Root Cause Analysis Methods for The Design of Aviation Parts

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Abstract

Fault modes, which aren't detected throughout the design phase if they are not defined with precautions have the crucial potential on the quality of mature products. At first glance, the impression of the quality failures may be underestimated, before the design of aviation parts are implemented to production. But these failures may cause some problems in aviation safety and reliability. Therefore, the failures during the project phase should be investigated by root cause analysis and defining the precautions both increase effectiveness of design and quality of the outputs. The aim of this study is, emphasizing the importance of root cause analysis on the design of aviation parts, and stating the analysis methods, which have been used mainly. In the scope of this effort, aviation regulations are researched which encourages the root cause analysis accordingly, related methods are evaluated for the resolutions. The common methods are classified based on the hazard review of the failures and explained to point out for the researchers.

Keywords: Root Cause, FMEA, Aviation.

1. Introduction

All of the parts have a designation phase as input and keep the features throughout their product life-cycle. Desired quality may be sustainable, on condition that the risk of the failures is disappeared.

Risk analyses support the root cause analysis and provide the finding out solution easier as proactive investigation. For the parts, Fault Mode and Effectivity Analysis (FMEA) has been used and all of the factors are classified and mitigated before the realization process.

The affection of the risks which are coming from the non-factors can't be tolerated for the parts of aviation. In this way, root cause analysis makes the iterations minimum, on the design and sustain the safety and the reliability of the aircraft and lessons-learned items are crucial experiences for the producers.

The aim of this study is to indicate the importance of the root cause analysis methods especially according to aviation regulations and famous producers. Accordingly reviewing all of the efforts with examples from the aviation sector, the root cause analysis methods have been classified depends on the criticality of the failure as minor, major and hazardous. In this way, the methodology in accordance with failure levels. This provides the methodology for the researchers. The literature is reviewed firstly for aviation and accordingly for automotive parts.

There are a wide variety of researches about root cause analysis for aviation is presented firstly as follows.

Washington et al. made a study about investigating safety system uncertainties for the complex aviation systems which are named Remotely Piloted Aircraft Systems (RPAS). The existing aviation safety systems are needed to develop and the aim of this research is to develop more sustainable and reasonable regulatory outputs determination via System Safety Assessment (SSA). The SSA process and outputs are analyzed in the purpose of improving the safety of RPAS. The analysis has been revealed by using a Bayesian Belief Network (BBN) which the method is using for the root cause analysis via risk-based approach. All of the failure determination have been compared, from Federal Aviation Authority (FAA), European Union Aviation Safety Authority (EASA) and North Atlantic Treaty Organization (NATO) regulatory bodies. In the conclusion of the study, by Bayesian Belief Network failure condition severity classification is handled and it is pointed out that risk-based approach supports RPAS to be more systematic and objective particularly for emerging aviation systems [1].

Freitas et al. made an investigation to find out failure analysis of the nose landing gear axle of an aircraft which landing gear can not work during the landing and cause the serious accidents. The reliability effect of this part is so crucial. So, the finding root cause analysis duration was supported numerical and experimental analysis. The Finite Element Analysis (FEA) was carried out and an electron microscope was used for the surface of fractures. The optical and scanning electron microscope analysis results are agreed on with numerical investigations. In conclusion, it was found that the failure occurred by overloading both shear and bending stresses, due to confronting a huge load on nose landing gear instead of main landing gear throughout the aircraft landed. The nose landing gear material will be converted into more durable high alloyed steels instead of low alloy steel. The root cause analysis was handled by verifying potential causes by numerical and experimental analysis via classifying parametric data [2].

Silveira et al. made a root cause analysis for the failure of the high-pressure turbine blade failures whose material is hardened nickel base alloy. During the analysis phase, electron microscope is scanned for the analysis with microstructural examination. The analysis was performed for the first blade was due to thermo-mechanical fatigue which the internal cooling cavities was started. It was found out, the carbides with cracked and primary have an important role for the potential of failure. The other blades failed as well by the severity of the fragments lacking. The first blade has the fatigue of thermal and mechanical side with tendency to creep. The precautions should be defined and implemented during the design phase [3].

Rabcan et al. made a study about deriving an algorithm for a diagnosis which is non-destructive concerning the signals. This algorithm is encouraged to solve blades of gas turbine related with signal of vibration after a non-destructive signal and classify it as hazardous and normal. To find out the problems on aircraft engine blades, the diagnosis is ordered to Fuzzy Decision Tree (FDT) that cumulates all of the mutual information. In this way, the accuracy of the information is about 98,5%. The classification of the algorithm is compared with FDT method. It is found that the

fuzzy tree method has superiority, It is similar to the fault tree method which is used for the detailed root cause analysis. The fuzzy decision tree shows all the relations between signals and the classification may be done more efficiently. This means root cause analysis methods are using also for consolidating all of the data [4].

There is a wide variety of research about root cause analysis for the automotive are presented secondly as follows.

Fröhling et al. made a root cause analysis about out-of-round or polygonized wheels problems that were detected on the high adhesion locomotives operating in South Africa. After the analysis; the axle vibration as torsional could cause the polygonisation for the wheels. Accordingly, the locomotive axle vibration was verified by the analytical and experimental way. Based on the results, two crucial reasons were defined for torsional vibration excitation and frequency was determined and tested as well. Consequently, the deduction in the torsional vibration amplitude was detected when the system of suppression was activated. The root cause was found by using physical model parametric measurements on track. This data comes up with a cause and effect matrix to resolve the potential causes [5].

Suresh and Mruthunjaya made a study about forged spline yoke shaft part which has been used to transmit the power of motion fot the system of driveline of automobiles. The root cause analysis was performed for the failure of the yoke shaft in the steering assembly. In order to find out the root cause; critical stress formation at the failed section, fatigue analysis was revealed which is validated by the Finite Element Method (FEM). In conclusion, the current model is analyzed under different crack conditions by lifetime estimations throughout the design phase and the forged fabrication process is changed. The root cause was found in the variable FEM analysis of spline regions and all data compared by parametric approach. It is investigated

2. Root Cause Analysis Necessity

The definition of the root cause analysis starts with the problem definition phase; which supports the investigators to grasp and solve them. When it is

that Yoke shaft failure is come from the spline region because of the fatigue [6].

Wang et al. made a study about the main reason classification and event location of the alarms in thermal power plants with bayesian networks. They used child nodes and multiple parent nodes to define dependence between an alarm variable and variables of root cause. Root causes of alarms are specified from the parent node set with the largest probability of conditions. By referring to the root cause analysis, the outcome may remove the negative effects of missing and wrong alarms in the nodes. This means determining relations between input and outputs, provides classifying all of the steps, and take the right actions [7].

Bhattacharjee et al. made a root cause analysis of the coal dust explosion disaster, this event is stated as lessons learned and the outcome of the root cause analysis is worthy inputs to define precautions. In this paper, an in-depth analysis of a mining disaster in India was analyzed and an Event Sequence Diagram is created in order to find out Why and How the accident has emerged abruptly. All of the efforts have been made to identify the root causes of the accident, using an Accident Causation Tree (ACT) like fault tree analysis which has been used for a common root cause analysis via its, parametric approach.

Swiss Cheese Model (SCW) was used as well to developing the understanding of the mechanism of the accident. The most crucial outcome to compiling the lessons learned points for the accident analysis was defined to prevent major accidents [8].

As a result of extensive literature review, the root cause analysis methodology is so crucial based on the problems. This makes the structure of the design quality better in order to optimize all of the parts. By the root cause analysis and design Fault, Mode Effect Analysis (FMEA) means the know-how which is critical and keeps sustainability of latter design development projects.

decided to use root cause analysis methods. Problem definition is so crucial to determine convenient root cause analysis for purpose of being close more the right solution. In Figure 1, the short

indication of a problem and potential causes are located. If the root causes of the problem are not analyzed properly, the problem may have recurrency.
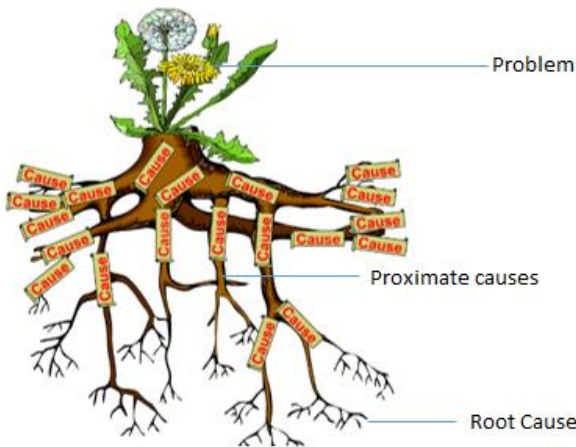

Figure 1. The Problem with Causes [9]

The cycle for the problem solving which is so familiar is indicated in Figure 2. Understanding the problem is the first step and in order to define the action, the root cause identification is critical which is the key of the blockage.
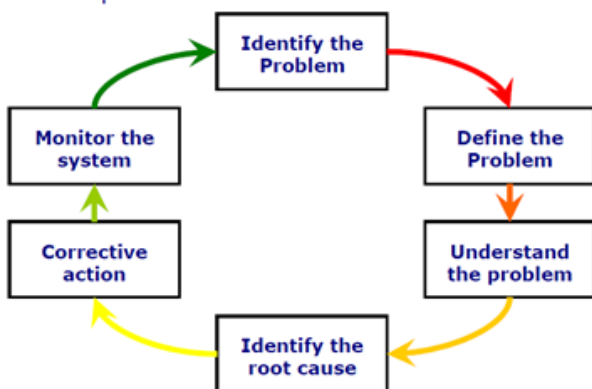

Figure 2. Problem Solving Process [10]

2.1 The Root Cause Analysis In Aviation

The root cause analysis method is so common in the aviation sector which is cited fundamental regulations as follows. The preventive actions should be defined for the problems whose root cause is found out to not have recurrency. The corrective actions may be completed when the root causes are eliminated. There are also 18 pcs citations of root cause analysis in EASA Notice of Proposed Amendments (NPA) in NPA 2013-01 (B) 'Part-M and 13 pcs citation in NPA 2013-01 (C) 'Part-145;

this shows the importance of the root cause analysis [11].

2.2 The Root Cause Analysis Methods

The five fundamental methods will be defined based on the severity of the faults.

2.2.1   Five - Why Analysis Method

The 5-Why method is firstly investigated by Sakichi Toyoda, by Toyota company in 1958, preferred as a first approach to close potential solution, it is generally used for the minor problems and performed the solution. It is realized by asking why to causes, and after 5 iterations alternative causes may be defined. This is a so practical method. In Figure 3, workable areas of why questions are asked consecutively [12].
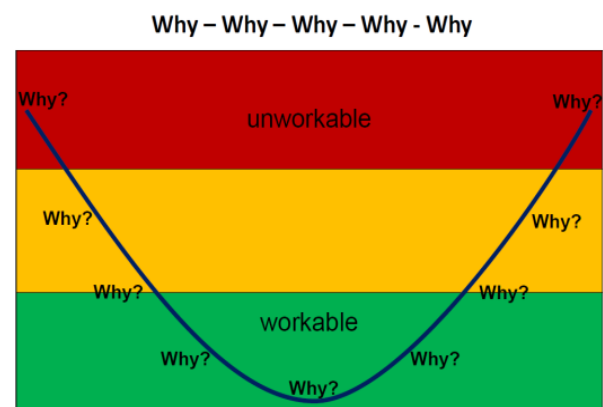

Figure 3. 5-Why Method Workable Areas [12]

2.2.2   Fishbone (Ishikawa) Analysis Method:

The fishbone analysis defines relations between cause and outputs with relations. All factors are classified. This method was firstly discovered by Prof. Kaoru Ishikawa in 1942 [12].   The potential causes are classified as environment, person, material, machine, process, and others. All of the causes are filled out and the output is the problem. All of the causes are scored by the core team and priority is defined which may be supported by using the Pareto diagram. As a result of this effort, an action list is created to analyze the results. In Figure 4. The root cause analysis structure is indicated.
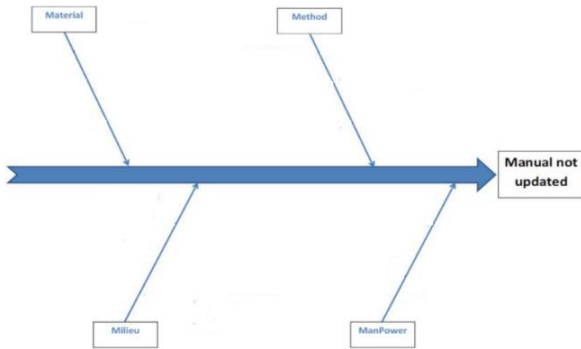
Figure 4. The Fishbone Root Cause Analysis Structure [12]

2.2.3 Fault Tree Analysis Methods

The fault tree is used to extend related potential causes for the different events and conditions. The events which cause the undesired outcomes are inquired as ''why'' and potential causes and the causes are classified as proximate cause, intermediate cause and the root cause [13]. In Figure 5, the Fault tree instance is shown which potential causes are evaluated with the related events and may be eliminated from the table.
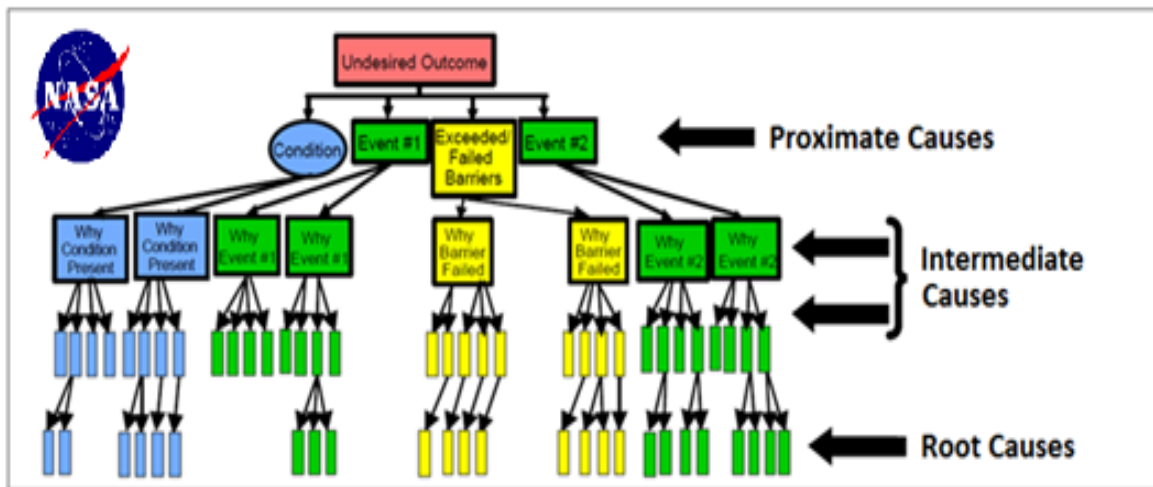

Figure 5. Fault Tree Analysis Structure [13]

Root causes are systemic problems or global factors located at the bottom of the tree. The contributing factors are sometimes left on the tree to show all factors that affected the event. Contributing factor means an event or condition that may have contributed to the probability of an outcome which isn't hoped but, if it was modified or disappeared, wouldn't by itself have impeded the probability. The fault tree analysis root cause method is preferred when there are several inputs, parameters, and events concerning conditions [13]. Consequently, this method identifies possible causes and different levels of occurrence.

2.2.4 Bow-Tie Method

The bow tie method is used commonly as a root cause analysis which defines the causes and consequences. The event is located in the middle of the causes and consequences. The causes are classified as basic and immediate causes. Basic causes are coming from personal and job factors; immediate factors are about acts and conditions. The causes and consequences are specialized by this method. Consequences are also classified as immediate and ultimate consequences.   In Figure 6. The bow tie method is indicated as schema.
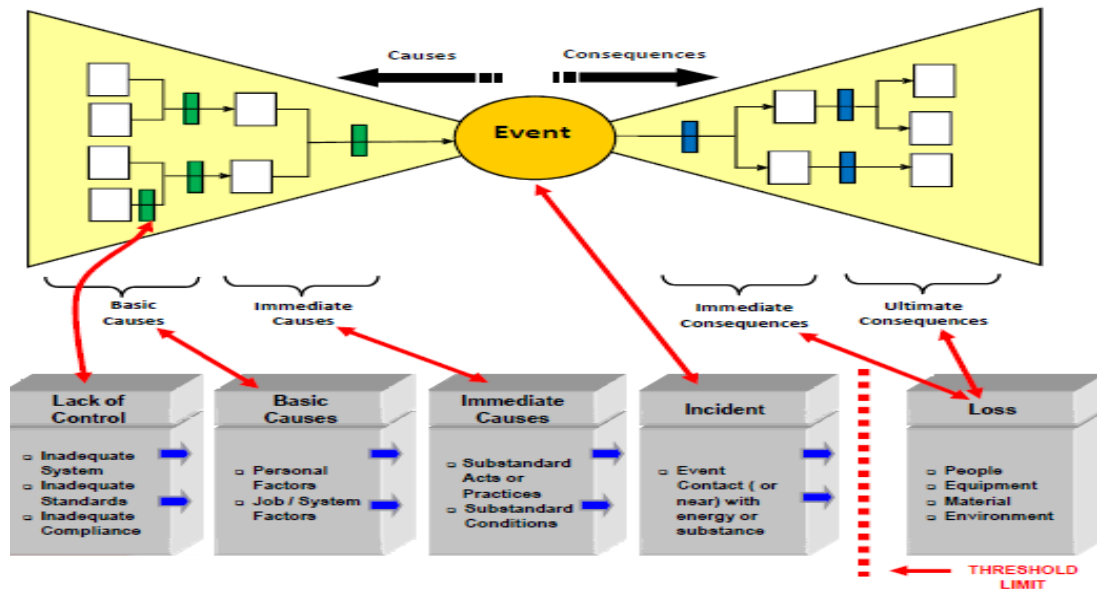
Figure 6. The Bow-Tie Analysis Method [14]

The bow tie method defines the risks and threats which present to taken preventive actions before the risk is realized as a proactive solution. These steps are used for the method of the bow tie as follows.

1. Definition of the dangers

2. Definition of non-desired conclusions

3. Definition of threats

4. Determine the outputs

5. Define preventive actions

6. Determine the factors of escalations.

The bow tie analysis method may be combined also with the Swiss Barrier model. Identifying the barriers is the most crucial to the bow tie method. It makes the create relations between all potential causes and risks. This is so beneficial to find out more deep outcomes of each part of safety and reliability in an organization. [14]

2.2.5 8D Method

The 8D is sometimes also referred to as Ford TOPS 8D, 8D, and Global 8D. This methodology is preferred for many industries particularly for the automotive sector. It is used like standardized process generally. It encourages to work together to solve problems with using 8 steps of the method to approach potential causes and effects. It is so efficient to define root causes and determine the permanent corrective actions. There are plenty of

report to provide noncurrence of common problems with this method. The method consists of the process schema, cause and effect diagram, Pareto analysis and the other root cause analysis methods which are mentioned in this study. 8D is used to find the root cause and optimize all the duration to take long term actions. There are 8 pcs steps for the method [15].

1. Notify the Awareness: This is the first step of the method that creates awareness of the related people.

2. Describe the Problem: To identify the problem, the 8D team provides to take as much information as possible from the external resources or the customer, which requires the first analysis performed in the problem-solving process. During the depicting the problem 5-Why analysis can be used with Pareto diagram to prioritize the points.

3. Implement and Verify Short Term Corrective Actions: In order to sustain the process, the short term corrective actions are defined and taken.

4. Define and Verify Root Cause Analysis: This step is so critical to defining corrective actions. The root cause analysis methods should be used considering the majority level of the problem. Cause and effect diagrams, Pareto analysis may be created to support all of the efforts.

5. Verify Corrective Actions: The defined corrective action should be verified by some measurements. Typical statistical methods are called as Statistical Process Control, Process Capability (cp), Process Capability Index (Cpk), histograms and Pareto analyses. A permanent action to be taken in the process to solve problem which is checking whether the complaint of customer brings about any modifications to the scope in the FMEA (Failure Mode and Effects Analysis) to check related documents and records.

6. Measuring of Effectiveness: In this step, comprises measuring the effectiveness of defined permanent corrective action and ensure if it is appropriate to solve the problem, but if it is considered for the aviation industry, the measuring period may be longer than one year based on the production volumes and risk classifications.

7. Prevent Recurrence: The 8D team analyses in this phase to be ensured whether the potential causes of the problem are executed or not.

8. Conclusion: In the scope of step, the conclusions of taken permanent actiosn are evaluated. The team traces and ensures solving of the complaint permanently with each steps of the method. All objective evidences shall be recorded as lessons learned to support next potential failures and problems. The team is congratulated for the success of this work [15].

3. Results and Discussions

The common root cause analysis methods which have been used for the aviation sector were surveyed and classified considering the criticality of the failures. These methods are so crucial in the purpose of sustaining the know-how and reflect the detections as lessons learned for new designs. Furthermore, the instances are supported by famous manufacturer aviation companies and related researchers.

When a nut design is considered as an aviation part, for instance, this part design shall be evaluated in terms of form, fit and function. The form refers to its construction and convenience for installation and serviceability.

The fit refers to dimensional features related to form and indicates the compatibility of the part on the assembly surface.

The function refers to its structure which is the main reason for the usage of it. For instance, the nut isn't used only for assembly of the shaft, it may also balance dynamic stress with keeping durability.

These fundamental terms are so crucial for the designation phase of aviation parts. These terms support to sustain Design FMEA during the development phase and it makes the detect root cause easier when any problem occurs with using an appropriate problem-solving process.

4. Conclusions

The commonly used root cause analysis methods that belong to aviation parts are consolidated in this investigation to classify them based on the criticality levels of the problems. Especially; aviation regulations and the studies of famous producers from the aviation were examined. (EASA, CAA, Boeing, Lockheed Martin, etc.) It is understood that the root cause analysis methods both support solving the problems properly with less time due to prevent recurrency and sustaining the know-how extension of the producers for every sector. This paper points out selecting the right root cause analysis methods against the criticality level of the problems is so crucial. Thereby, in the light of this review research, the methods are classified and indicated in Figure 7 as a result, It is indicated for the researchers. For the minor issues, the 5 Whys method is preferred, but for the solutions of major problems, the Fishbone method is used, as well the fault tree is preferred when the preventive actions would be defined.
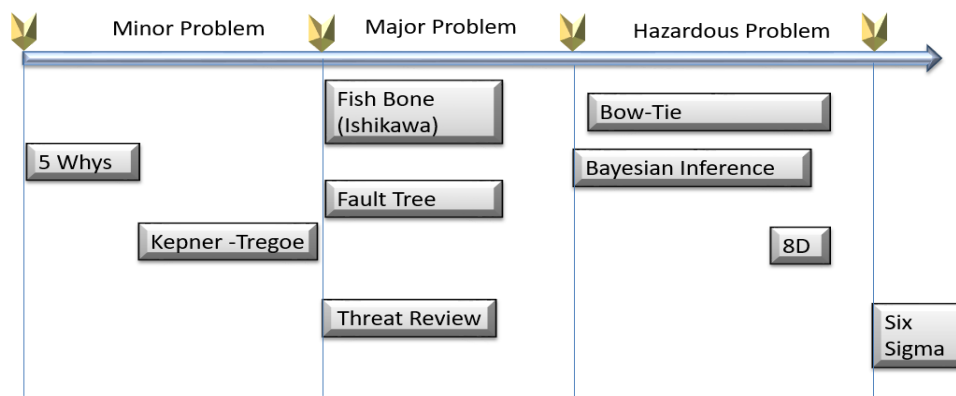
Figure 7. The Root Cause Analysis Methods Based on The Criticality of Problems

5. Nomenclature

FAA: Federal Aviation Administration
CAA: Civil Aviation Authority
NASA: National Aeronautics and Space Administration
EASA: European Aviation Safety Agency
NATO: North Atlantic Treaty Organization
ACT: Accident Causation Tree
SCW: Swiss Cheese Model
FMEA: Fault Mode and Effect Analysis

Ethical Approval
Not applicable.

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