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Technology Corner: Fault Tree Analysis

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Author: Joe Ficalora
Vice President of Technology
Sigma Breakthrough Technologies, Inc.

Fault Tree Analysis (FTA):

One of the more useful tools in Lean Six Sigma problem investigations is the Failure Mode and Effects Analysis or FMEA. This tool gathers and organizes team inputs, problem detection, severity and occurrence in a useful and valuable way to track risks to input variables and output variables. It prioritizes those risks in a manner that allows the highest risks to be addressed first. When combined with other Lean Sigma tools like the Cause and Effect matrix, it helps the team focus on the input variables most important to the key output variables in a process being studied.

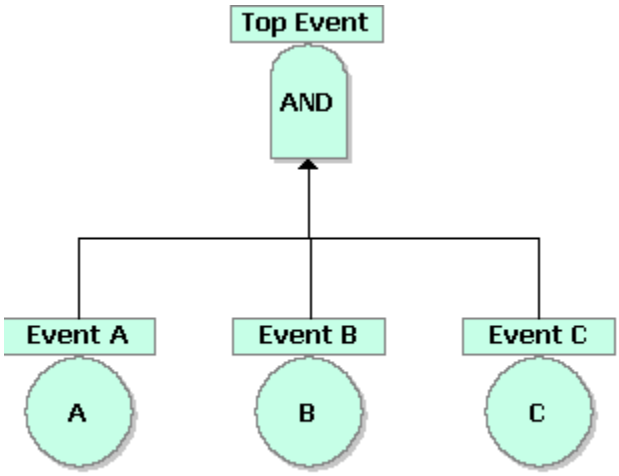
However, sometimes in a Lean Sigma project, a key failure mode may have such high risk and/or may be so complex that it needs further investigation to prevent it from ever reaching a customer. This happens in Lean Sigma applied to product and services design as well as in process improvement. What often happens is that a separate FMEA is begun to "eliminate" this key failure mode completely. This is not always easy or entirely effective for a complex product or complex service involving software, different business functions, multiple branches, multiple subsystems and hundreds of different paths. The tedium can often overcome teams and diminish their efforts over time, plus the most critical paths to prevent are non-obvious.

Consider the examples of nuclear power plant faults, medical delivery systems, pharmaceutical prescriptions, or even air traffic control to name a few complex products and services. Some failure modes will arise that require 2, 3 or more contributing causes to be present in one form or another. The number of potential failure-cause combinations can be in the hundreds or even thousands. While the primary simple failure mode causes can be identified, analyzed and reduced in occurrence and severity, any complex failure combinations involving 4, 5 or even 10 contributing causes are not easy to find by manual inspection. If human life is at stake, or other severe consequences, a more thorough and compelling analysis is really needed.

Fault Tree Analysis (FTA) is a technique that combines probabilities, fault logic, hierarchical structures, Monte-Carlo simulation and graphical displays to provide a more nearly complete analysis than Failure Modes and Effects Analysis alone. This is usually done in software, because of the combinatorial methods and simulations.
Unlike FMEA, which treats each cause as separate and ranked against all other causes, FTA looks at the hierarchy in the system. The system is defined in its branches by logical AND, OR, and other logical combinations. By including combinatorial logic of the failure causes, e.g. Cause1 AND Cause 2, Cause 3 OR Cause 4 OR Cause 5, better analysis and priorities may be determined.
Figure 1. Illustrates a simple three Cause AND Failure tree.

To illustrate, we can see that if three causes are needed to create an event, say a fire, you could illustrate the logic like in Figure 1. Here we could say Event A was a fuel spill, Event B was the existence of Oxygen, and Event C was a point with a temperature at or above the ignition temperature of the fuel. All three need to be present in order to have a fire.

Figure 1
Three Cause AND Failure Tree



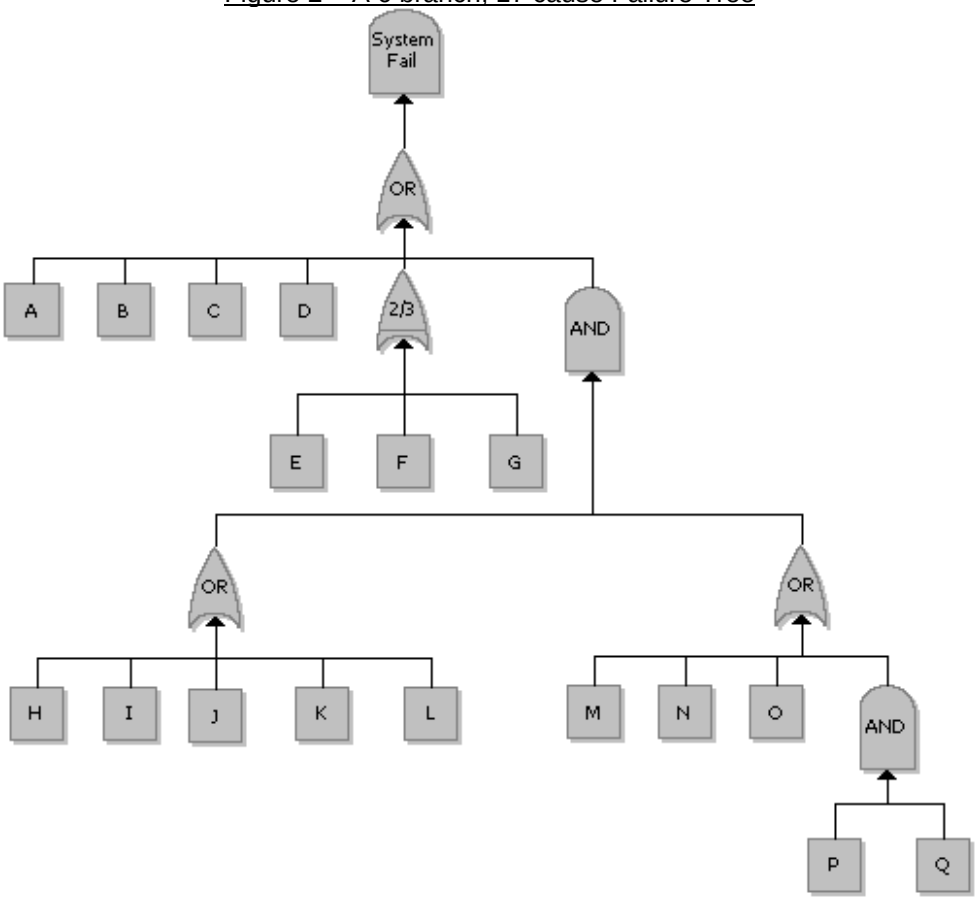
In the simple example in Figure 1, an FMEA and an FTA would focus on the most probable occurring event since all three are required to create the fire for this simple example.

Some failure modes can happen when any of several possible inputs are present. The logical analog in this case is an OR gate to join these inputs in a Fault Tree. In an OR Gate between two inputs the logic works as this simple table:

Input 1	Input 2	Gate Output
0	0	0
1	0	1
0	1	1
1	1	1

Often the FMEA approach with a complex system is to fully load the number of controls 1:1 with each cause, which can be both expensive and even miss the emphasis on the most crucial paths to failure. Consider a product or service FMEA with 17 causes listed in Figure 2. In the traditional Lean Sigma FMEA, all 17 causes would be worked by the team to prevent or detect all 17 potential causes that have high probability. Without the logic included in the diagram, the team's priority would be focused by the Risk Priority Number (RPN) of individual causes ranked against the top system failure mode.

Figure 2 – A 6 branch, 17 cause Failure Tree



What else is needed to perform the analysis? Failure or event probabilities are needed for each basic event in the tree. These probabilities may be arrived at through simulation, process capability analysis, designed experiments, or any other statistical or Six Sigma method aimed at determining an event or failure probability. Indeed, determining these probabilities can be an entire spin-off project. Some of the best feedback received when sketching out the Fault Tree is often around how many new information and analysis gaps a product or service development team may have uncovered.

Fault Tree Analysis or FTA can be described as the analysis of probability, hierarchy and failure logic of complex systems to find the paths and the probabilities that contribute to a specific system failure. Analyzing the paths is best done with software, since there are well over 20 failure paths in the example of Figure 2, which is still a simple Fault Tree compared to actual usage. Fault Tree Analysis often does three specific steps, Tree Validation, Qualitative Analysis, and Quantitative Analysis. Tree Validation is exactly as its name implies, error checking of the logic in the Fault Tree hierarchy. Qualitative Analysis determines all the possible paths that can lead to the top level system failure. Quantitative Analysis then determines the probabilities of the possible paths to rank order them for system improvement and determine the total probability of the system failure occurring with all items in the system.

Fault Tree Analysis Techniques and Software

Fault Tree Analysis methods have been incorporated into many software packages both big and small. This approach is also related to and analogous to a Reliability Block Diagram in many ways, so it is often offered as part of a reliability software package, or by the companies that produce reliability software.

You can get started with an open downloadable package by OpenFTA. This software is reasonably stable and has been used by the author at clients getting started with FTA. More advanced packages are available by ReliaSoft (BlockSim), Dyadem (FTA-Pro), Item Software, and Relex.

FTA in Lean Sigma Projects

Fault tree analysis work should be integrated with the DMAIC roadmap in Lean Sigma at the beginning and later stages of project work. Specifically, after a PFMEA has determined the top failure modes and their causes, an effort should be made to understand if any of the top ranked ones are truly more complex than indicated. Do other elements of the system participate but are not included in the failure mode? Does this top failure mode have serious health, operator, business or financial impact? If it is serious and complex, perhaps a Fault Tree should be utilized to arrive at the best control plan.

If the Lean Sigma project has design goals, for either product or service design, chances are it will be complex enough to perform a Fault Tree Analysis on the top ranked items from the Design FMEA or DFMEA. FTA originated in the product world because of the complex nature of large system designs, but has equal use in any complex system involving many diverse elements like software, operator or human factors, and electro-mechanical or electro-optical subsystems.

Lastly, if the Lean Sigma project is focused in the Healthcare area, where a patient may be at risk, an FTA should be implemented for any top ranked failure mode that appears threatening and complex to analyze. Accrediting and regulatory bodies that require root cause analysis for sentinel events would welcome this level of sophisticated analysis.

While in the past the connections for evaluating input variables might have followed a path like Process Map → C&E Matrix → FMEA → Control Plan, we now have an additional item to add thus: Process Map → C&E Matrix → FMEA → FTA & Control Plan.

Summary

In this brief overview of Fault Tree Analysis, we reviewed its relationship to FMEA, Lean Sigma projects and mentioned some of the software packages available. For further information please follow up with the links contained at the end of the article. While the basics of FTA seem straightforward, implementing it the first time on your project will have challenges not covered herein. If you would like expert help in getting started with Fault Tree Analysis, please contact this author at JFicalora@sbtionline.com or SBTI through www.sbtionline.com .

This quarter's FTA tip – if you have a serious warranty issue or sudden rise in product or service failures, consider constructing a Fault Tree to find all root and contributing causes.

Web Based References:

1. http://www.patientsafety.gov/SafetyTopics/HFMEA/HFMEAIntro.pdf
2. http://www.weibull.com/basics/fault-tree/andgate.htm
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