly) works well, we can eliminate this area and focus on other areas for root causes. In a way, it is doing segregation by following the product structure.

CONCLUSION

Most people have not thought much about the deeper meaning of “root cause” and therefore are not very clear on when and where to stop searching for root causes. Events in the universe form an infinite chain of causation, where no absolute root cause exists until you reach “God.” There is no true absolute root cause per se. So-called root causes are what people subjectively choose to serve in the role of origination. The task to find the root cause is really the task to decide when and where to terminate the chain of causation. The key resides in the business mindset, ROI. There are three keys that can help us land on appropriate root causes with high ROI, the leverage point, the Pareto principle, and the sphere of influence.

Here is a good RCA framework and problem-solving mentality.

1. Identify as many potential factors/causes to the problem as possible. In many cases, this process is based on experience or expert opinions. A structured approach with a big picture view will help avoid omissions.
2. Establish differentiation among the causes based on ROI. A quick easy way is to assess opportunity and controllability. The purpose of the first two steps is to establish hypotheses.
3. Seek objective data evidence to verify the hypotheses. If no existing data is available, perform experiment(s) (DOE) to generate new data.

There are five popular tools that can meet the full spectrum of requirements for cause–effect analysis. From simple to complex, they are as follows:

- Is/is not comparative analysis.
- 5-Why’s—Good for digging deep, yet with narrow focus.
- Fishbone Diagram (Cause–Effect Diagram)—Good for investigating broad, yet not too deep, causes for a single effect.
- RCT—A diagram that begins with UDEs and works back to root causes and core problems. It is a combination of the Fishbone Diagram and the 5-Why’s and allows studying the interactions among causes.
- Cause and Effect Matrix (X–Y Matrix)—Used to quantify and prioritize the impacts of a group of causes (X’s) on a group of effects (Y’s) through a numerical ranking. It was originally designed to handle multiple effects.

There are strong connections as well as differences between RCA and troubleshooting. They both rely on cause–effect relationships to find solutions. The difference is that RCA is more useful for the pursuit of long-term gains (focusing on why), while troubleshooting is more useful for finding quick turnaround, short-term solutions (focusing on what, where, and how). The following are some unique techniques that are especially good for troubleshooting.

- Is/is not comparative analysis
- Relationship diagram
- FTA
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REFERENCES