Root Cause Analysis: Techniques and Best Practices: For Current product improvement which can be implemented in New product design

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Abstract

Root Cause Analysis (RCA) has become an effective tool used to look for and eradicate the fundamental causes of product and process deficiencies. More and more industries are focusing on aspects of quality and dependability, and in this respect, RCA serves a valuable function in ongoing process improvement initiatives where it is effectively used on existing products and more importantly on new product development. This research article analyzes the historically accepted forms of RCA, considers suggestions on how RCA can be executed optimally, and examines the application of the results of RCA into new product planning. Moreover, it looks into how contemporary technological developments improve RCA procedures, thus producing better solutions. The results of this study also stress the importance of integrating RCA into the product development process to improve the quality, decrease the number of defects and address the new requirements.

Keywords: Root Cause, Failure, Design, Development

1. INTRODUCTION

In the rapid advancement of product development, there is a continuous pressure felt by companies to produce high quality products that are compliant to the expectations of the consumer. Root cause analysis (RCA) can be known as a fundamental technique in quality management as it aims at defining the root for defects or failure in products and processes. Corrective reviews do not only enable wayward actions, but they also help in identifying methods that can be used in preventing possible issues in current products, and enhancing new product designs.

It should be also noted that RCA implementation into new product development processes is capable of being viewed as a proactive approach to quality management since the experience obtained from handling existing products is applied in the creation of new products. Hence, the objective of this research is to present a clear and extensive understanding of RCA techniques and practices now, how and when to apply them, and in particular, how to apply RCA in the new product development context especially utilizing contemporary technologies.

2. ESTABLISHED TECHNIQUES FOR ROOT CAUSE ANALYSIS

There are several RCA techniques over the years which have been identified and have hence offered different ways of analyzing root causes of a problem. The choice of the right approach may therefore be determined by the severity of the problem that needs to be addressed, the type of data, and the setting within which RCA is to be conducted.

A. Five Whys Analysis

Originating from the Toyota Production System, Five Why's is a problem-solving tool whereby asking why

five times the side issues are eliminated to get to the root of an issue. This method is especially beneficial in cases when certain problems are not visible and it can be incorporated into the different phases of the product development process [1].

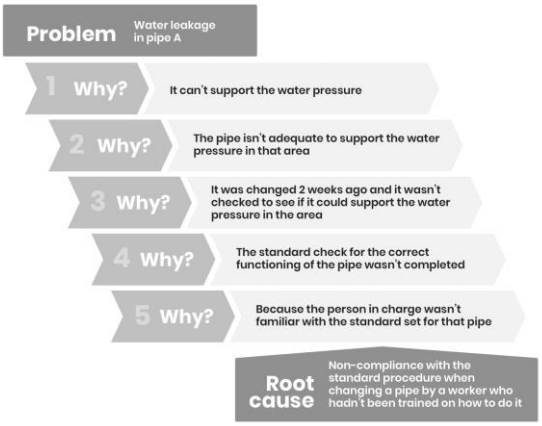

Fig. 1. Five Whys technique example

B. Ishikawa (Fishbone) Diagram

To be more precise, the Ishikawa diagram, also referred to as the Fishbone diagram, is a tool that is used to categorize possible causes of a particular issue under major headings that includes human factors, materials, methods, machineries, and environment. This technique is used where one may find it relatively difficult to solve the problem with one approach only but rather deal with the problem based on various dimensions[2].

C. Failure Mode and Effects Analysis (FMEA)

FMEA is a preventive RCA technique that helps in identifying the various ways that a product or a process may fail and how the failure modes will impact the overall capability of the system. It categorizes these failures according to the rate of occurrence and criticality, and whether they are easy to identify so that working groups can effectively address them and establish protection measures[3].

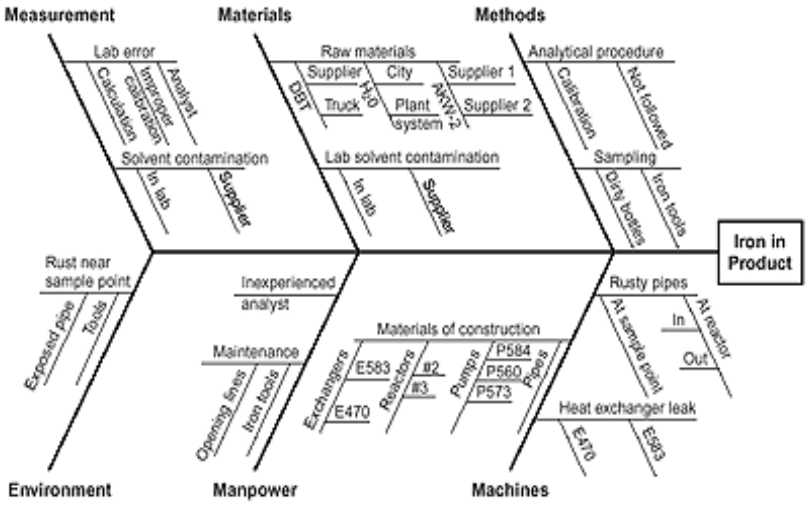

Fig. 2. Fishbone Diagram

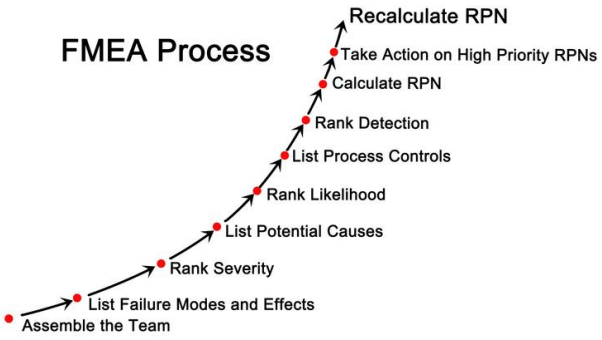

Fig. 3. FMEA Analysis

D. Fault Tree Analysis (FTA)

FTA is a deductive, top-down model that employ Boolean logic to explain the possible causes of a particular failure or an undesirable event. Due to the potential of the method for identifying a wide range of causes that could potentially lead to the problem, FTA is most useful in industries where failure is potentially lethal including aerospace and nuclear energy industries[4].

E. Pareto Analysis

This technique takes its root from the Pareto principle, which argues that problems are caused by some 20% of their causes although most of them which are at 80% may be of lesser intensity. Pareto Analysis ensures that the organizations put the most effort in tackling the core issues rather than 'noise' or the trivial many as they facilitate the allocation of resources to major concerns[5].

F. 8D Problem-Solving Method

RCA is a team-based methodology, one of which is known as 8D (Eight Discipline) that is aimed at developing solutions to identified problems. This process comprises of eight steps such as identification of the issue, constituting of a team with members from different departments, taking of corrective measures among others. It is used especially in manufacturing and car industries when there is a problem that happens over and over again and the quality of the product needs to be improved [6].

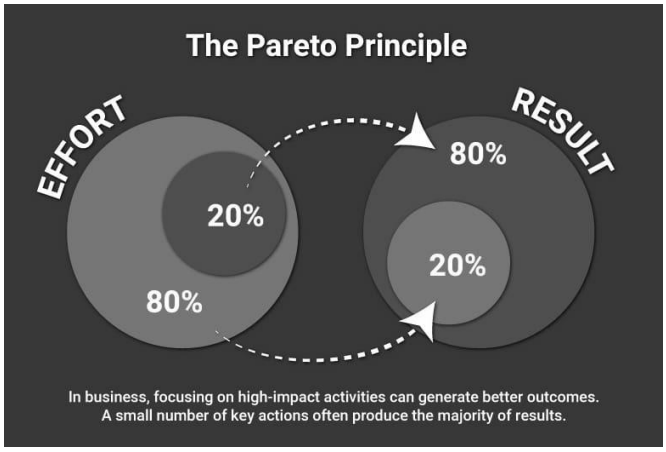

Fig. 4. Pareto analysis

3. BEST PRACTICES FOR IMPLEMENTING RCA

There are certain standard procedures to be followed while performing RCA and these standard operating procedures help to get the best out of RCA, that is, accurate results that will assist in improving the system.

A. Cross-functional Teams

Besides, effective RCA entails coordination of a group of people who are from different functional areas. This guarantees considering all the possible root causes and that targeting solutions is technically correct and implementable. Interdisciplinary cooperation also contributes to the culture of everyone's accountability and, therefore, never-ending improvement[7].

B. Data-Driven Approach

This means that RCAs should be data-driven to ensure that the causes of the problems are well identified. Whenever possible, data on production, customers' feedback, or quality issues collected from different sources such as reports and logs are used providing a base for decisions rather than assumptions. With the help of ML algorithms, RCA is becoming more accurate as well as is complemented with elements that can be not seen at first sight[8].

C. Thorough Documentation and Knowledge Sharing

Having records of the RCA process, identified findings and results of the corrective actions that have been taken is important for learning. Thus, the documentation is useful when conducting further RCA and helps to avoid such problems in the future. Communication of past experience between departments and teams guarantees that experience on one product or process is transferred to another and this promotes the concept of the new generation of improved performance[9].

D. Integration into Continuous Improvement Initiatives

It is however important to emphasize that RCA is not a one-off exercise but should be considered as a regular activity in the suite of organizational improvement programs. The application of RCA on existing products and the new products entering the development life cycle can provide continuous high-standard quality throughout the organization while also improving organizational effectiveness. RCA is also considered to be a constituent of Lean & Six Sigma methodologies and focuses on the progression of CI[10].

E. Proactive Integration into Product Development

RCA integration in the development schedule is vital as it helps in the early study of possible challenges that are likely to be encountered in the development stage. Due to early identification of causes of failure, new products containing minimal defects can be perfectly developed within a shorter period and at reasonable costs. This is especially applicable in the present design context wherein methods such as Design Failure Mode and Effects Analysis (DFMEA) prove advantageous since they facilitate design risk assessment that may result in future design failure[11].

4. Technology Advancement in Root Cause Analysis

RCA processes have benefitted from various aspects of modern technologies thus improving their efficiency and capabilities. These technologies not only enhance the transport and documentation of conventional RCA approaches and enhance new processes for analyzing issues and handling quality.

a. Artificial Intelligence and Machine Learning

AI and hence machine learning algorithms are also being adopted to further advance the conventional RCA techniques. These technologies can take inputs from various sources process them and analyze them to give high accuracy in identifying the probable modes of failure. RCA processes can be initiated by the use of trained machine learning models that identify anomalies and head to solutions faster and more accurately[12].

b. Big Data Analytics

Big data analytics in RCA used gives an organization the flexibility of handling big data datasets that was not possible initially. Some of the benefits of analytical tools comprise identification of factors that are

invisible when applying conventional RCA methods. Additionally, big data analysis has to do with real-time checking and with the anticipation of failures, often described as predictive maintenance[13].

c. IoT and Sensor Technology

IoT devices and sensors give information on the status of products and the surrounding environment in real-time basis. This information stream is a valuable source for RCA as it can help observe key parameters changing and recognize situations which require further investigation in time. As it was indicated in the previous sections, IoT-enhanced RCA systems can send alarms when specific rates are exceeded and start the RCA processes[14].

d. Digital Twins

Digital twin technology is the process of making a copy of the actual product or a process in the digital world. This has the capability of enabling the engineers to perform virtual trials with a view of comparing the effects of various variables. Hence, by adopting the digital twins in RCA, it becomes possible to unlock the potential solutions in the virtual context and then apply them in the real world with lesser chances of arriving at a wrong solution[15].

e. Blockchain for RCA Documentation

This is because RCA findings and corrective actions can be well documented and stored on blockchain technology. With the help of blockchain, it will be possible to guarantee that the records in RCA are protected from any kind of alteration; moreover, they can be easily reviewed. This is more relevant in business sectors that have strict compliance needs or where record-keeping is famed to be strategic[16].

5. IMPLEMENTING RCA IN NEW PRODUCT DESIGN

The experience obtained by RCA is rather useful when it comes to designing a new product. Through the implementation of findings from RCA of existing products while designing new ones, organizations shall be in a position to prevent occurrences of problems leading to product quality and reliability.

a. Design for Reliability

Previous RCA findings of some of the products could help reveal areas that cannot allow for any compromise in matters concerning reliability. Through the application of the above knowledge during the designing of new products, engineers will be able to develop designs that have low risks of failure, and which are capable of meeting the perceived needs of customers. Some of the most useful in this regard include reliability-centered design and robust methodologies design[17].

b. Proactive Risk Management

In this context, the established RCA techniques can be implemented in the design phase; for instance, DFMEA to minimize potential hazards. It is proactive such that failure modes that may be realized are handled even before they occur become issues and thus, less chances of defects in the final product. The use of AI-based risk assessment tools augments this process by offering probabilistic analysis and recommendation[18].

c. Knowledge Transfer and Organizational Learning

In this regard, it is recommended that RCA data be collected and disseminated systematically amongst the design teams to ensure that the best practices of the product under analysis are incorporated into the next one. All these are important in enabling the knowledge transfer which is associated with a feedback loop that enables product improvement and to ensure that past problems are not repeated. Companies that support the dissemination of knowledge and integration of cross-functional teams are in a better position to bring to market products that meet or surpass the customers' expectations[19].

d. Sustainability Considerations

Considering that sustainability turned into a crucial factor influencing product design and manufacturing, RCA can help define possible environmental repercussions of the created product. In applying RCA in

sustainability issues, the organization can create products that meet need, functional and quality demands and at the same time, meet sustainability objectives such as, eradicating carbon footprints and recycling[20].

6. Recent Technological Advancement in RCA- A Case Study

This study aims at increasing efficiency of Root Cause Analysis (RCA) especially within manufacturing big data environment. The study also recognizes some of the limitations of traditional RCA methods like the fact that they rely heavily on human input which is time-consuming and may at times be biased besides the fact that they can prove hard to implement when dealing with large databases. The research suggests a new approach to ensemble the BN for RCA by offering an intelligent, human-interpretable probabilistic reasoning technique[21]. Some key findings of this study are given below:

- To deal with the sparsity of data and improve the model's stability, the model uses ensemble learning methods: the aggregation of multiple BNs trained using bootstrapped samples.
- Due to probability distribution of the BN approach the results are easily visualized and can be more easily interpreted by the on-site staff. This is very useful in a manufacturing environment where decisions an organization makes have to be backed by data but must be easily explained to individuals who may not necessarily have a strong background in data analysis.
- To validate the proposed method, experiments were performed on real-life plastic manufacturing data. The obtained experimental results proved the efficiency and reliability of the ensembled BN framework in detecting causal factors and determining quality risks with reasonable accuracy and insensitivity to data noise.
- It also provides an evaluation of various BN structure learning algorithms that are used in the study. The search algorithm was complemented with hybrid knowledge sources and provided better results in the probabilistic approaches to root cause analysis and quality risk estimation.
- An evaluation method was developed to give credit to the degree of accuracy and stability of the RCA findings. This method was useful in identifying the level of variance between as expected and what happened hence useful for model evaluation purposes.

  All in all, this thesis delivers novel research to the field of RCA with creating ensembled Bayesian Networks, which is a more solid and understandable technique. The paper recognizes the drawbacks of conventional approaches to RCA and presents a realistic approach tailored to contemporary production settings.

7. Case Studies and Applications

In this section, this article includes case studies from different industries to demonstrate how RCA is implemented in present product enhancement and new product development.

a. Automotive Industry

In the automotive industry, RCA has been often used for studying the causes of safety and reliability problems. RCA has been used in the analysis of a major issue involving the airbag defect that has required the recall of products in the market around the world. The recommendations compiled from this RCA work were then used to enhance the fabrication and performance of new airbags cutting down on failure regularity[22].

b. Aerospace Industry

RCA plays an important role in the aerospace industry where it assists in elimination of risks that may endanger the safety of an aircraft. One of the real-life examples is a case where an engine failure occurred during the flight that led to an investigation showing that the manufacturing defect in one of the key components was at the core of the problem. Some of the recommendations made from this RCA were

incorporated into redesigning the component and avoiding the same failures in the manufacturing process[23].

c. Consumer Electronics

In the consumer electronics industry for instance, RCA has been applied to tackle problems of product reliability which include battery failure in smartphones. RCA was used to ascertain the reason for failure in the units and the results were used to make modifications to the designs that enhanced battery performance in the subsequent production models.

8. CONCLUSION

When it comes to understanding how Root Cause Analysis is one of the key tools to enhance product quality and guarantee new designs' success. Through the continuous identification and elimination of known causes of failures, organizational productivity is enhanced, product reliability improved, failure rate lowered, and, in the end, customer satisfaction realized. Subsequent developments of current technologies like AI, big data analytics & digital twins have made RCA even more effective and efficient in problem-solving. Thus, the understanding and the continued implementation of RCA in the existing products, coupled with new products still to be developed as industries advance, will stand as a key determinant to long-term sustainable success.

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