Root Cause Analysis and Quantitative Methods – Yin and Yang?

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Abstract

The concepts of *Yin and Yang* originate in ancient Chinese philosophy and metaphysics, which describes two primal opposing but complementary forces found in all things in the universe. This concept is well suited to describe the relationship between qualitative root cause analysis and quantitative methods such as fault tree analysis. This paper will describe root cause analysis, and then show how it is complimentary to more robust quantitative methods when developing solutions for event based problems such as airplane accidents. In practice, one must jump between the yin (RCA methods) and the yang (Quantitative methods), while simultaneously realizing that these are part of a larger whole, which involves effectively solving event based problems.

Introduction

Comments and discussions at past International System Safety Conferences, along with other dialogue among system safety professionals indicate there is a misunderstanding of:

- What constitutes Root Cause Analysis (RCA)
- The value of RCA, and
- If, and how RCA methods should work with more formally established quantitative methods, such as Fault Tree and Markov Analysis

This paper is intended to help clear up ambiguity by doing the following:

1. Providing a high level overview of Root Cause Analysis and Quantitative Methods
2. Showing how the two interact, and
3. Presenting continuum concept that explains how RCA and Quantitative Methods are related

Root Cause Analysis

Root Cause Analysis (RCA) is typically applied to event based problems that you wish to prevent from recurring. "Event based problem" means a series of events (conditions, actions, triggers, etc.) that culminated in an unwanted outcome. Conducting a Root Cause Analysis requires resources, so they are typically performed on high significance items. An example of a high significance, event based problem is an airplane accident due to an uncommanded thrust reverser deployment inflight.

Here is where the confusion starts. You can call <u>any</u> event based problem solving methodology a Root Cause Analysis, and you are correct. There are no universally accepted standards for RCA. In the absence of an accepted standard or specification, root cause analysis is anything that anybody wants it to be. For the same reason, you can call any cause of a problem a "root cause," and you are correct.

The theory behind root cause analysis is deceptively simple; We solve event based problems by eliminating or mitigating at least one cause. In some cases, added layers of protection are provided as a means to control or mitigate causes. The effectiveness of a solution depends on several factors, such as the degree to which it prevents recurrence and the cost of the solution. Based on this theory of controlling causes, it can be seen that the more we understand the causes of an event based problem, the better we can control it.

The key similarity between all root cause analysis methodologies is a recognition that controlling causes translates into controlling the problem. Aside from this, RCA methods vary greatly. The lack of standardization presents a dilemma in writing this paper. To compare Root Cause Analysis to anything, we need to somehow draw boundaries around what we mean by Root Cause Analysis. To establish these boundaries, we will describe some key characteristics of RCA, and then use these characteristics to describe some commonly known RCA methods and concepts.

In writing the following characteristics and summarizing the methods below, there is no attempt to provide a level of subjective goodness or badness. Each RCA method has it's strengths and weaknesses. The particular needs of the situation and/or the organization drive the selection of the most appropriate RCA method.

Root Cause Analysis Characteristics: Three RCA characteristics are presented below. There are many other characteristics that can be used to further describe RCA methods, such as cause evidence requirements, solution generation, report generation, and so forth. The three characteristics below were chosen primarily to help illustrate the wide range of methodologies and concepts that have been described as Root Cause Analysis.

Table 1: RCA Characteristic 1 - Degree of Methodology

Degree of Methodology	Description
Well Defined	A clear methodology is provided which guides the user through the RCA Process with a focus on finding effective solutions. The most common process steps involve something like: 1) Define the Problem, 2) Analyze the problems and 3) Identify/Implement Solutions. Most of the commercial RCA products are based on a well defined methodology.
Loosely Defined	This means items such as brainstorming, multi-voting, or creating an Ishikawa fish bone diagrams. There are loosely defined methodologies for these.
No Methodology/ Collection of Concepts	Some courses and books fall into this category. In this approach, many concepts are presented to the user. Some concepts may be tools, while others may be ideas. In theory, the user finds what they want, and perhaps builds their own methodology to apply the knowledge.

Table 2: RCA Characteristic 2 - Degree of Causal Information Detail (DCID)

DCID	Description	Examples	Effort Required
Very High	All possibilities that can cause the top level event	Similar to fault tree diagrams used in system safety assessments. Show what happened and also include every possible cause that can cause the same problem.	Very high. May not be practical for some event based problem solving.
Medium to High	High precision mapping of causes and effects, including actions and conditions.	Cause and Effect Diagrams used in Apollo Root Cause Analysis and Reason Root Cause Analysis. Note that some causal categorization trees are called cause and effect diagrams, which is somewhat misleading.	Low to moderate, depending on training, experience of practitioner. Can be higher effort for higher significance events based on need to understand causes in higher detail.
Low	Cause Grouping and/or low precision mapping of causes and effects	Ishakawa fish bone diagrams, timeline causal analysis, predefined causal categorization trees such as MORT, voting on causes	Low to moderate, depending on training, experience of practitioner.
Very Low	Text type narrative	Story or timeline of events. Commonly used in "Blue ribbon panel" type reports.	Same as above

Table 3: RCA Characteristic 3 - Level of Automation

Level of Automation	Description	Examples
High	Enterprise and/or stand alone software is available that automates the process, performs integrity checks, generates reports.	RealityCharting® software, based on Apollo Root Cause Analysis methodology. Reason® software based on the Reason RCA methodology
Some	Some elements of the process are automated	Database that automates the categorization and analysis of causes.
None	No software automation available (except for word processing, spreadsheets, etc.).	Completing a standard problem report form where you check off the pre-defined root cause categories, such as human error, equipment, procedures, etc.

Summary of Select RCA Concepts and Methodologies: The following table summarizes the RCA characteristics for some different RCA methods and concepts.

Table 4: Summary of Select RCA Concepts and Methodologies

RCA Method or Concept	**Degree of Methodology (Table 1)**	**Degree of Causal Info. Detail (Table 2)**	**Degree of Automation (Table 3)**	**Comments**
Blue Ribbon Panels/ Expert Opinions	None (unless developed by group)	Very Low	None	Rely on the experts to ensure that solutions line up with causes.
Brainstorm & Vote	Loosely Defined	Low	None to Some	
Five Why's (Also called "Why-Why)	Loosely Defined	Low	None	Ask why five times, arrive at "root cause"
Ishikawa Fish Bone Diagram	Loosely Defined	Low	None to Some	Some charting software like MS Visio® includes templates for this
Management Oversight and Risk Tree (MORT)	Well Defined	Low	None to Some	Pre defined causal categorization tree originally developed by the DOE in the 1970's
RealityCharting® software (Based on Apollo RCA methodology)	Well Defined	Medium to High	High	Commercial Product
Wikipedia.com (search on "Root Cause Analysis"	Collection of Concepts	Depends on concept	None	Public web site

Table 4 illustrates the diverse range of methodologies and concepts that may accurately be called Root Cause Analysis. It's easy to see how there can be confusion regarding what constitutes a root cause analysis. The items listed above, and many more can be considered a Root Cause Analysis concept or methodology.

The FAA's Office of Aircraft Certification (AIR) has used several of the methods listed above, which have provided added insight into understanding and resolving issues. Parts of Aircraft Certification began using the Apollo Root Cause Analysis methodology, a commercial product, in the late 1990's. This method was appropriate for certain higher complexity problems encountered by Aircraft Certification. (This is not an endorsement of the Apollo RCA methodology, but simply a statement that it meets our particular organizational and situational needs.) To facilitate comparison of RCA methods and Quantitative Methods for the remainder of this paper, and to keep the paper under 10 pages, we will use examples of Apollo Root Cause Analysis. This should adequately represent a comparison of quantitative methods to an RCA approach having a well defined methodology.

<u>A Brief Overview of Apollo Root Cause Analysis</u>

The methodology is as follows: 1) Define the Problem, 2) Analyze the Problem using Apollo Cause and Effect Chart (also called a Realitychart), 3) Identify solutions and 4) Implement solutions. Apollo RCA is based on cause and effect principles and utilizes a cause and effect diagram that is similar to fault tree analysis diagrams. The figure below illustrates a typical Apollo RCA Cause and Effect Chart (also known as a Realitychart).

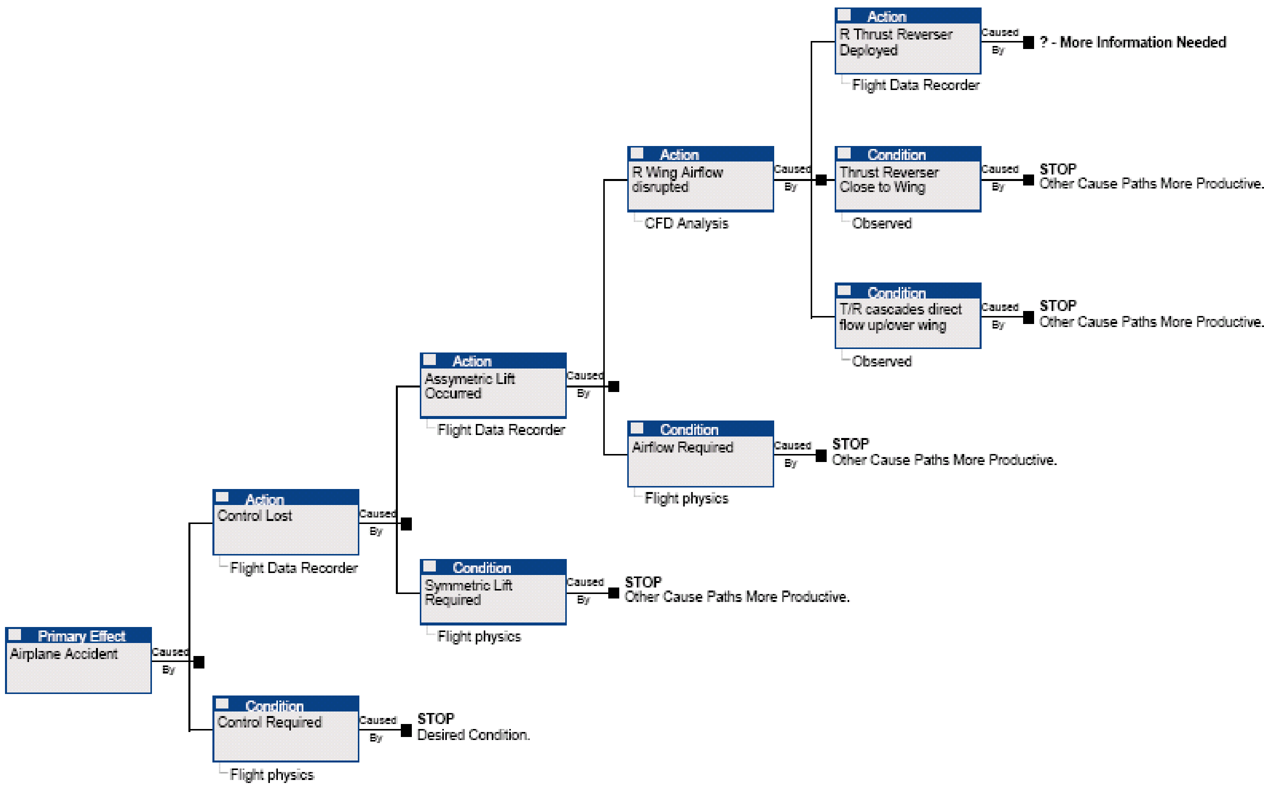

Figure 1: Example Cause and Effect Chart (Realitychart) using Apollo RCA Methodology

Typically, Realitycharts are considerably more complex than this and can involve hundreds of causes. Read this chart as follows: The primary effect (Airplane Accident) was caused by control lost, and control is required. Now, focus on the box titled "control lost" and read that it is caused by Asymmetric Lift occurred and Symmetric lift is required. Continue following the causal paths in this manner. Each cause box is either an action or a condition cause. (Every effect must have at least one condition cause and one action cause.) The field below the cause box is evidence for that cause. You must include a reason for stopping each cause path.

Note where the Realitychart indicates more information is needed. In this example, we would be interested in further exploring why the thrust reverser deployed. For a complex system such as a turbine engine thrust reverser, quantitative methods such as a fault tree analysis would have been used in design and certification. We would obtain and review the quantitative analysis documents to continue our root cause analysis. We may find an oversight in the quantitative analysis, that the inflight thrust reverser deployment was incorrectly classified as non catastrophic, or other possibilities. You continue building out your cause and effect chart until you have enough of an understanding of the problem such that you can develop effective solutions.

When using the Apollo method to find solutions, you examine each cause and see if there are solutions for that cause. You then determine which solutions meet your effectiveness criteria, pick from the list of candidate solutions, and then implement those solutions. Your effectiveness criteria may require quantitative analysis to evaluate a solution to see if it meets your organization's goals and objectives.

Here's an example of how you might use the cause and effect chart in Figure 1 to find a solution (corrective action):

Cause to be mitigated:	R Thrust Reverser Deployed
Proposed Solution:	Redesign thrust reverser control system to reduce probability of an inflight deployment to acceptable levels
How?:	Develop design enhancements, then use quantitative analysis to verify the enhanced thrust reverser control design has a sufficiently low probability of an inflight deployment, while simultaneously not making the reverser unreliable when needed during landing, all the while tolerating certain latent failures and occasional maintenance abuse. If design solution flunks the quantitative analysis test, re-design and re-evaluate.

If you develop a great (and effective) solution and find you have no cause to attach it to, then you missed that cause in your analysis. In these cases, you should go back and add that cause, then attach the solution to it. If you can't find any effective solutions, continue exploring causes and then try again. It is an iterative process.

The diagrams and reports generated by a thorough root cause analysis create a clear, auditable trail of how the solutions were attached to causes and then evaluated for effectiveness. These reports would include or reference any quantitative analysis used during the RCA. An organization's RCA program can help to reveal recurring causes, especially ones that appear in RCA results from different incidents. These recurring causes typically indicate systemic issues. When used to analyze accidents, these systemic issues typically reveal organizational factors such as problematic procedures, or a culture where personnel have ceased to regularly follow procedures.

We've mentioned use of quantitative methods in support of the RCA process. The next section provides an overview of quantitative methods.

Quantitative Methods

Quantitative methods of event analysis facilitate the quantification of the system under study being in a certain state. There are many methods and tools available to perform such analyses, including combinatorial methods, such as fault tree analysis or dependence diagrams, and stochastic methods, such as Markov analysis. The analyst can choose the quantitative analysis method that best suits the issue under study.

Fault tree analysis is a very popular quantitative analysis method, because it provides the analyst with a very intuitive hierarchical graphical representative of a specified system failure or success state, and provides a means to determine the lower level causal events. Significant latent failures can also be easily identified with a fault tree analysis, when fail-safe system architectures are analyzed.

The probability of the primary events are usually expressed in terms of system component failure rates, λ and their corresponding exposure times, t. The failure rates are usually based on statistical in-service field data or they are predicted failure rates based on a reliability analysis. Sometimes the failure rates are documented in the FMEA and the system components with like effects are summed together and rolled up into the FTA primary events.

Designers of modern aircraft often use fault tree analysis during the preliminary stages of the aircraft and system design process to evaluate the fail-safe attributes of various proposed system architectures. In addition, FTA is a analysis tool that provide a means to allocate lower level safety requirements, in the form of probability budgets, once the top level design requirements are defined via a hazard analysis.

Another useful feature of FTA, is that it can identify vulnerable areas of a design where system independence is claimed, thus establishing areas of further study to verify that common mode issues are precluded, or adequately controlled.

Fault tree analysis also works well as a complement to bottom up single failure analyses, such as Failure Modes and Effects Analysis, in that it provides a means to ensure that the failure effects from the FMEA have a corresponding primary event in the FTA. Any disconnects could be indicative of an error in the analysis. Some analysts also use the FMEA, along with system component failure rates, as a way to roll up failure modes with like effects to establish the numerical probabilities for the primary events in the FTA.

Stochastic methods of system analysis, such as Markov Analysis, are also very useful types of quantitative analysis, in that multiple system states can be analyzed using one system model. The Markov model depicts the system in all of it's various possible failed states, and provides a method to determine the probability of being in any one state. The system is first modeled in all of it's possible states. Then, the transition rates between operating states and failed states is determined. A set of differential equations is then solved to determine the probability of being in any one given state. One of the benefits of using Markov Analysis is that in addition to failure rates, the analysts can add "repair" rates into the model, so that maintenance intervals can be established to provide adequate protection against the effects of significant latent failures in designs using fail-safe system architectures.

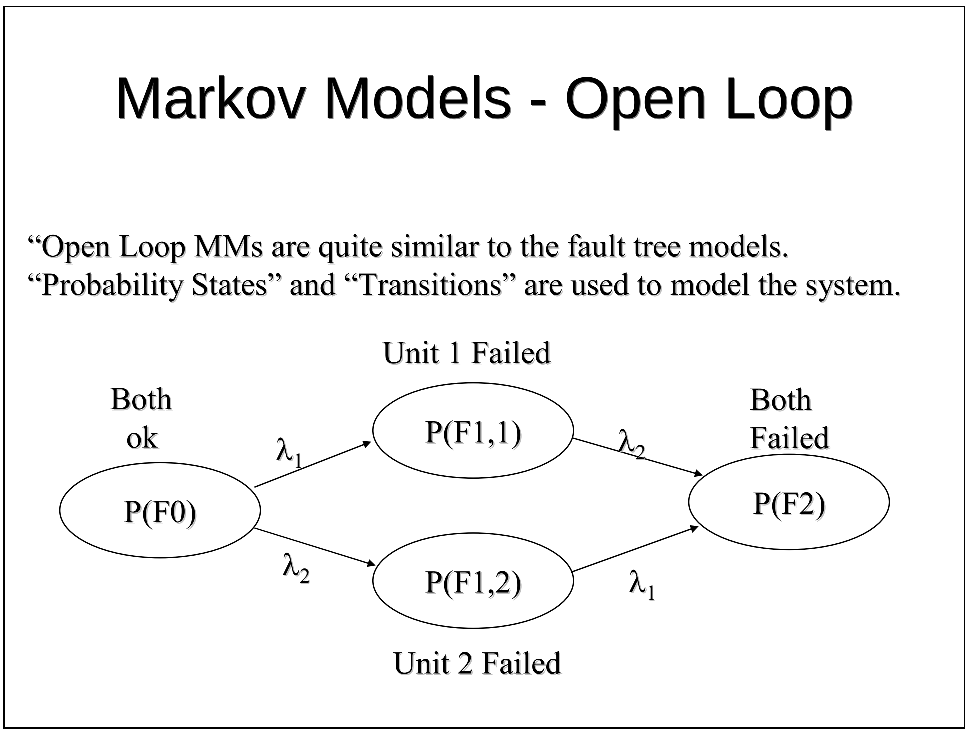

Figure 2: Example of Markov Model

Quantitative analysis methods, such as FTA analysis are often used to compliment a RCA. There are many causes that can be further analyzed to better understand the quantitative contribution of a particular event under study. For example, in the thrust reverser deployment RCA example above, we can further examine the Thrust Reverser Deploy event using FTA:

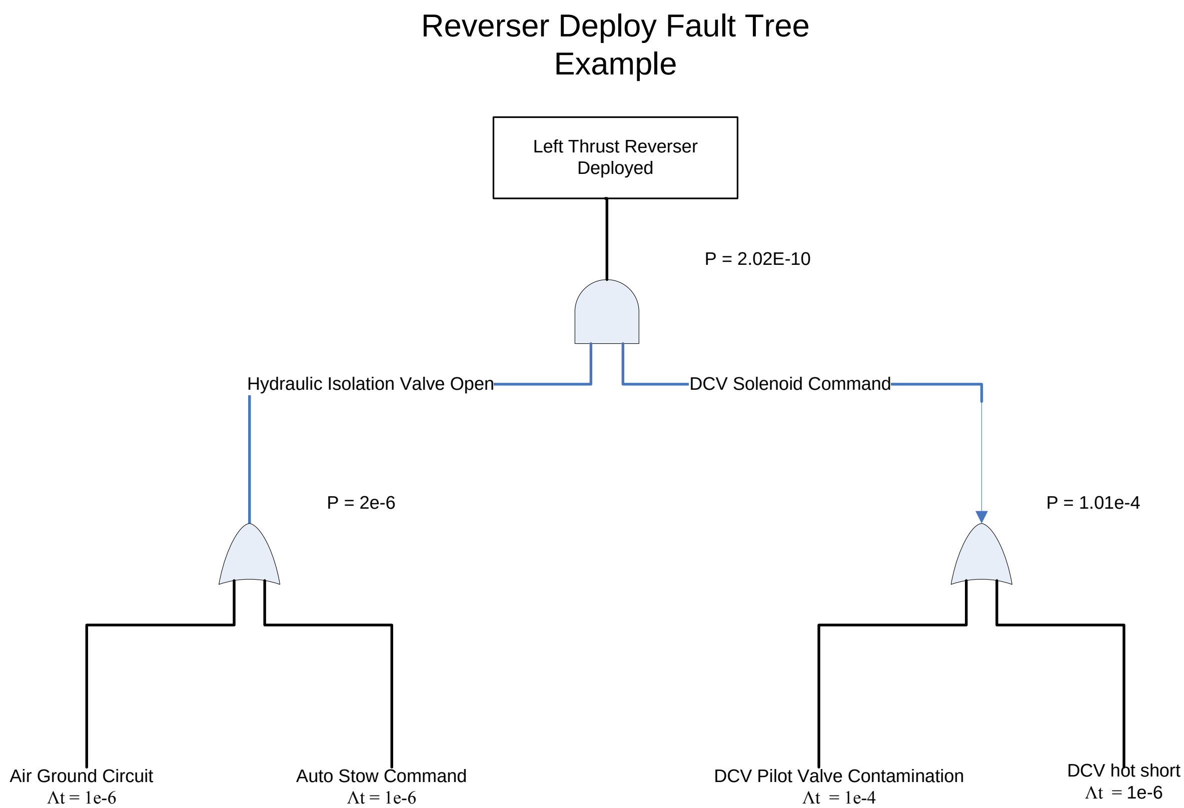

Figure 3: Example of a Fault Tree Analysis

In summary, quantitative methods, such as FTA are similar to a RCA in that the tool allows for the determination of lower level causal events. However, a structured RCA is tailored more for qualitative determination of actionable causes, a FTA is tailored more to analyzing the combinatorial conditions required to occur to lead to a certain system state. There are some limitations to using FTA, in that system events related to human error are difficult to analyze quantitatively because of the sometimes complex interdependencies and latencies that may exist between primary events that are based on human error conditions. FTA is more tailored to analyze hardware, where the assumptions of primary event independence are more easily validated or the dependence of such events can be more easily modeled.

Summary of Root Cause Analysis and Quantitative Methods

Table 5 helps to illustrate these concepts and when each type of analysis is used.

Table 5: Summary of Root Cause Analysis and Quantitative Methods

	System Design, Certification	Operation - if Failures or Accidents occur
RCA	Not typically used in this stage, unless high significance failures occur in design, manufacture, test, etc.	To prevent or mitigate recurrence, effective solutions are required. Start with the RCA, use it to determine causes, and then to find solutions. Use quantitative methods to help determine causes and/or to evaluate solutions for effectiveness.
Quant. Methods	Used for High Consequence Systems. In some industries, required by regulations.	Used in conjunction with RCA to develop effective solutions. See discussion above.

The following flowchart illustrates the interaction between RCA and Quantitative Methods in finding solutions (corrective actions) following an event based problem such as an incident or accident.

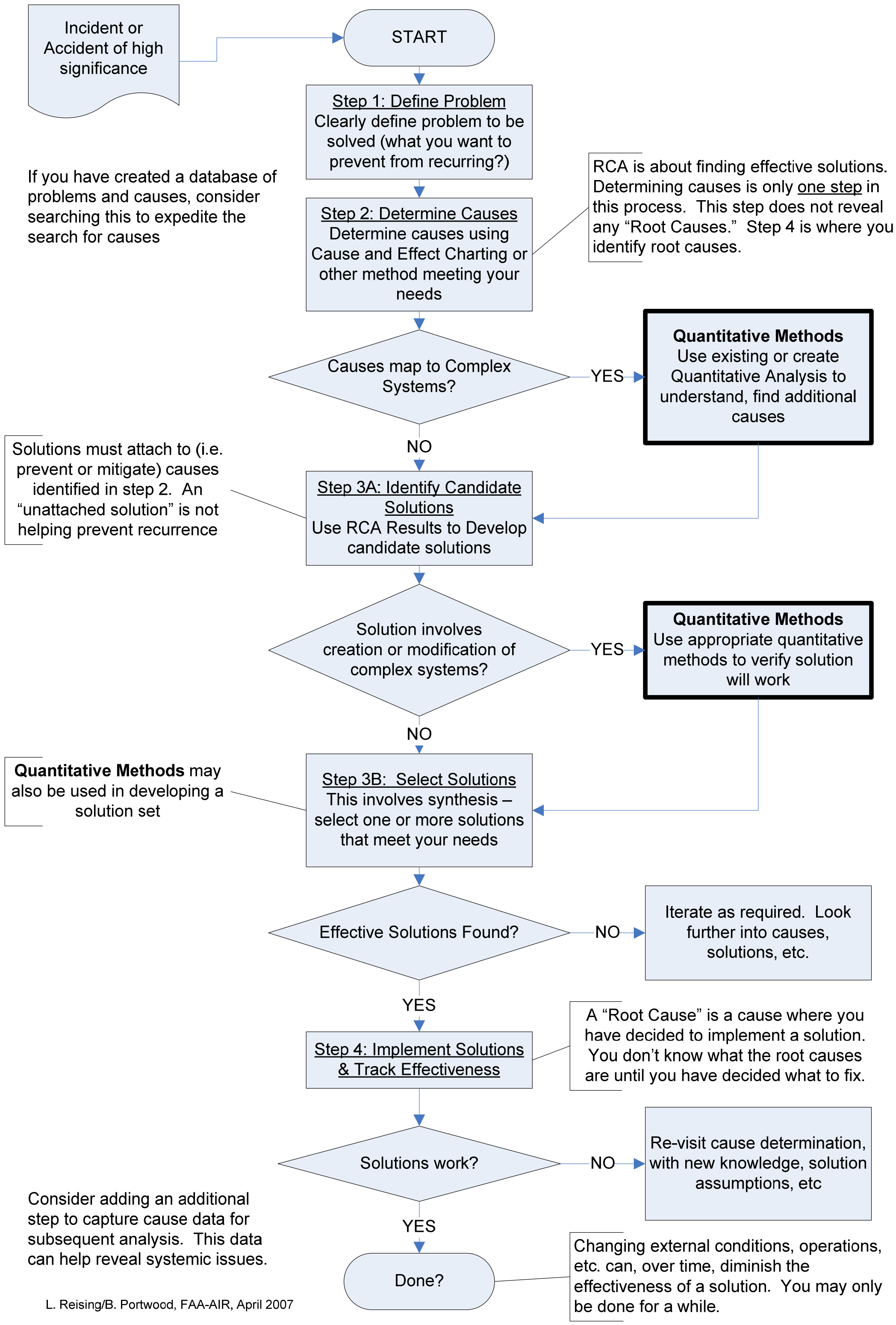

Figure 4: Interaction of RCA and Quantitative Methods in resolving Event Based Problems

The Causal Analysis Continuum

Another perspective on the relationship between root cause analysis and quantitative methods is provided Figure 5. This continuum concepts illustrates some differences between RCA methods. There is no implied subjective assessment of goodness or badness in any of these regions. The approach used should be based on the needs of the organization and of the situation.

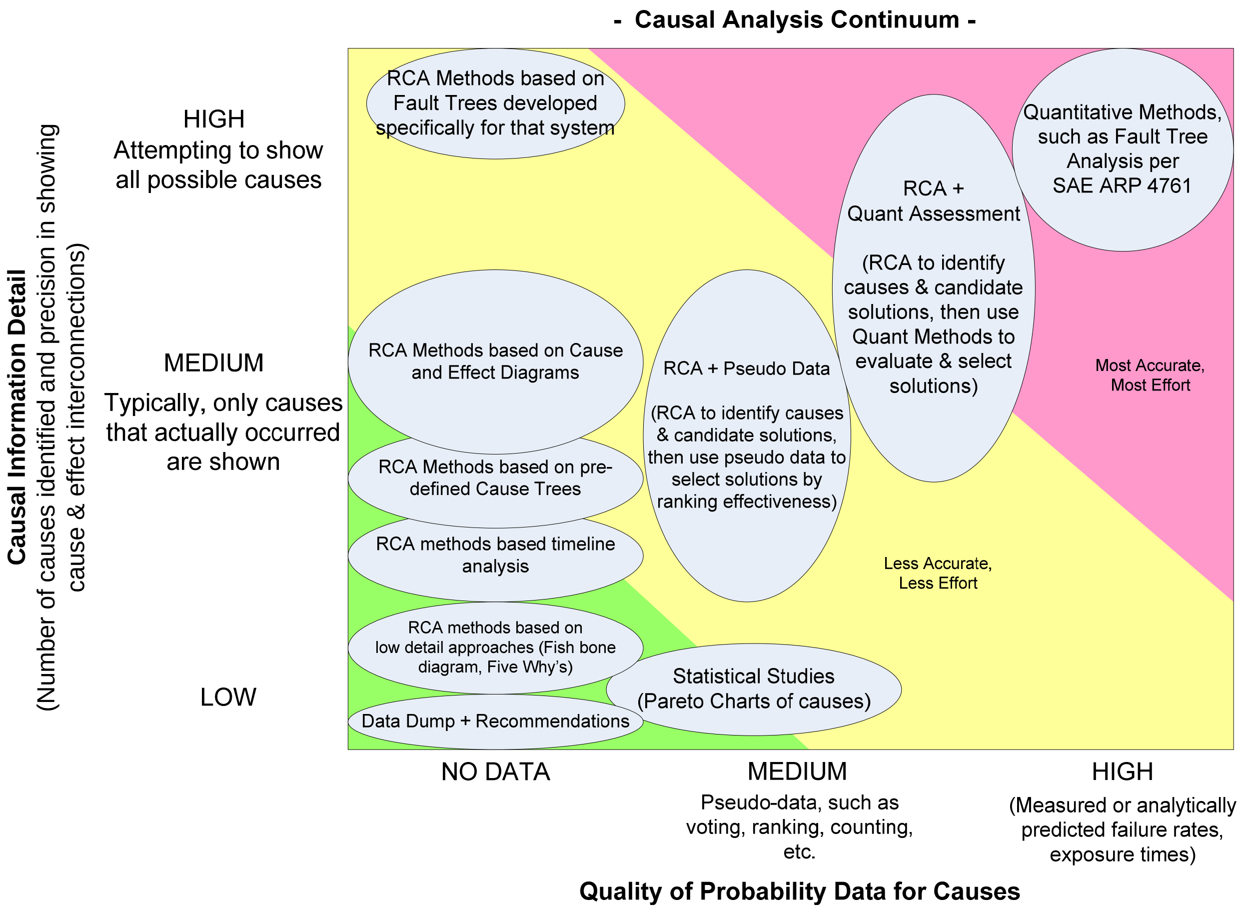

Figure 5: The Causal Analysis Continuum

The following provides clarification on the analysis methods shown in Figure 5:

The Data Dump + Recommendations: (lower left corner) refers to a typical narrative report, possibly including a timeline, data, statements, etc. followed by expert recommendations based on expert judgment. The causal interconnections between the problems and solutions are not always clearly explained in these types of reports. We rely on the competence and experience of the experts to ensure the solutions match up with causes of the problem.

Timeline Analysis: is sometime used to identify causes. This involves a timeline that includes events (actions) and conditions that were present at each point in time. The timeline causal analysis is typically presented in a table and does not provide detailed information on how each event or condition cause interconnect.

Pre Defined Cause Trees: These are typically an extensive list of cause categories, grouped in a hierarchical manner by similar categories such as equipment problems or people problems. These can look similar to cause and effect charts, but they are vastly different. In Causal Categorization Trees, the cause interconnections are based on grouping/categorizing by arbitrarily chosen attributes and do not reflect a cause and effect relationship. Sometimes, when the causes are sorted/categorized into groupings, the number of causes in each group is counted and a pareto chart is created. This statistical approach, however, may be misleading if the true cause and effect relationship behind the cause groupings is not understood.

Cause and effect diagrams: These were discussed earlier in this paper, and an example is shown in Figure 1.

Summary

The abstract referred to concepts of *Yin and Yang* , representing complimentary, but opposing forces, as a means to describe the relationship between qualitative root cause analysis and quantitative methods. Are RCA and Quantitative Methods complimentary? This paper shows how both can be used, in a complimentary fashion, to find effective solutions to event based problems. Are they opposing? In the eyes of a highly quantitative minded system safety professional: Perhaps yes. The RCA is purely qualitative, whereas quantitative methods are based heavily on quantitative data and often complex mathematical analysis. Both RCA and Quantitative methods are part of a larger whole, or continuum of approaches used in finding solutions for event based problems.

Biography

Brett Portwood, B.S. Physics, Technical Specialist for Safety and Integration, Los Angeles Aircraft Certification Office, ANM-130L, 3960 Paramount Blvd., Lakewood, CA 90712, USA, telephone 562-627-5350, e-mail – brett.portwood@faa.gov

Mr. Portwood is the FAA Technical Specialist for Safety and Integration. Brett has 16 years experience with the FAA in certification of airplane systems, including fly-by-wire flight guidance systems, flight management systems, navigation systems, communication systems, surveillance systems, electronic displays, and electrical systems. As a Technical Specialist, Mr. Portwood provides technical expertise in the area of safety assessment methods and associated integration issues to FAA certification engineers and industry. He also was the FAA representative on the SAE S-18 System Safety Assessment Committee that authored ARP 4761, *Guidelines and Methods of Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment.* Mr. Portwood is also actively supporting the development of certification and continued operational safety risk management processes as part of the FAA's Safety Management Process Team. Prior to joining the FAA, Brett spent 10 years in industry performing fault and failure analysis of avionics systems for a wide range of aircraft in addition to participating in the Navy nuclear program performing fault/failure analysis on nuclear reactor monitoring systems. Mr. Portwood has received a Bachelor of Science Degree in Physics from San Diego State University and has published professional papers on trends in system safety assessment methods.

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Mr. Reising is a Program Manager in the FAA's Transport Standards Staff. He holds a BS in mechanical engineering, and has 21 years experience in the development and application of regulatory safety standards for commercial transport aircraft. Mr. Reising was an early adopter of Root Cause Analysis and is currently using it to analyze transport category accidents, incidents, internal process issues, and external issues. Recent work includes supporting the development of the FAA course on airplane accident lessons learned, deploying an ISO 9001 compliant Quality Management System (QMS) within the FAA, and supporting the development of Aircraft Certification's Safety Management System. Mr. Reising is a certified instructor in Apollo Root Cause Analysis, a FAA ISO 9001 QMS lead auditor, and a member of the American Society for Quality.

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