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Fault Tree Analysis Report

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Academic integrity declaration

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- no animals were harmed in the writing of this essay.
- the thesis submitted has not been previously submitted to this university or any other.
- that all content, including primary and/or secondary data, is true to the best of my knowledge.
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Abstract

A fault tree analysis was performed on the process of making a hot drink, initially under normal conditions and then again under adjusted conditions with increased failure probabilities for key process steps. These exercises demonstrate the utility of this approach for identifying the causes of process failure.

Keywords:

Fault tree, analysis, probabilities, human factors, hot beverage

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List of Abbreviations

FTA – Fault Tree Analysis

1 Introduction

Fault Tree Analysis (FTA) is a technique widely used within engineering domains to evaluate and assure the safety of a system or process. The creation of an FTA allows the user to calculate the precise probability of a given event, as well as the combination of factors which would be required for that event to take place. FTAs also enable a user to visualise pathways from an initiating event to a top level event, illustrating safety features and vulnerabilities.

An FTA is performed through arranging events in a tiered manner, with basic initiating or contributory events at the bottom, using a series of gates to show the relationship between these events.

Events are illustrated in the following manner:



A basic event; contributory events to these are not shown on the FTA. In industry, these often reference out to a separate FTA.

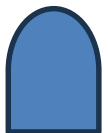


An emerging event, linked to contributory factors.

The relationships between events are illustrated using gates, as follows:



OR gate: only one contributory factor need occur to initiate the next event.



AND gate: all contributory factors must occur to initiate the next event

This essay will perform a FTA on the process of making a hot drink (tea or coffee). The FTA, displayed on the following page, shows the required basic events and the events required to progress through the process to the eventual production of a hot beverage.

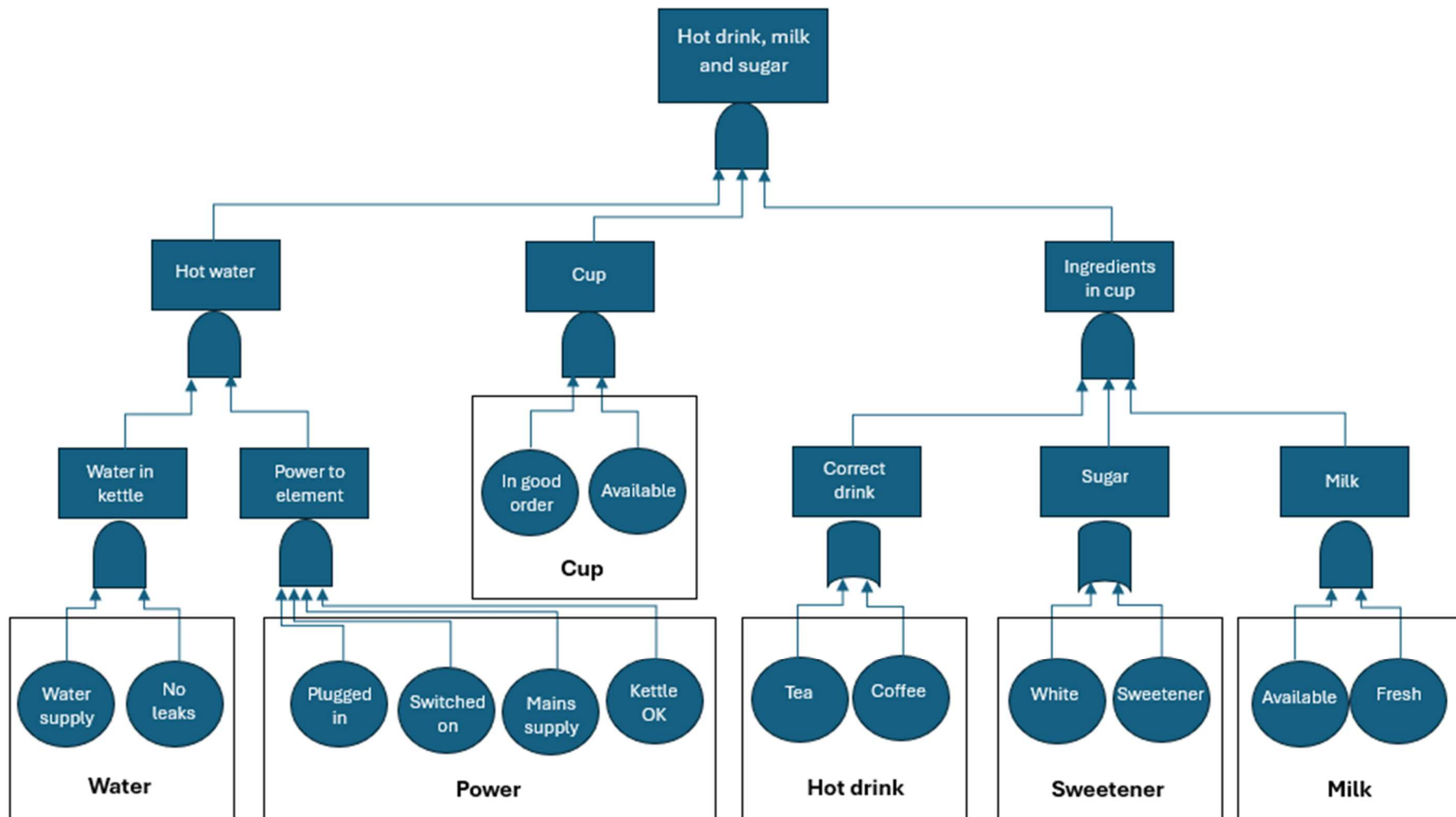


Figure 1 - Hot beverage fault tree

The above tree further illustrates both **AND** and **OR** gates, as follows:

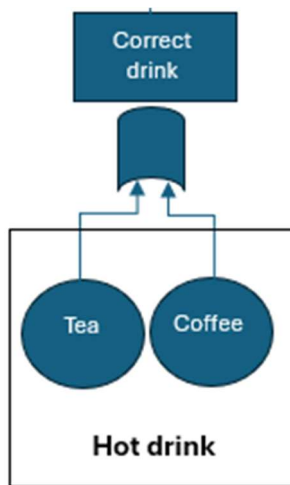


Figure 3 - OR gate example

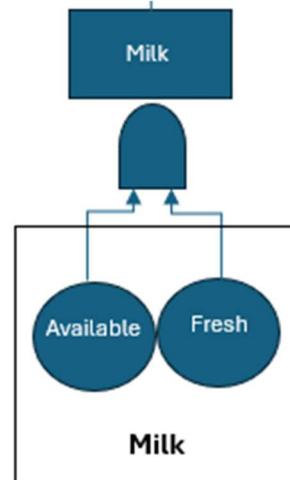


Figure 2 - AND gate example

Figure 2 shows that either tea OR coffee can be selected to move the process to the next stage, while Figure 3 shows that milk must be both available AND fresh to proceed to the next stage of the process.

The process illustrated within Figure 1 shows that the production of a hot drink depends upon six critical factors;

- Availability of a kettle of water,
- Providing power to the heating element of this kettle,
- Availability of tea/coffee,
- Availability of sweetener
- Availability of sufficient fresh milk, and
- Availability of a serviceable mug

For the purposes of this report, it will be assumed that none of these factors is optional; that is, the User requires a hot beverage, in a mug, with sweetener and fresh milk.

2 Calculation of probabilities

In addition to illustrating the events within a process, FTAs are often used to calculate the probability of an event happening. This is done by assigning a probability to the basic events, and using these to mathematically calculate the probability of combinations of these events happening.

For example, if Event 3 requires both Event 1 AND Event 2 to occur, the probability of Event 3 will be:

$$P_{E3} = P_{E1} \times P_{E2}$$

Where:

P_{E1} = the probability of Event 1 occurring

P_{E2} = the probability of Event 2 occurring, and

P_{E3} = the probability of Event 3 occurring

The events within FTA for production of a warm beverage have been assigned the following probabilities:

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

Table 1 - Initial probabilities

2.1 Level one

Using the above probabilities, the probability of a hot drink being produced will now be calculated.

First, probabilities are assigned to the basic events at the base of the tree. In the case of AND gates, these are then multiplied together to give the probabilities of the first level of events occurring. In the case of OR gates, the probability of the event occurring is taken from the most likely contributory event. These calculations are shown in Figure 4 below:

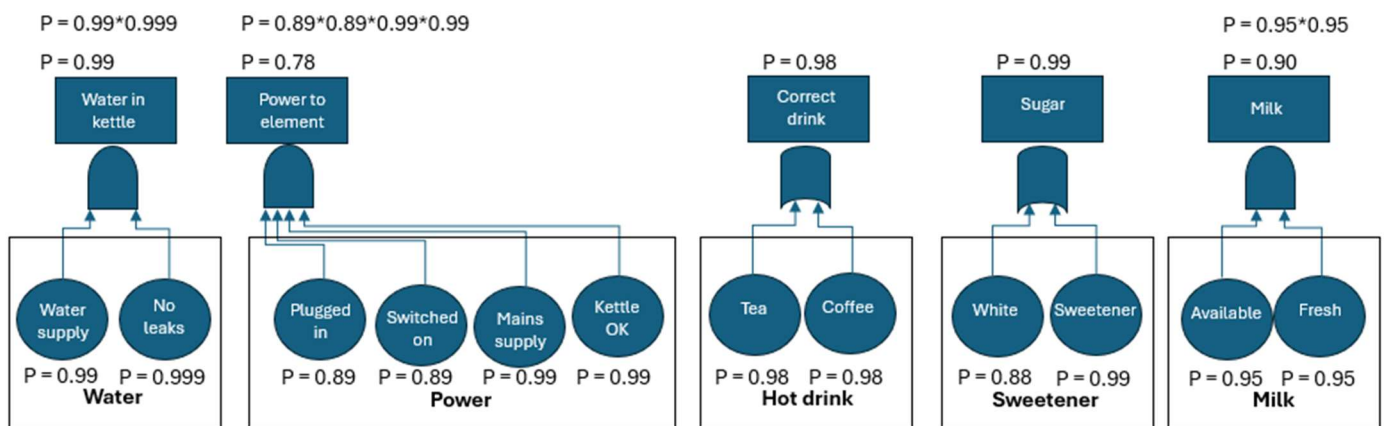


Figure 4 - Level one calculations

Figure 4 shows the following:

- The probability of getting a kettle full of water is 0.99
- The probability of supplying power to the heating element of the kettle is 0.78
- The probability of having the correct drink is 0.98
- The probability of having sugar/sweetener is 0.99
- The probability of having fresh milk available is 0.90

These calculations give a good indication of vulnerabilities in the system. A probability of 0.78 for supplying power to the kettle heating element translates to a surprising 0.22 probability of failure in this step.

Should a process engineer wish to reduce this probability of failure, the format of the FTA allows a reader to examine which contributing steps have a high probability of failure. In the case of the heating element being powered, Figure 4 shows that the probabilities of the kettle being plugged in and switched on are both relatively low, and a process engineer may wish to take steps to increase these probabilities. These could involve human factors solutions, or a redesign of the interfaces between the kettle and the power grid.

2.2 Level two

With the level one calculations complete, the second level of the FTA can be addressed. The calculations for this are contained in Figure 5:

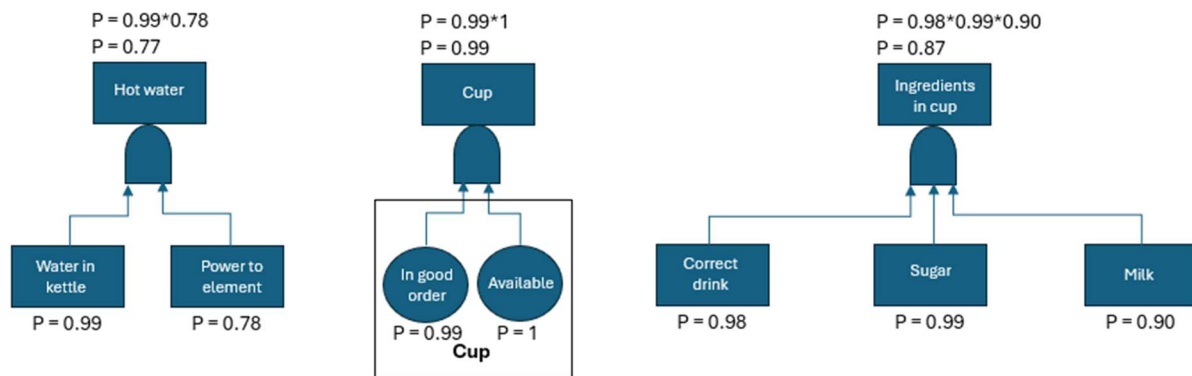


Figure 5 - Level two calculations

Figure 5 shows that:

- The probability of hot water being produced is 0.77,
- The probability of a serviceable cup being available is 0.99, and
- The probability of having all the ingredients required for the hot beverage is 0.87

The level two calculations show that the low probability of a working heating element is contributing to a lowered chance of hot water being produced, despite the high probability of water being available.

Similarly, although there is a high chance of both a suitable drink and sugar/sweetener being available, the lower chance of having suitable milk

available reduces the probability of all ingredients being present to a concerning 0.87.

A User wishing to increase this probability may wish to examine the earlier steps in the FTA, which would lead them to milk availability and freshness. These two factors could then be addressed down the appropriate procurement and storage lines to raise the probabilities, contributing to an overall higher chance of having all the required hot beverage ingredients present.

2.3 Level three

The probabilities of the final product being produced can now be derived using the results acquired in the level two calculations. These level three calculations can be seen in Figure 6.

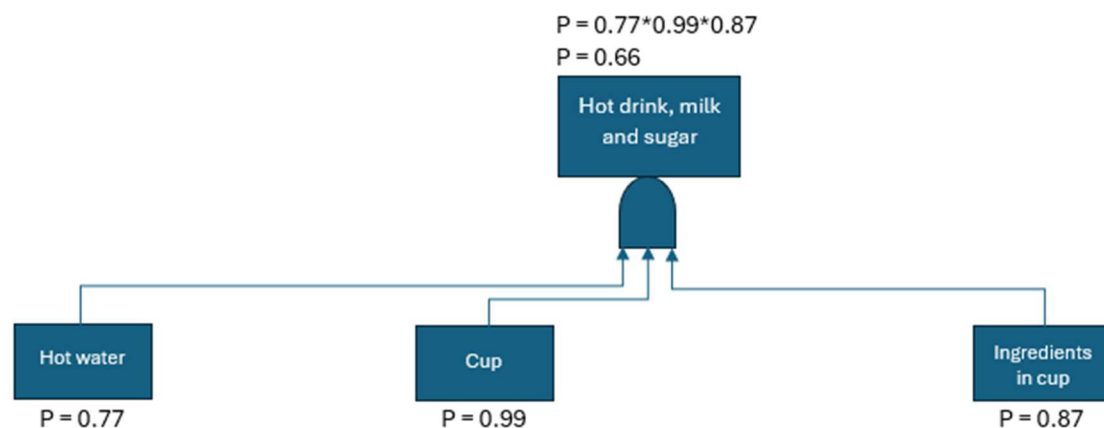


Figure 6 - Level three calculations

Figure 6 shows that the final probability of a hot beverage served in a mug with sugar/sweetener and fresh milk as per spec. being produced is 0.66.

As the probability of success is 0.66, the chance of a failed attempt is a surprising 0.37, meaning that approximately one in three attempts will end in failure. Examination of the wider FTA shows that this is chiefly due to milk supply and storage, as well as kettle power supply and user interfaces.

3 Calculation of probabilities (reduced ability)

The probabilities connected to FTA events can be adjusted to reflect changing real world conditions. This will be demonstrated using the Hot Beverage Tree by applying the following scenario:

The User has woken up in the night and wishes to make a hot beverage. The user is fatigued and working in the dark, which reduces the Users abilities as follows:

- A 25% reduction in ability to both plug in and switch on the kettle
- A 10% reduction in ability to select an appropriate mug

The revised probabilities are shown below:

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	0.68
Switch on reliability	0.68
Mains supply failure chance	0.01
Cup availability	0.90
Cup reliability	0.99
Milk availability	0.95
Milk freshness	0.95
Sugar availability	0.88
Sweetener Availability	0.99

Table 2 - Adjusted probabilities

3.1 Level one

The calculations for level one of the FTA are done as before:

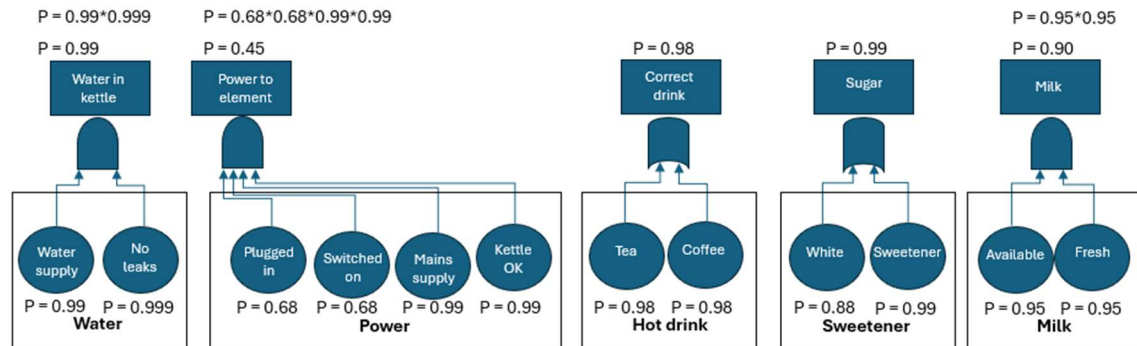


Figure 7 - Level one calculations (reduced ability)

The impact of the reduced ability is immediately apparent. The probability of power being supplied to the heating element has decreased to 0.45, giving a startling 0.55 probability of failure.

The reduction in the Users ability has had no other effects at this point. It is possible that if some were, it would not have a significant effect on the probabilities; for example, if the Users ability to select coffee was reduced, hot drink selection would be unaffected as long as the Users ability to select tea remained the same, because selection of the correct drink is dependent upon an OR gate. This would mean that, as long as the User was still able to select tea with a probability of 0.99, the chance of the correct drink being selected would be unchanged. There is a similar resilience in sugar/sweetener selection.

3.2 Level two

The calculations for level two are again based on the results of the level one calculations:

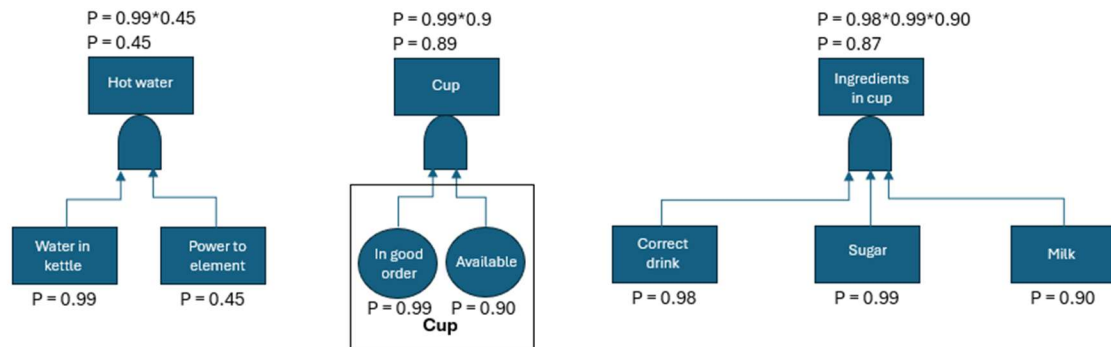


Figure 8 - Level two calculations (reduced ability)

The 'knock on' effect of the element power supply issues can again be seen working its way up the process; the probability of having hot water has dropped from 0.77 during the day to 0.45, a reduction of nearly 50% despite the initial loss of ability being only 25%. This illustrates well the impact a failure at a previous level can have on a later step, even if other factors (in this case, the chance of having water in the kettle) are unchanged.

The reduced ability of the User to select a cup has led to a significant drop in the probability of a suitable cup being acquired. It is expected that this will exacerbate what is predicted to be an already dramatic increase in the chance of process failure.

3.3 Level three

Using the results of the level two calculations, the probability of a hot beverage being successfully produced can be calculated:

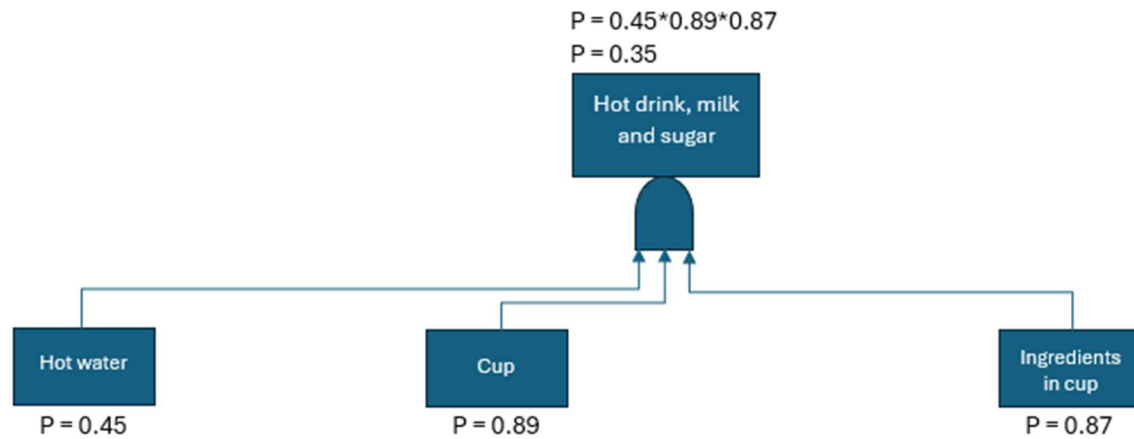


Figure 9 - Level three calculations (reduced ability)

As shown in Figure 9, the probability of a hot beverage being produced has dropped from 0.66 during daytime operations to 0.35; the chance of failure has almost doubled from 0.37 to 0.65. This further illustrates the 'knock on' effect that an increased chance of failure early on in the process can have.

The initially high chance of failure during daytime operations could be traced back to milk storage and procurement, and a relatively high chance that the User would fail to both plug the kettle in and turn it on. The vastly increased failure chance during night operations can be traced back to the User undertaking the process while fatigued and without adequate lighting, which both exacerbated the existing problems with kettle interaction and introduced a cup selection issue.

4 Conclusions

This report has illustrated the utility of an FTA in calculating the probability of success for a given process, thereby providing safety and reliability assurance based on mathematical evidence. The FTA is also a useful tool for mapping out a process for scrutiny, enabling the root causes of failures to be identified, quantified and addressed.