

ACDA5021 – Systems Engineering

Fault Tree Analysis

Determining the probability of the successful making of a hot drink from a process chart using Fault Tree Analysis

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Spring 2026

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Abstract

This report looks at fault tree analysis (FTA), a top-down analysis method for systems in reliability and safety engineering and identifies some of the key benefits that has led to FTA becoming one of the most widely used failure analysis tools in engineering. To assist with this, a success/failure analysis was performed twice on a hot-drink making process, looking at the difference between operation of the system in ideal conditions, and considering human factors. Doing the process allowed for clear identification of the most likely places for error to affect the system's success. Operating in ideal conditions had a system success probability of more than 0.68 but operating under specific human factors such as fatigue decreased the probability of success to under 0.35, demonstrating how easy it is to quickly identify the impact of human factors and changes in circumstance using FTA, and how this can prevent system problems further down the line.

Introduction to Fault Tree Analysis

Fault Tree Analysis (FTA) is a top-down analytical process used in performability and reliability engineering to identify all possible root causes that may lead to the failure of a system, and the probability of such events occurring [1].

It was initially developed in the 1960s by Bell Labs as a means of analysing the Minuteman ICBM during the Cold War, and its success has led to the tool being used across the engineering discipline in the years since, particularly in aerospace, defence and energy disciplines [1]. Today, it is one of the world's most used failure analysis tools [1].

FTA breaks down a system into its individual component parts using a simple process chart and then calculates the probability of failure (or success) of each component and combines those probabilities to determine the likelihood of system failure (or success) [2].

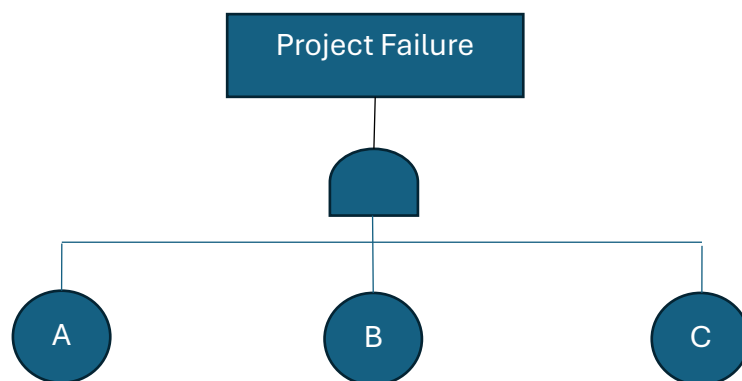


Figure 1: Example of a simple AND gate chart.

System failure can occur through any one of a list of possible component failure, or it may be that the system does not fail until several components fail. These different types of failure are expressed using AND/OR gates [2].

AND gates are used to denote when total failure can only come about due to failure of several components. Figure 1 shows an example of a simple AND process chart, whereby Project Failure is only achieved through the failure of components A, B and C. The symbol in the centre of the chart is an AND gate [1] [2].



Figure 2: OR gate.

Figure 2 shows an OR gate. If this symbol was placed into the chart in Figure 1 instead of the AND gate, this would mean that the system would fail if any of component A, B or C were to fail [2] [1].

The probability of system failure will be different depending on whether all or one of the components are required to fail to cause failure.

Solving Logic Gate Probabilities

Referring to Figure 1 as is, with an AND gate, if component A had a probability of failure $P(A)$ of 0.05, component B had a probability of failure $P(B)$ of 0.08 and component C had a probability of failure $P(C)$ of 0.06, then the probability of failure of the system $P(F)$ is the product of each individual probability, so $P(F) = P(A*B*C) = P(0.05*0.08*0.06) = \mathbf{0.00024}$

If there was an OR gate (Figure 2) in place of the AND gate, then the probability of system failure would be slightly more complicated, found using the formula $P(F) = 1-((1-P(A))*(1-P(B))*(1-P(C)))$, so $P(F) = 1-(0.95*0.92*0.94) = 1-(0.82156) = \mathbf{0.17844}$

In each case, the probability of success would be the reverse, so $P(S) = 1-P(F)$.

Fault Tree Analysis of Hot Drink

Problem Summary

In this report, FTA will be used to determine the probability of successfully making a hot drink. Figure 3 shows the process chart that will be used to determine the success probability, and Figure 4 shows the table of individual component probabilities. Two calculations will be carried out, one in ideal conditions where Bill, the tea maker, is in the best possible shape to make the drink, and one considering environmental and human factors, where Bill has woken up in the middle of the night and some probabilities have changed.

Make Hot Drink

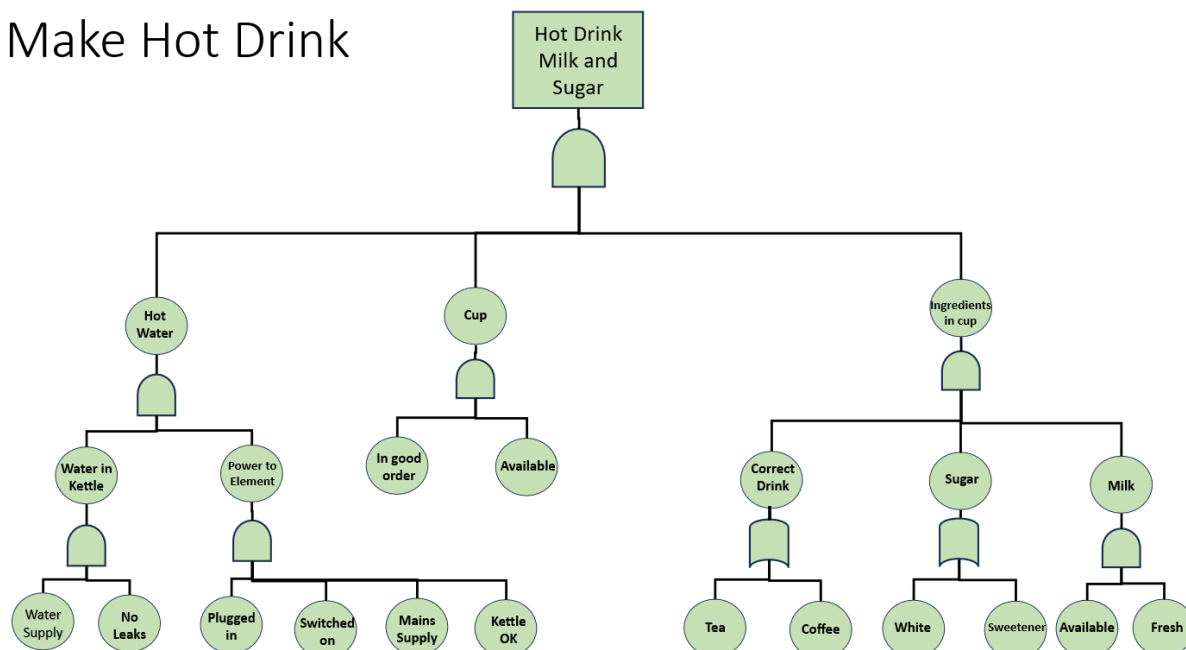


Figure 3: Process Chart for making of hot drink.

Event	Probability
Tea availability	0.98
Coffee availability	0.98
Chance of leaky Kettle	0.001
Chance of water supply failure	0.01
Kettle reliability	0.99
Plug in operation reliability	0.89
Switch on reliability	0.89
Mains supply failure chance	0.01
Cup availability	1
Cup reliability	0.99
Milk availability	0.95
Milk freshness	0.95
Sugar availability	0.88
Sweetener Availability	0.99

Figure 4: Table showing probabilities of each event within the process chart.

As Figure 3 shows, the successful making of a hot drink relies on successfully obtaining hot water, a cup, and the correct ingredients. These are the top-level components of the system. However, with further investigation these components can be broken down further into subcomponent levels to investigate the likelihood of component failure. In order to establish the overall probability of success, FTA must be solved from the ground up. The next section of the report aims to resolve the probability of success in ideal conditions, using the multipliers described in Figure 4.

Ideal Conditions

Solving Ingredients Branch

Firstly, FTA will be used to find the probability that the correct ingredients are both selected and then put into the cup correctly.

Probability of Milk in Cup

As per Figure 3, the probability of having milk in the cup depends on both availability and freshness. The probability of milk being available is 0.95, and being fresh is also 0.95. This is an AND gate and therefore the probability of having milk in the cup correctly is $P(0.95 \times 0.95) = \mathbf{0.9025}$

Probability of Sugar in Cup

Sugar will be added to the cup if any of white sugar or sweetener are available. The probability of white sugar availability ($P(A)$) is 0.88 and sweetener availability ($P(B)$) is

0.95. This is an OR gate and therefore the probability of sugar in the cup is $1 - ((1 - P(A)) * (1 - P(B))) = 1 - (0.12 * 0.05) = 1 - (0.006) = \mathbf{0.994}$

Probability of Correct Drink

The drink will be added to the cup if either tea or coffee is readily available. The probability of tea availability ($P(A)$) is 0.98 and the probability of coffee availability ($P(B)$) is 0.98. This is an OR gate and therefore the probability of drink availability is $1 - ((1 - P(A)) * (1 - P(B))) = 1 - (0.02 * 0.02) = \mathbf{0.9996}$

Probability of Ingredients in Cup

Having the correct ingredients to make the hot drinks relies on all three subcomponents to be successful. This is an AND gate and therefore the final probability for the ingredients branch of the process chart is $P(0.9025 * 0.994 * 0.9996) = 0.896726166$, or **0.897** to three decimal places.

Solving Cup Branch

The cup will be available if a cup is both available, and in a usable condition. The probability of availability is 1 and the probability of usability is 0.99. This is an AND gate and so the probability of the cup being successfully chosen for the drink is $P(1 * 0.99) = \mathbf{0.99}$

Solving Hot Water Branch

Probability of Water in Kettle

Water will be in the kettle and available to use if there is both a working water supply and the kettle is useable, i.e. free of leaks. The chance of water supply failure is 0.01, and therefore the probability of availability ($P(A)$) is 0.99, and the probability of a leaky kettle is 0.001, meaning the probability of a non-leaking kettle ($P(B)$) is 0.999. This is an AND gate, and so the probability of water in the kettle is $P(0.99 * 0.999) = \mathbf{0.98901}$

Probability of Power to Kettle

Power reaching the kettle relies on four things – the kettle being plugged in, switched on, connected to a working mains supply, and having a reliable heating element inside. The probability of being plugged in ($P(A)$) is 0.89, the probability of being switched on correctly ($P(B)$) is 0.89, the probability of mains supply working correctly ($P(C)$) is 0.99 (1-0.01), and of having a reliable heating element ($P(D)$) is 0.99. This is an AND gate, and so the probability of power to the kettle is $P(0.89 * 0.89 * 0.99 * 0.99) = \mathbf{0.77633721}$

Probability of Providing Hot Water

The final probability of providing hot water to the drinking water relies on both water and power. This is an AND gate and so the probability of hot water being provided for the drink is $P(0.98901 * 0.77633721) = 0.7678052640621$, **0.768** to three decimal places.

Final Probability of Success

The final probability of successfully making a hot drink is a combination of the hot water, cup and ingredients. This is an AND gate and taking the previously calculated probabilities, it is found that the probability of successfully making a hot drink is $P(0.768 \times 0.99 \times 0.897) = 0.68200704$, **0.682** to three decimal places, in ideal conditions.

Application of Human Factors

According to the task proforma, Bill has woken up in the middle of the night to make the drink, in which case fatigue and lower awareness are likely to be two human factors which reduce the probability of successfully making the drink.

The likelihood of correctly switching on and plugging in the kettle have both dropped to 75% of their normal levels, and the likelihood of selecting a cup has dropped to 90% of ideal conditions.

The probability of switching on and plugging in correctly are both 0.89. At 75% capacity this value drops to **0.6675**, and so therefore the total probability of power being provided to the kettle now changes to $P(0.6675 \times 0.6675 \times 0.99 \times 0.99) = 0.436689680625$, **0.437** to three decimal places. This has a knock on effect on the total probability of hot water being provided, which is now $P(0.436689680625 \times 0.98901) = \mathbf{0.432}$ to three decimal places.

The probability of selecting a cup was originally 0.99. With human factors accounted for this now drops to **0.891**.

The probability of the correct ingredients being combined remains 0.897.

This means, accounting for human factors and changes in circumstance, the probability of successfully making a hot drink is now $P(0.432 \times 0.891 \times 0.897) = \mathbf{0.345}$ to two decimal places.

Conclusion

The probability of success moving from **0.682** to **0.345** is a notable drop from ideal conditions, where the chance of success has decreased from over two-thirds to just over one-third, a drop which means making a hot drink has gone from being more likely to succeed to more likely to fail.

In conclusion, this report highlights the benefits of conducting FTA on processes, as it is a simple but effective way to spot the most likely sources of error, either mechanical or human, and FTA can be conducted iteratively looking at different circumstances, either environmental or human, to see how certain factors coming in to play can sway results, and affect the likelihood of system success or failure. From any system as simple as making a cup of coffee, all the way through to testing and evaluating ICBMs, fault tree

analysis has proven to be one of the simplest yet most effective ways to conduct failure analysis on systems.

References

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- [2] IBM, “What is Fault Tree Analysis?,” IBM, [Online]. Available: <https://www.ibm.com/think/topics/fault-tree-analysis>. [Accessed 10 April 2026].