A Fault Tree Analysis of Human Reliability: Assessing the Effects of Fatigue on Task Performance

OWEN MILLER

BAE SYSTEMS, UNIVERSITY OF WALES TRINITY ST DAVID

25/04/2025

Word Count: **1315** not including Abstract, Bibliography, Headers, Figures

I. Abstract

This report investigates the impact of human factors, specifically fatigue, on the reliability of a manual task using Fault Tree Analysis (FTA). The process of making a hot drink was modelled as a series of interdependent steps involving human action and basic system functions. Probabilities were assigned to each step under two conditions: normal and fatigued. In the fatigued scenario, reduced performance was applied to selected actions such as plugging in the kettle, switching it on, and selecting a cup. These were incorporated into an FTA structure to determine the overall probability of success.

The analysis found that task reliability dropped from 20.29% under normal conditions to 10.27% under fatigue, despite changes to only a few steps. This result highlights how minor reductions in human reliability can have a significant impact on system outcomes, especially when failures occur within AND gate logic. The report also outlines key contributors to human error, such as fatigue, stress, and inexperience, and discusses mitigation strategies using structured procedures, automation, and design interventions. The findings emphasise that human error should be treated as an expected factor in system performance and managed accordingly during design and operational planning.

II. Table of Figures

Figure No	Figure
1	Hot Drink Fault Tree
2	Hierarchy of Hazard Controls
3	Fatigued Fault Tree
4	Normal Fault Tree

III. Table of Tables

Table No	Table
1	Event Success and Failure Chance

IV. Table of Contents

I. Abstract 2

II. Table of Figures 3

III. Table of Tables 3

IV. Table of Contents 4

1. Introduction 5

2. Calculations 7

3. The effect of human factors 10

4. Conclusion 15

5. Bibliography 16

6. Appendix 18

1. Introduction

Fault Tree Analysis (FTA) is a method used to assess how different failures can combine to cause an undesired event. It breaks a system or task into smaller components and uses logic gates to link basic events together. These logic gates, typically AND plus OR, determine how failures interact. An AND gate means that all connected failures must occur for the top event to happen, while an OR gate means that the failure of any single input is enough to trigger the top event [1].

FTA is useful for identifying weak points in a process and understanding which events have the biggest effect on overall system reliability. It also allows for the calculation of a numerical probability of failure, based on known or estimated values for each contributing factor.

For AND gates, the probability of the output event occurring is calculated by multiplying the probabilities of all input events [2]:

$$P_{\text{AND}} = P(A) \times P(B) \times P(C)$$

For OR gates, the formula accounts for the chance of any input event causing the outcome [2]:

$$P_{\mathrm{OR}} = 1 - [(1 - P(A)) \times (1 - P(B)) \times (1 - P(C))]$$

These calculations are applied at each stage of the fault tree and are carried forward through the branches to determine the overall probability of the top-level event.

This report applies FTA to the task of making a cup of tea under fatigue conditions—specifically, a scenario where the individual (Bill) wakes during the night and attempts the task while tired. Each step in the process is assigned a probability of success or failure, and the structure of the fault tree is used to calculate the overall chance of successfully completing the task. The impact of fatigue on task reliability is explored in more detail in the Human Factors section.

2. Calculations

This fault tree analysis models the task of making a hot drink, with the top-level goal being the successful combination of hot water, a usable cup, and correct ingredients. These elements are structured into three major subsystems within the fault tree (Figure 1). Probabilities for each step are defined based on a normal (non-fatigued) case, and adjusted values are used for a fatigued scenario, where human reliability is reduced. **Note:** See appendix 1 for full fault trees.

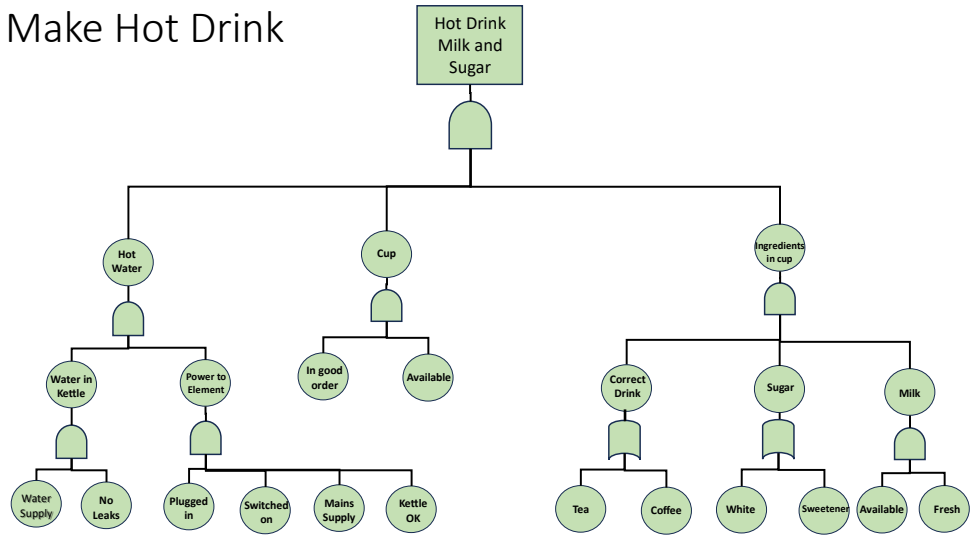

Figure 1 – Hot drink fault tree

Event	Probability	Success Chance	Failure Chance	Fatigued effect %	Fatigued Success Chance	Fatigud Failure chance
Tea availability	0.8	0.8	0.2	1	0.8	0.2
Coffee availability	0.9	0.9	0.1	1	0.9	0.1
Chance of leaky Kettle	0.1	0.9	0.1	1	0.9	0.1
Chance of water supply failure	0.01	0.99	0.01	1	0.99	0.01
Kettle reliability	0.99	0.99	0.01	1	0.99	0.01
Plug in operation reliability	0.7	0.7	0.3	0.75	0.525	0.225
Switch on reliability	0.7	0.7	0.3	0.75	0.525	0.225
Mains supply failure chance	0.01	0.99	0.01	1	0.99	0.01
Cup availability	1	1	0	0.9	0.9	0
Cup reliability	0.7	0.7	0.3	1	0.7	0.3
Milk availability	0.9	0.9	0.1	1	0.9	0.1
Milk freshness	0.8	0.8	0.2	1	0.8	0.2
Sugar availability	0.6	0.6	0.4	1	0.6	0.4
Sweetener Availability	0.9	0.9	0.1	1	0.9	0.1

Table 1 – Event Success and Failure Chances

All probabilities are treated as chances of success, and logic gates define how each stage contributes to the outcome. The analysis uses:

$$P_{\text{AND}} = P(A) \times P(B) \times P(C)$$

- AND gate: All input events must succeed.
- OR gate: At least one input must succeed.

$$P_{\text{OR}} = 1 - [(1 - P(A)) \times (1 - P(B)) \times (1 - P(C))]$$

2.1. Hot Water Sub System:

This branch includes two AND gates.

Fatigued:

- Water in kettle =

  0.99×0.9 = 0.891

- Power to element =

  0.525×0.525×0.99×0.99=0.2701

- Hot water =

  0.891×0.2701 = 0.2407

Non-Fatigued:

- Power to element =

  $0.7 \times 0.7 \times 0.99 \times 0.99 = 0.4802$

- Hot water =

  $0.891 \times 0.4802 = 0.4279$

2.2. Cup Subsystem

Fatigued:

- In good order = 0.7
- Available = 0.9
- Cup =

  $0.7 \times 0.9 = 0.63$

Non-Fatigued:

- In good order = 0.7
- Available = 1.0
- Cup =

  $0.7 \times 1.0 = 0.7$

2.3. Ingredients in Cup Subsystem

These values are the same for both scenarios.

- Correct drink (tea or coffee):

  $1-(1-0.8)\ (1-0.9) = 0.981$

- Sugar (white or sweetener):

$1-(1-0.6)(1-0.9) = 0.961$

- Milk:

  $0.9 \times 0.8 = 0.72$

- Ingredients =

  $0.98 \times 0.96 \times 0.72 = 0.6774$

2.4. Final Success Probability

Fatigued:

$0.2407 \times 0.63 \times 0.6774 = 0.1027$ or 10.27%

Non-Fatigued:

$0.4279 \times 0.70 \times 0.6774 = 0.2029$ or 20.29%

This calculation shows that fatigue has a clear and measurable impact on the ability to complete a task. In this case, performance was reduced in only a small quantity of steps, but it still had a noticeable effect on the overall outcome. Fatigue is a human factor, and like other human factors, it can significantly affect tasks that rely on people to carry out key actions. This highlights the importance of considering human reliability when evaluating systems that involve manual input or decision-making [3].

3. The effect of human factors

Human factors refer to the physical, psychological, and environmental influences that affect how people interact with systems. These factors directly impact how

well someone can perform a task and whether they are likely to make an error. In systems that rely on human input, these effects must be considered when evaluating overall reliability [4].

3.1. Effectors on the reliability of humans

Unlike machinery, humans are not consistent in how they perform. Performance can vary based on a number of common factors [5]:

- **Fatigue** – reduced alertness and slower actions.
- **Stress** – caused by pressure, distractions, or urgency.
- **Discomfort** – poor lighting, noise, temperature, or ergonomics.
- **Inexperience** – unfamiliarity with steps or equipment.

These factors affect concentration, reaction time, and decision-making ability. Human factors occur naturally and often vary from moment to moment. In this analysis, fatigue was used as a specific modifier to simulate reduced performance when attempting a task after waking in the night.

3.2. Fault Tree Link

In the fault tree, fatigue was modelled by reducing the success probability of key actions: plugging in the kettle, switching it on, and selecting a usable cup. These actions occur at AND gates, meaning a failure in any one of them prevents success. The knock-on effect from reduced human

performance had a direct and measurable impact on the outcome (reduced by roughly 10% in this example) [6].

3.3. Mitigating human error

Although human factors cannot be fully removed, their impact can be reduced through thoughtful system design and operational controls. Several strategies are widely used to manage human reliability, including simplifying tasks, using automation where possible, improving training, and managing environmental conditions such as noise and lighting [7].

In reliability engineering, the probability of human error during a simple decision or action is typically estimated at 1 in 1,000 (1×10^{-3}) under normal conditions. This means that, on average, a person will make a mistake once every 1,000 times they perform a similar operation. However, this probability is not fixed [5]. Under adverse conditions (factors discussed earlier) the likelihood of error can increase significantly. Under poor conditions, the probability of human error can rise to 1 in 25 (4×10^{-2}) or higher [5].

Given this variability, areas of a system that are heavily dependent on human input particularly those linked to critical steps in an AND gate structure, should be designed with additional controls to minimise risk. These controls can include:

- Inspection and checking steps to catch errors before they propagate.
- Heavily regimented Safe Operating Procedures (SOPs) to guide behaviour consistently.
- Automation or redesign to remove the human element entirely, if feasible.

These principles align closely with the Hierarchy of Control [8] (figure 2) commonly used in hazard assessments. Although primarily designed for safety management, this framework can also be applied to quality and reliability systems. It prioritises removing the hazard (or in this case, removing the chance for human error) wherever possible, followed by engineering controls, administrative controls and finally personal interventions like training and supervision.

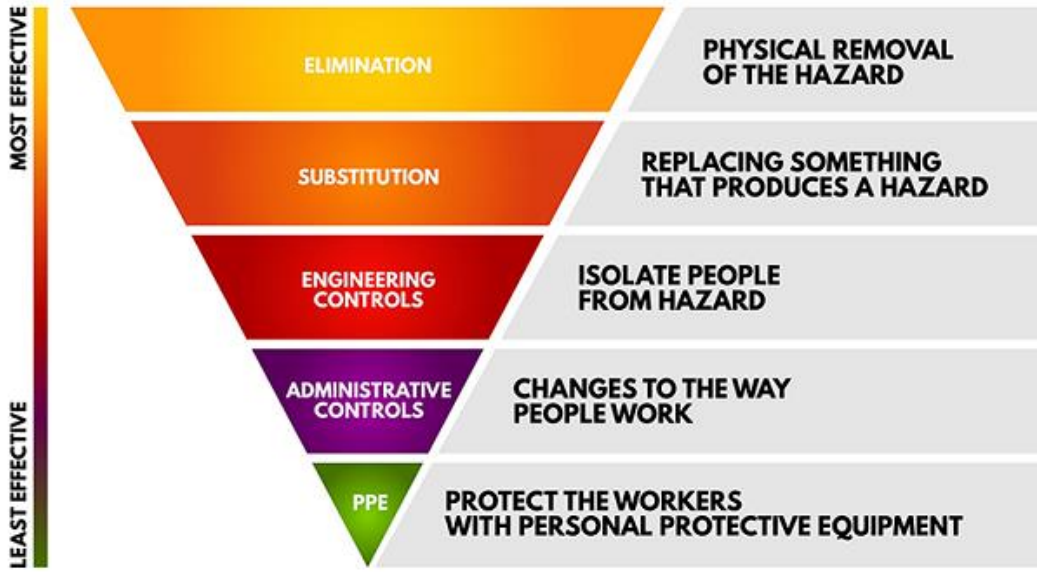

Figure 2 – Hierarchy of hazard controls [8]

By applying this structured approach to tasks identified as vulnerable in the fault tree, such as plugging in and switching on the kettle or selecting a usable cup the overall reliability of the system can be significantly improved.

4. Conclusion

This report has shown that even small changes in human performance can cause significant reductions in task reliability. Using FTA, it was found that fatigue alone affecting just a few steps was enough to halve the chance of successfully making a hot drink. This demonstrates that human reliability is a critical factor in systems where people are responsible for completing key actions.

The findings highlight those tasks involving human input, especially those placed at failure-sensitive points in a process, should not be treated as fixed or guaranteed. Instead, they require additional control, oversight, or redesign to reduce the risk of failure. Human factors should be considered early in system design, particularly where consistency and reliability are required.

Overall, this analysis reinforces that human error is not a rare exception, it is an expected part of system behaviour that must be managed just like any technical risk.

5. Bibliography

[1] “What is fault tree analysis (FTA)?,” IBM, 30 06 2023. [Online]. Available: https://www.ibm.com/think/topics/fault-tree-analysis. [Accessed 15 04 2025].

[2] T. O. Educator, Director, *Fault Tree Analysis FTA Explained With Example Calculation.* [Film]. The Open Educator, 2020.

[3] A. C. M. R. D. A. Florin NICOLAE, “HUMAN RELIABILITY USING THE FAULT TREE ANALYSIS. A CASE STUDY OF A MILITARY ACCIDENT INVESTIGATION,” in *International Conference - Knowledge-Based Organissation*, Constanta, 2016.

[4] Health and Safety Executive, “Introduction to human factors,” Health and Safety Executive, [Online]. Available: https://www.hse.gov.uk/humanfactors/introduction.htm. [Accessed 18 04 2025].

[5] G. G. G. P. Lorenzo Ciani, “Human reliability in railway engineering: Literature review and bibliometric analysis of the last two decades,” *Safety Science,* 03 2022.

[6] S. L. John Andrews, “An Introduction to Fault Tree Analysis,” University of Nottingham, Nottingham.

[7] health and Safety Executive, “Managing human failures: Overview,” health and Safety Executive, [Online]. Available:

https://www.hse.gov.uk/humanfactors/topics/humanfail.htm. [Accessed 22 04 2025].

[8] Texas Department of Insurance, “Reducing hazards with the Hierarchy of Controls,” Texas Department of Insurance, [Online]. Available: https://www.tdi.texas.gov/tips/safety/hierarchy-of-controls.html. [Accessed 24 04 2025].

6. Appendix

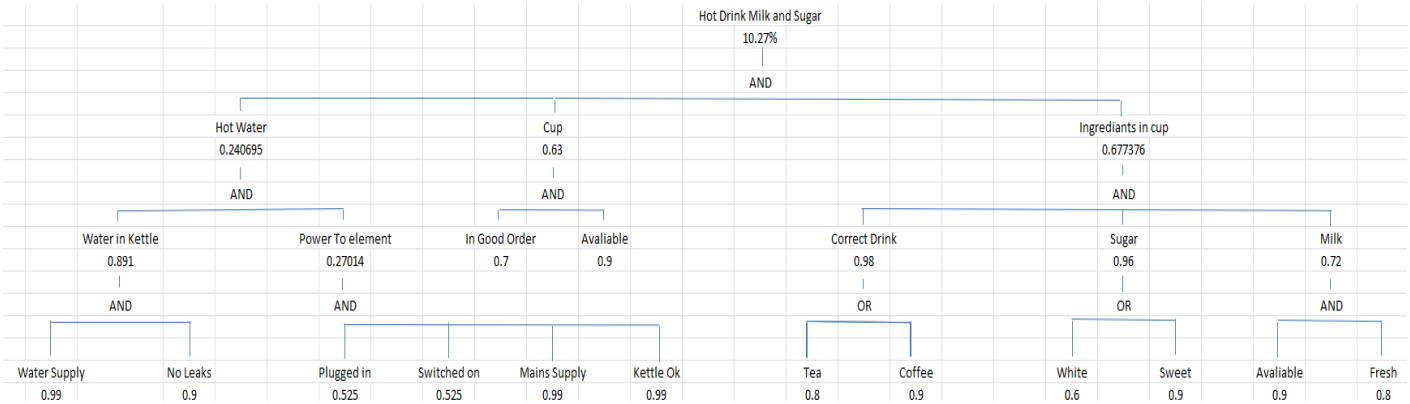

Figure 3 – Fatigued Fault Tree

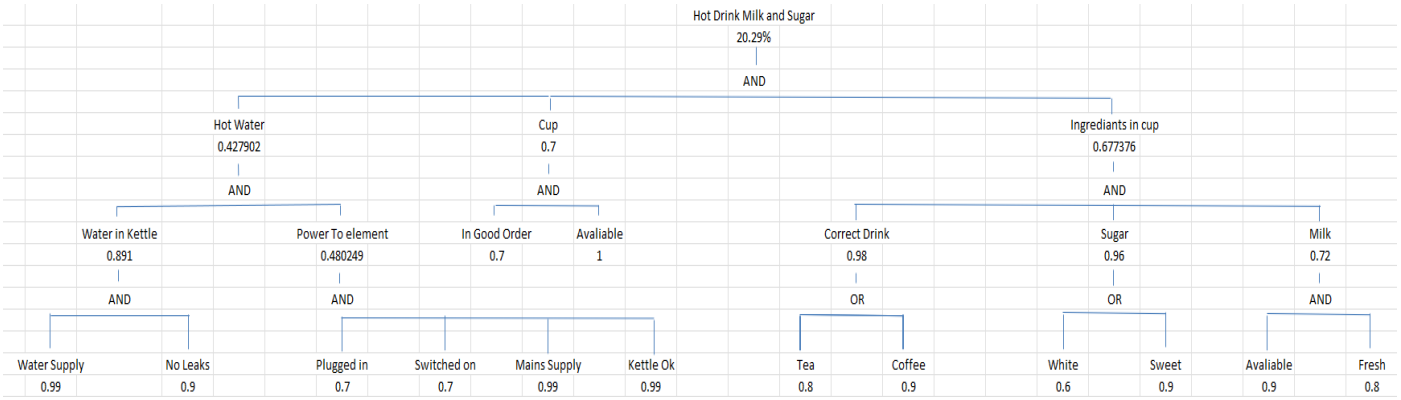

Figure 4 – Normal Fault Tree