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Quality info

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Root Cause Analysis

Root cause analysis (RCA) is the process of finding the basic underlying cause for an effect we observe or experience. In the context of failure analysis, RCA is used for finding the root cause of frequent machine malfunctions or a big machine breakdown. But what exactly is RCA, and how is it done?

In this article we take an in-depth look at how to perform RCA: We outline the steps, describe common tools and techniques, and give a couple of practical examples. Let's start by defining what RCA is.

What is root cause analysis (RCA)?

Root cause analysis is *the process of tracing causes of an observable problem and identifying the basic* underlying issue *that was causing it*. Fixing the identified basic problem should stop the recurrence of other problems that originated due to it.
If the problem fixed is not the underlying cause, there is no guarantee that the same fault will not occur again. RCA tries to follow the chain of cause and effects to pinpoint the problem that, when eliminated, makes all the other faults disappear.

RCA is not a process that guarantees an outcome. Conducting RCA can be complicated and generally involves a vast amount of data collection and scrutiny. The result of an RCA is not always black and white. It is not a litmus test that can conclusively indicate whether the problem we identified is the root cause. More often than not, we will get only a strong correlation between cause and effect and not a causal relation. From there, an experienced professional must judge whether to investigate further.

RCA is a craft that requires domain knowledge and experience. Otherwise, any fixes implemented will likely be just a cosmetic solution to the problem. In the worst-case scenario, the changes we make can result in worsening the problem.

Despite this dose of uncertainty, RCA is still a powerful tool for understanding and improving the fundamental nature of systems and procedures.

The origin of RCA

RCA has existed as an investigative tool for centuries. But it was never formalized for a long time. It was formally introduced to the world of engineering and technology by Sakichi Toyoda. He was the founder of Toyota Industries Corporation, and he is widely considered to be the father of Japanese industrialization.

One could argue that the innovations from Japanese manufacturing like kaizen and other lean manufacturing processes can be attributed to the practice of finding the root cause of problems and fixing them, rather than being satisfied with a cosmetic solution. All these process improvement techniques have helped to improve the efficiency of manufacturing processes all over the world.

Why conduct RCA?

There are two broad ways in which RCA can be used:

1. To identify the root cause for problems (the more common way)

2. To recognize the root causes for positive changes experienced: Sometimes, the procedures we implement give results that are better than expected; when the reason for the phenomenally good results cannot be easily explained, RCA can be used to identify it.

When to conduct RCA

Conducting RCA requires a significant investment of time, manpower, and money. It will cause further disruption in the production line or the system in which RCA is to be conducted. Therefore, RCA should not be done for every single fault. There is no cut-and-dried rule for when to conduct RCA.

Here are some of the instances based on which experienced professionals can make an informed decision whether to conduct RCA:

- Persistent faults. If the same fault occurs repeatedly, it is worth investigating.

Because the same fault is recurring, we can deduce that the fault will not be cleared by fixing the visible problem. There is some underlying reason for the recurring faults. Such incidents should be investigated with RCA.

- Critical failure. The degree of how critical a failure is can be measured using the cost to the plant or the total downtime due to the particular failure. When such a failure occurs it must be investigated to identify the root cause of the failure. This will help avoid such occurrences in future. Explosions at an oil rig and airplane crashes are examples of critical failures that need to be investigated.

- Failure impact. There are critical machines and critical subprocesses in any system. A failure of these will halt the entire operation because there might not be a backup or mitigation plan for that particular machine or process. In essence, the criticality of the machine or process determines whether to conduct RCA for a failure.

RCA process is based on the 3 Rs

Recognize

The true cause for an effect we observe is not always obvious. Cosmetic fixes don't do much to correct the underlying fault. The elaborate exercise of RCA is conducted to pinpoint the true cause, so we can take corrective actions that will eliminate future issues. As mentioned earlier, RCA can also be done to identify the cause for an unexpected positive outcome.

Rectify

Once the root cause is recognized, the corrective course of action has to be undertaken. If the root cause is addressed, the same problem should not be cropping up again. If the same problems reappear, it is highly likely that the cause identified was not the root cause. You will have to conclude that the previous RCA conducted was not comprehensive, and more investigation needs to be done.

Replicate

Once the root cause is figured out and rectified, you must ensure that the same fault will not occur again in the same system in another location, or at a later time. If the RCA was done to identify the reasons behind unexpectedly good outcomes, you will have to test whether the same factors can be replicated in other scenarios and environments.

In essence, root cause analysis is used to precisely figure out what happened, how it happened, and why it happened, for any incident that occurs.

RCA is applied across many different industries

RCA is in essence a knowledge tool for identifying the root cause of any event or fault. Faults and problems occur in almost every industry, and RCA techniques can be used to investigate the underlying cause and contributing factors.

The most obvious and ubiquitous use we come across is in medical diagnosis. The same symptoms can be caused by a whole set of illnesses. It is the duty of the doctor to identify the underlying cause before a patient can be treated effectively. Almost all episodes of the popular TV show *House, M.D.* are exercises in root cause analysis, although in an unconventional manner.

Many other industry verticals use root cause analysis on a regular basis. Some of them are:

- Manufacturing (machine failure analysis)
- Industrial engineering and robotics
- Industrial process control and quality control
- Information technology (software testing, incident management, cybersecurity analysis)
- Complex event processing
- Disaster management and accident analysis
- Pharmaceutical research
- Change management
- Risk and safety management

RCA is a structured way of thinking and investigating any type of incident. With that in mind, RCA is not just limited to the areas mentioned above. It can be implemented in any sector or industry where the root cause of a problem needs to be identified.

Root cause analysis steps

RCA can be accomplished using many different tools and techniques. These make use of different conceptual models to identify the problem at the root. Alhough all the tools differ at a cosmetic level, each of the techniques has to go through the conceptual steps to conclude the analysis.

Step 1: Problem statement

A problem statement and definition are essential for any form of analysis, not just RCA. This is a clear description of the problem and symptoms experienced. It gives the scope for the analysis.

Without a precise problem statement, RCA will be like a rudderless boat, without a direction to sail toward and unable to change direction. A well-defined problem statement also helps to determine the scale and scope of the potential solution to be implemented.

Step 2: Data collection

All available data related to the incident should be collected. Take, for example, machine failure in a manufacturing plant. Some of the pertinent information that needs to be collected is given below:

- Age of the machine
- Time of continuous operation
- Operating patterns
- Maintenance schedule
- Operators handling the machine
- Specifications of the machine
- Schematic of the plant infrastructure

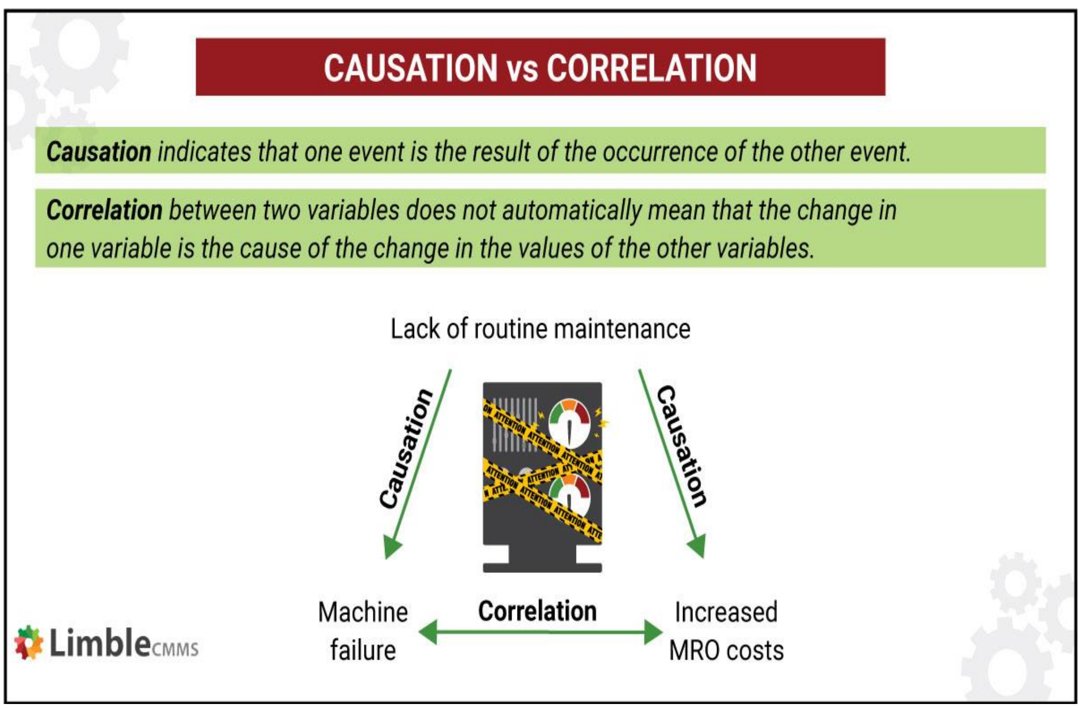
- Operating characteristics of the machine
- Characteristics of the operating environment

Inspecting the machine in person also provides information that could be beneficial for RCA. For facilities that collect data for predictive analytics (in other words, that run predictive maintenance), it will be easy to collate data quickly.

Step 3: Chronology, differentiation, and mapping

A timeline of events must be established. This will help to determine which factors among the data collected are worth investigating. RCA needs data points that potentially lead to the root cause. Chronological sequencing of events and data is very helpful in deciphering causal events from noncausal events.

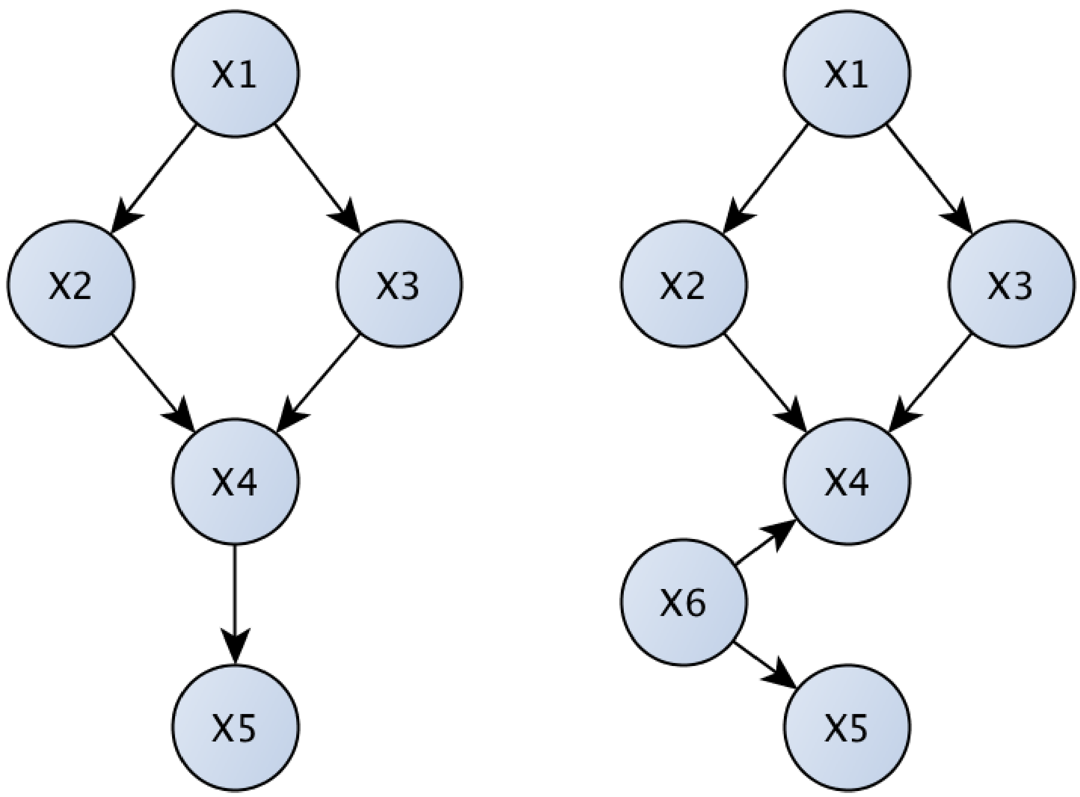
From the data collected, correlations can be found between various events, their timing, and other data collected. This can be used as an initial step to differentiate between causal and noncausal events. One important thing to remember is that correlation does not mean causation.



Causation vs. correlation

You cannot conclude any analysis when a correlation is identified. Causal relations need to be investigated.

From the data collected, chronological sequencing, and clustering, we should be able to create a causal graph (or use one of the root cause analysis tools we'll discuss below). This graph can be used to represent the relationship between various events that occurred and the data collected. The different paths are given different probability weights and can serve as a visual tool to track down the root cause.



Example of causal graph.(Source)

Step 4: Root cause resolution

Once the root cause is identified, the solution to fix it can be easily determined. It can be mapped against the scope defined in the problem statement. If the solution fits the scope, it is implemented.

Fixing the root cause should eliminate the recurrence of the symptoms. If the symptoms occur again, we would need to go back to the drawing board and conduct RCA again.

Once the problem is solved, steps must be taken to avoid its recurrence. There can be multiple solutions applied to solve a single problem. For example, the root cause could be the wear of a bearing, which happened much earlier than expected. In such a case the procedure has to be adjusted to change the bearing at an earlier time. Similar steps taken to avoid recurrence of fault can be changes in the maintenance schedule, different modes of maintenance, and changes in design.

The implemented solution will have to be in line with the available resources. So, if the root cause is pushing the machine too hard, the obvious solution is to shorten machine run time. However, when the production schedule doesn't allow it, another solution might be to schedule preventive maintenance more frequently.

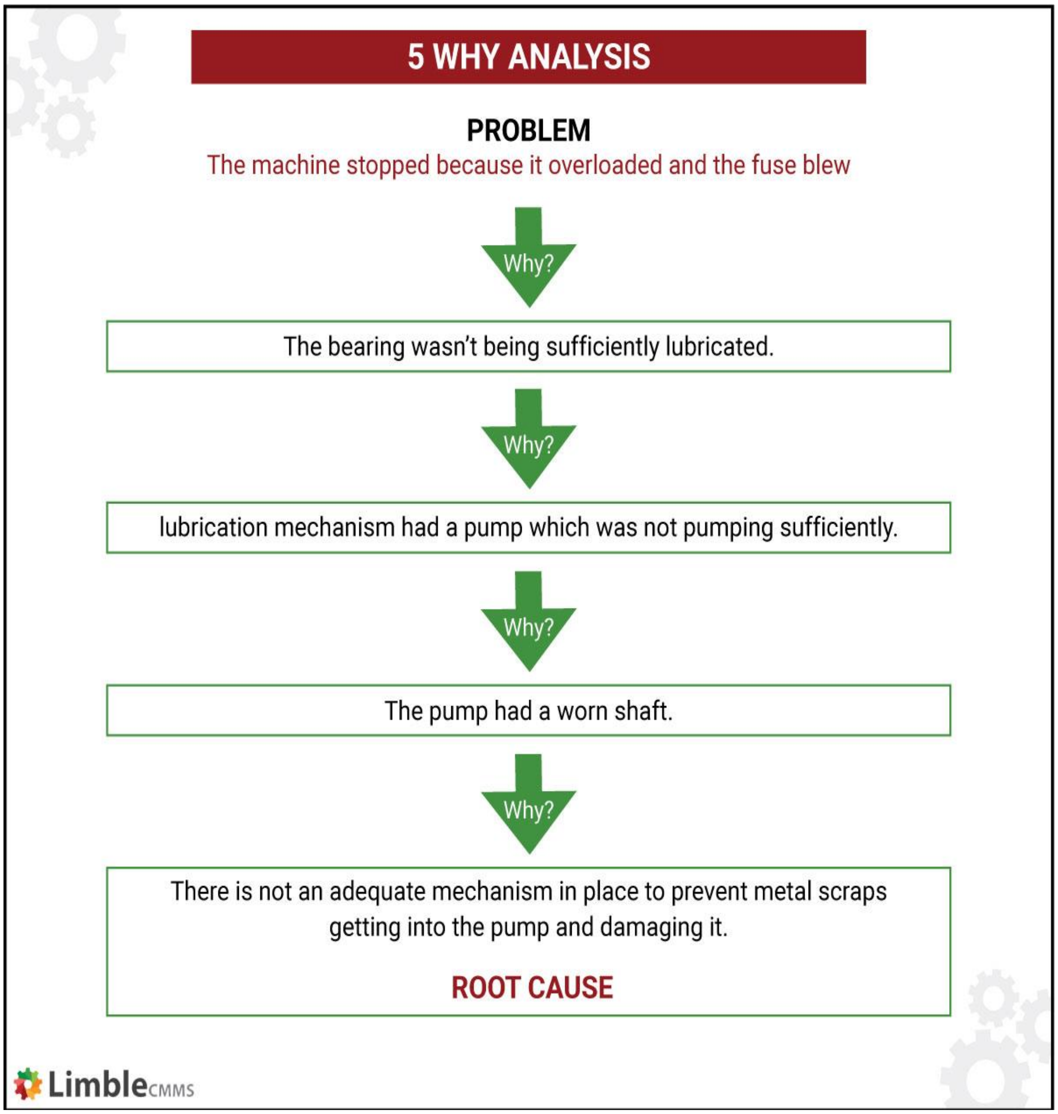
Root cause analysis is not a singular way to an answer. It is a conceptual framework for investigating the true reasons behind the events we observe. Many frameworks are available to execute RCA that have been tried and tested by experimenters. None of these methods are foolproof, but they provide a solid base for how to go about root problem investigation. Let's discuss some of the prominent tools and techniques.

Each of the RCA tools has its own merits, and certain methods are more suitable for different industries and the types of problems that are being investigated. Each company and its management team should have a protocol to adhere to when conducting RCA. Different companies might prefer different techniques. In some instances, external consultants might be brought in to conduct RCA. In such cases, the consultants will have a preferred technique or a combination of techniques they use to conduct RCA. This is one of the reasons why it is hard to create a universal template for RCA that everyone can follow.

Oftentimes, the company will have a preferred RCA technique. If that one does not give the needed answers, other techniques might be explored.

5 Why analysis

The 5 Whys technique, developed for root cause analysis, addresses everything with a "why," just like a curious child. When we ask why the visible problem occurred, we can trace its cause. Then the question why can be asked about the cause we just identified.

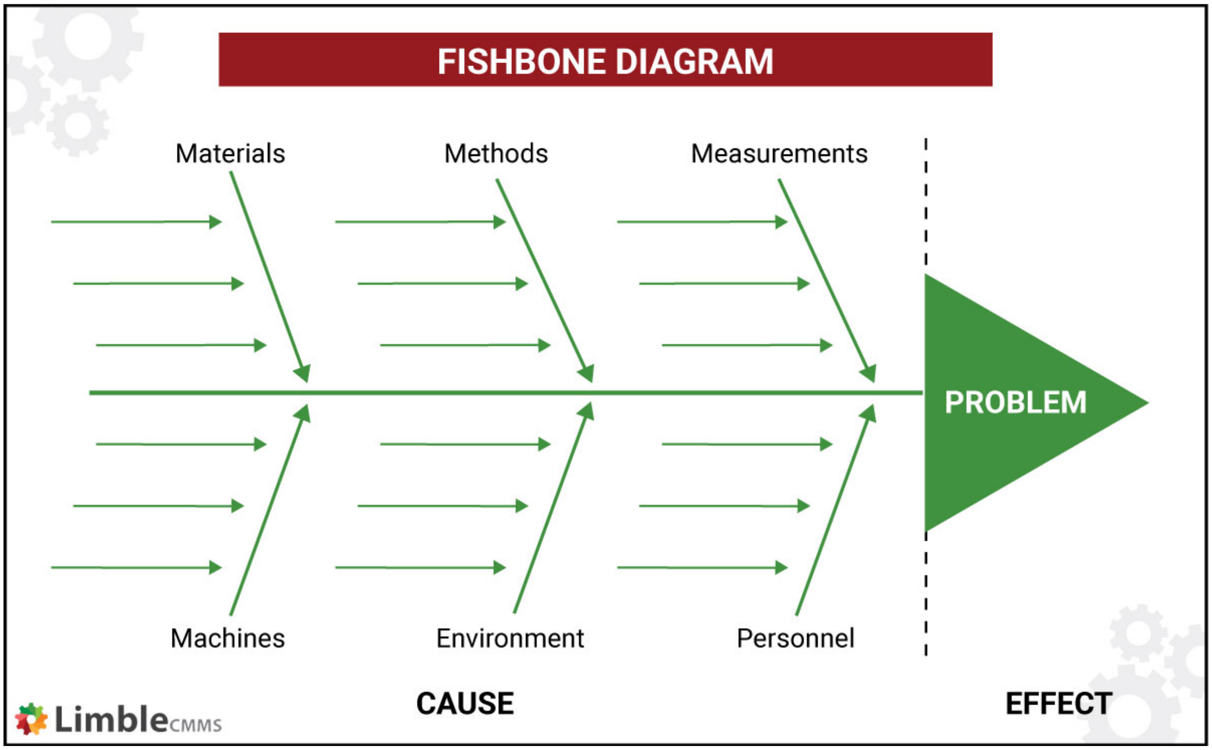


A flow of questions aimed at discovering the root cause of an event

This process can be continued till a stage where there is no need to ask why any further. At that point, we should have reached the root cause of the problem. As a rule of thumb, asking and finding answers to five subsequent whys should be enough to unveil the root cause of most problems. Hence the name 5 Why analysis.

Fishbone diagram (aka Ishikawa diagram)

The Ishikawa method for root cause analysis emerged from quality control techniques that were employed in the Japanese shipbuilding industry by Kaoru Ishikawa. The shape of the resulting diagram looks like a fishbone, which is why it is also called a fishbone diagram. This diagram is predicated on the idea that multiple factors, including the five main ones called the 5 Ms, can lead to the failure/event/effect we are investigating



The 5 M framework—aka. a fishbone diagram—from the Toyota Production System is utilized for RCA with the Ishikawa method.

The 5 Ms are:

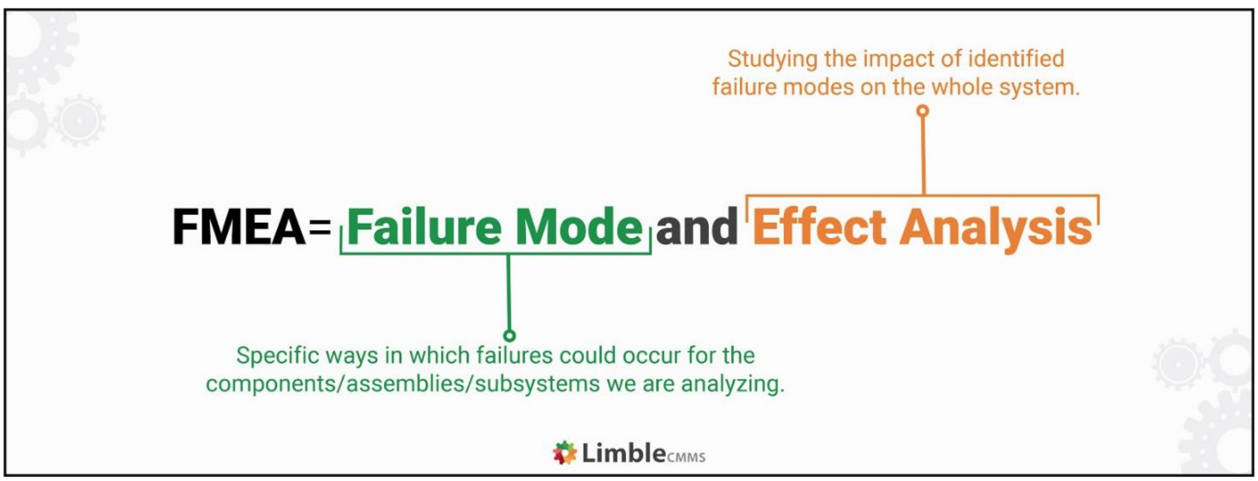
1. Man/mind power
2. Machines
3. Measurement
4. Methods
5. Material

The problem or fault is written down at the right end of the diagram, where the fish head is presumed to be. The cause for it is represented along the horizontal line. Further effects and their respective causes are written along the fish bones that represent each of the 5 Ms. This process is continued until the team conducting it is convinced that the root cause is identified.

The fishbone diagram serves as a visual aid for structured brainstorming sessions. The same technique is also used for product design, ergonomic design, and process improvement.

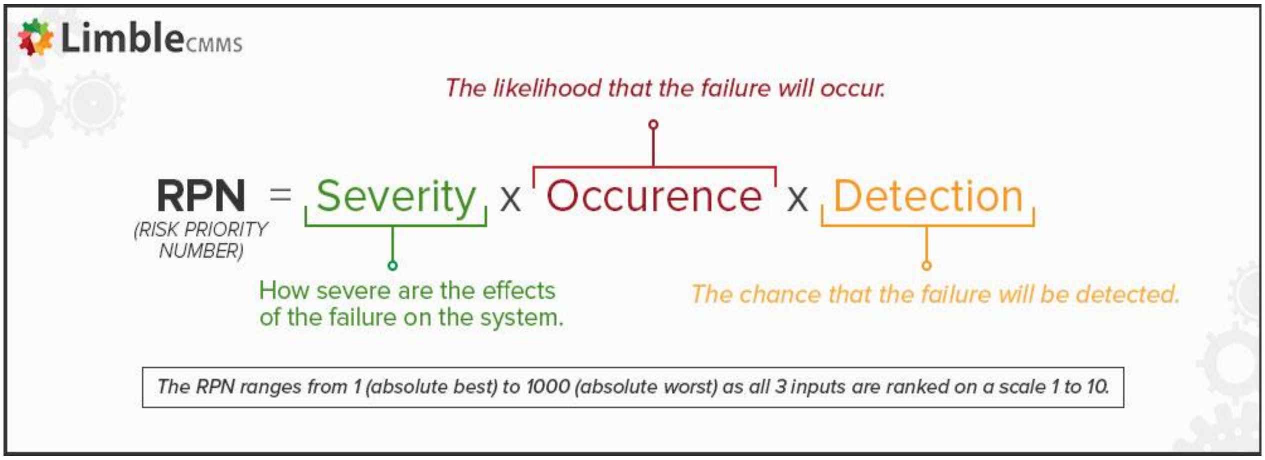
Failure mode and effects analysis (FMEA)

FMEA is a proactive approach to root cause analysis, preventing potential failures of a machine or system. It is a combined systematic approach of reliability engineering, safety engineering, and quality control efforts. It tries to predict future failures and defects by analyzing past data.



Failure mode effects and analysis (FMEA)

A diverse cross-functional team is essential to undertake FMEA. The scope of the analysis must be well-defined and conveyed clearly to all the team members. Each subsystem, design, and process is brought under the microscopic scrutiny of the cross-functional team. The purpose, need, and function of each system are questioned. Potential failure modes are brainstormed. Failure of similar processes and products in the past can also be analyzed to supplement the process.

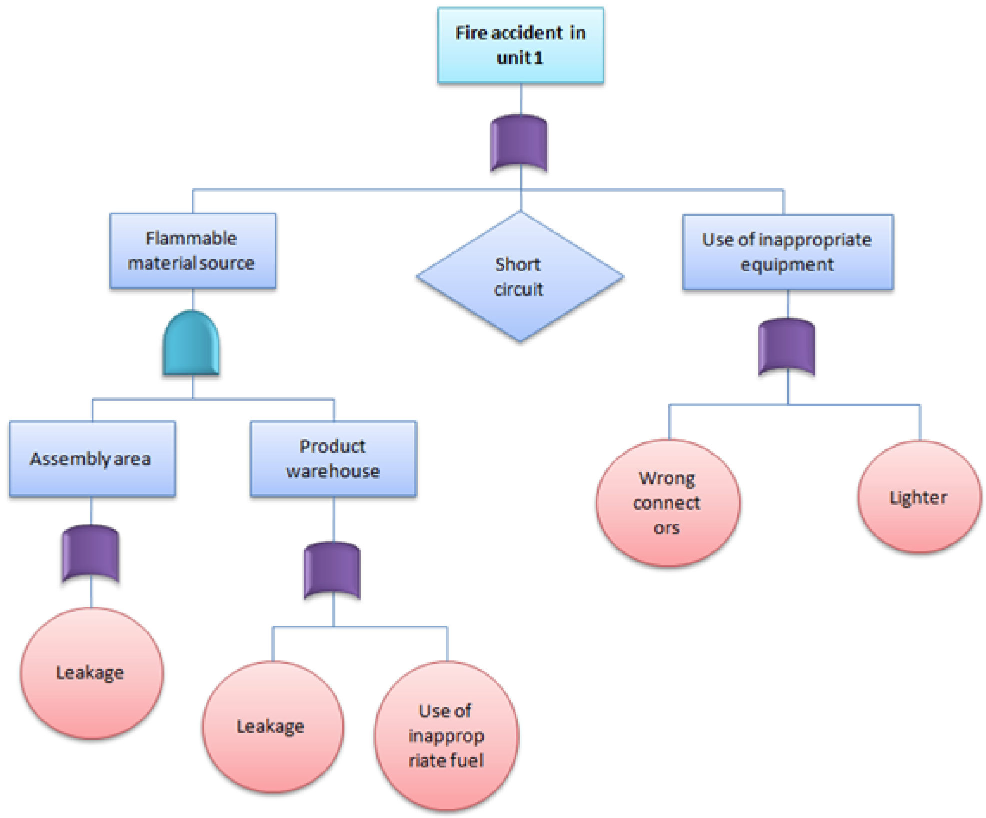


Risk priority number (RPN)

The potential effects and disruptions that could be caused by each of the identified failure modes are assessed and used to calculate its risk priority number (RPN). If the failure mode has a higher RPN than a company is comfortable with, it must be addressed by changing one or more factors outlined in the image above.

Fault tree analysis

Fault tree analysis is a method for root cause analysis that uses Boolean logic to figure out the cause of failure. It was developed in Bell laboratories to evaluate an intercontinental ballistic missile (ICBM) launch-control system for the U.S. Air force.



Fault tree analysis (FTA).Image source

Fault tree analysis tries to map the logical relationships between faults and the subsystems of a machine. The fault we are analyzing is placed at the top of the chart, and information flows down through various "gates" symbolizing the relationships between input and output events. If two causes have a logical OR gate combination causing effect (depicted by the purple symbol in the illustration above), they are combined with a logical OR operator. For example, if a machine can fail while in operation or while under maintenance, it is a logical OR relationship.

If two causes need to occur simultaneously for the fault to occur, it is represented with a logical AND gate. For example, if a machine fails only when the operator pushes the wrong button *and* relay fails to activate, it is a logical AND relationship. It is represented using the Boolean AND symbol (depicted by the turquoise symbol in the illustration above).

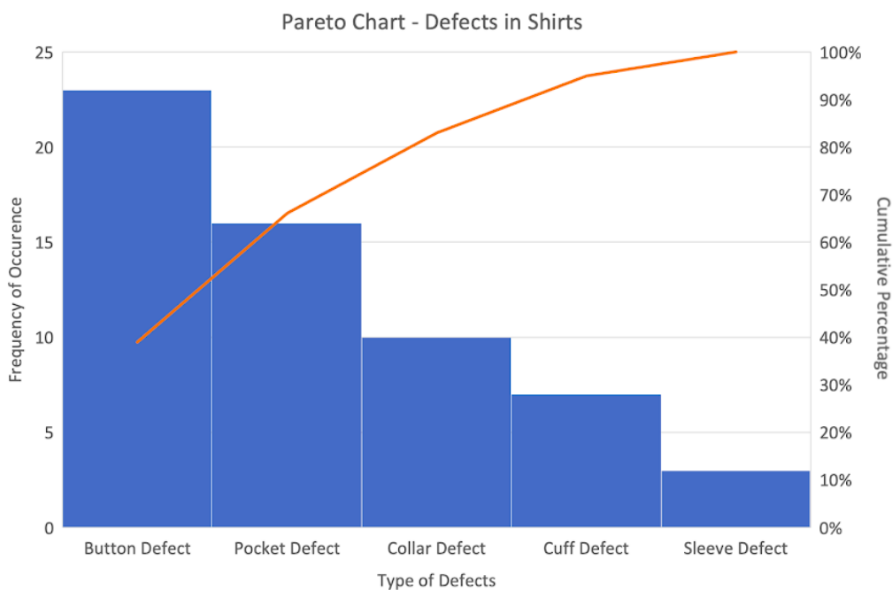
The symbols used in the diagrams represent different kinds of events: A circle is used for a basic event, a pentagon for an external event, a rhombus for an undeveloped event, an ellipse for a conditioning event, and a rectangle for an intermediate event.

The fault tree created for a failure is analyzed for possible improvements and risk management. This is an effective tool to conduct RCA for automated machines and systems.

Pareto charts

Italian economist Vilfredo Pareto recognized a common theme with almost all frequency distributions he could observe: There is a huge asymmetry between the ratio and the effects caused by them. As a rule of thumb, he indicated that, in any system, 80 percent of the results (or failures) are caused by 20 percent of all potential reasons.

The principle is dubbed the Pareto principle (some know it as the 80–20 rule). This skew between cause and effect is evident in many different distributions, from wealth distribution among people to failures in a machine.



Pareto chart. Image source

With the Pareto principle in mind, failures and their possible causes are analyzed. A bar graph and line graph are drawn indicating the frequency of faults and the causes for the faults. With this graph, we are able to observe the skew between causes and failures. Usually, we will discover how a small percentage of factors causes the majority of faults.

The causes that contribute to the most number of faults are then analyzed further, and corrective actions are taken to eliminate the most common faults.

Pareto charts are excellent tools to determine the priority for taking up root cause analysis. According to the Pareto principle, eliminating 20 percent of the most common causes of failure can result in reducing the overall number of malfunctions by 80 percent. Pareto charts will indicate the top failure causes to be further investigated and addressed, according to the criticality of the machine, the impact failure of a specific part, or a combination of the two.

Honorary mentions

Root cause analysis is open-ended, and it has many widely used tools in various industries. Major ones were mentioned in the sections above. Still, there are other noteworthy tools for RCA. Here are a few honorary mentions:

- Cause and effect diagrams. The fishbone diagram is an example of cause and effect diagrams. There are many similar tools that try to map the relationship between causes and effects in a system.
- Kaizen. It is another tool from the stable of Japanese process improvements. It is a continuous process improvement method. Root cause analysis is embedded within the structure of kaizen.
- Barrier analysis. It is an RCA technique commonly used for safety incidents. It is conducted on the premise that a barrier between personnel and potential hazards can prevent most safety incidents.
- Change analysis. When a potential incident occurs due to a change in a single element or factor, change analysis is employed as the root cause analysis technique.
- Scatter diagram. Scatter diagram is a statistical tool that plots the relationship between two data in a two-dimensional chart. It can also be used as an RCA tool.

Root cause analysis examples

RCA example No. 1

Injection-molding machines are widely used around the world to create plastic in almost any shape or form. The part produced by the machine should match specifications for the same, within allowable tolerance.

Let's imagine there is a high incidence rate of faulty products, and we need to get to the bottom of it.

First, the problem needs to be well defined. This includes explaining the precise defect the plastic output is having. By observing the output, we can determine if it is one of the four main defects that could occur with injection molding. They are:

- Flash
- Gassing and venting
- Part distortion
- Short mold

Let's presume that the defect is part distortion. The problem has to be clearly written down, with the number of defects occurring as a percentage. Once that portion is completed, all the available data must be collected. Maintenance logs can be pulled from a computerized maintenance management system (CMMS), manuals from the injection-mold machine manufacturer can be reviewed, etc.

Information should be collected on each defective product. From this, the deviation from specifications should be measured. The heat signature of the product is taken once it comes out of the mold. The temperature of molten plastic in the barrel is also measured.

We know that part distortion almost always occurs due to temperature problems. But we can't be sure where the temperature problem is—in the barrel while heating, or in the mould while cooling. From the data collected, we would be able to identify that. Let's assume the heat signature of the finished product is different from the expected one.

This determines that the problem is in the cooling process. Further investigation concludes that the root problem is the wrong spatial arrangement of cooling liquid conduits.

Changing the conduit arrangement that best fits the mold currently being produced will solve the problem of part distortion.

RCA example No. 2

Imagine an investigation into a machine that stopped because it overloaded, and the fuse blew. Investigation shows that the machine overloaded because it had a bearing that wasn't being sufficiently lubricated. The investigation proceeds further and finds that the automatic lubrication mechanism had a pump that was not pumping sufficiently; hence, the lack of lubrication. Investigation of the pump shows that it has a worn shaft.

Investigation of why the shaft was worn discovers that there isn't an adequate mechanism in place to prevent metal scraps getting into the pump. This enabled scraps to get into the pump and damage it.

The apparent root cause of the problem is metal scrap contaminating the lubrication system. Fixing this problem ought to prevent the whole sequence of events recurring. The real root cause could be a design issue if there is no filter to prevent the metal scrap getting into the system. Or if it has a filter that was blocked due to a lack of routine inspection, then the real root cause is a maintenance issue.

Compare this with an investigation that does not find the causal factor: Replacing the fuse, the bearing, or the lubrication pump will probably allow the machine to go back into operation for a while. But there is a risk that the problem will simply reoccur until the root cause is dealt with.

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