Master's thesis

2021

Tord-Eskil Hannevik Tørressen

Master's thesis

NTNU
Norwegian University of
Science and Technology
Faculty of Engineering
Department of Marine Technology

Tord-Eskil Hannevik Tørressen

Human Reliability Analysis of Operator in Autonomous Shuttle Ferry

June 2021

NTNU
Norwegian University of
Science and Technology

NTNU
Norwegian University of
Science and Technology

NTNU
Norwegian University of
Science and Technology

Human Reliability Analysis of Operator in Autonomous Shuttle Ferry

Tord-Eskil Hannevik Tørressen

Masters in Marin Technology
Submission date: June 2021
Supervisor: Stein Haugen

Norwegian University of Science and Technology
Department of Marine Technology

Preface

This master thesis was written in the mounts January through June and represents the final work done for the Department of Marine Technology at the Norwegian University of Science and Technology (NTNU).

I want to thank my supervisor, professor Stein Haugen, for his constant insights and contributions to the development of the thesis. I would further like to thank Ph.D. student Chuanqi Guo for taking me along with him on a guiding tour of the ferry, which provided much insight into the ferry itself.

Trondheim, 10th of June 2021

Tord-Eskil Hannevik Tørressen

Summery

Autonomous vessels are an up-and-coming concept that aims to reduce the requirement of human intervention. In Trondheim, this concept is currently under testing. An autonomous shuttle ferry is under construction to allow for easy crossing of the canal between Ravnkloa and Fosenkaia. The ferry is set to be fully autonomous with an operator located at an onshore control center. The operator's role will be to intervene during emergencies. What this thesis will aim to identify is the reliability of the operator. To what extent will the operator be able to complete his tasks successfully.

The thesis takes upon three different scenarios where the operator might be required to intervene, including a potential collision, a fire emerging onboard the ferry, and a passenger falling overboard. A human reliability analysis (HRA) is then carried out using a combination of two different approaches, the THERP, and HEART methods.

From the results, it is found that the operator will not be able to resolve any of the three emergency scenarios. The only role the operator will be able to fulfill successfully is as a connector. The operator will be able to contact necessary assistance such as the fire department, emergency department, and coast guard. It was further found that the most significant factor affecting the operator's reliability was the shortage of time he was presented with. However, providing the operator with more time was found to be complicated. Instead, it is proposed to reduce the operator's responsibility and thereby the number of tasks he needs to do. The result was a reduction of failure by 50 % or more depending on the case, collision avoidance, fire, or man overboard.

Based on the results, it is concluded that the operator's role should be minimal. Since the operator is not able to contribute past getting the passenger assistance, his role should be constricted to only that. By reducing the number of tasks the operator is expected to perform, the amount of time available to perform each task will increase. The result is then a higher reliability of performing a small number of tasks.

Sammendrag

Autonome fartøyer er et fremtredende konsept som tar sikte på å redusere kravet til menneskelig inngripen. I Trondheim er dette konseptet for tiden under testing. En autonom skyttelferge er under konstruksjon for å gjøre det enkelt å krysse kanalen mellom Ravnkloa og Fosenkaia. Fergen er satt til å være fullstendig autonom med en operatør som befinner seg på et kontrollsenter på land. Operatørens rolle vil være å gripe inn i kriser. Hva denne oppgaven vil ta sikte på å identifisere er operatørens pålitelighet. I hvilken grad vil operatøren være i stand til å fullføre sine oppgaver med riktig.

Oppgaven tar ut tre forskjellige scenarier der operatøren kan bli pålagt å gripe inn, inkludert en potensiell kollisjon, en brann som dukker opp ombord på fergen og en passasjer som faller over bord. En menneskelig pålitelighetsanalyse utføres deretter ved hjelp av en kombinasjon av to forskjellige metoder, THERP og HEART.

Fra resultatene er det funnet at operatøren ikke vil være i stand til å løse noen av de tre nødsscenariene. Den eneste rollen operatøren vil kunne utføre med suksess, er som en kobler. Operatøren vil kunne kontakte nødvendig assistanse som brannvesenet, ambulansen og kystvakten. Det ble videre funnet at den mest betydningsfulle faktoren som påvirket operatørens pålitelighet var tidsmangelen han ble presentert med. Å gi operatøren mer tid ble imidlertid funnet å være komplisert. I stedet foreslås det å redusere operatørens ansvar og dermed antall oppgaver han trenger å gjøre. Resultatet var en reduksjon av svikt med 50 % eller mer, avhengig av tilfelle, kollisjon unngåelse, brann eller mann over bord.

Basert på resultatene konkluderes det med at operatørens rolle skal være minimal. Siden operatøren ikke er i stand til å bidra ut over å få passasjerene assistanse, bør hans rolle begrenses til bare det. Ved å redusere antall oppgaver det forventes at operatøren skal utføre, vil tiden som er tilgjengelig for å utføre hver oppgave øke. Resultatet er da en høyere pålitelighet for å utføre et lite antall oppgaver.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Background

The use of urban ferries to connect two sides of a city separated by water is not a new concept. Norway has been using this strategy since the late 1800. This is evident from the three cultural monuments still operating today. Sundbåten in Kristiansund, Norway's oldest company for public transportation, developed in 1876, figure 1.1a.[29] Kolbjørn III, seen in figure 1.1b, developed in 1893, located in Arendal.[28] And Beffen seen in figure 1.1c, located in Bergen and developed in 1894.[26] However, using autonomous ferries as a replacement for manned ferries is an up-and-coming concept.

(a) Sundbåten [5] (b) Kolbjorn [12] (c) Beffen [4]

Figure 1.1: Urban ferries in Norway

Ravnkloa is the most well-known commons in Trondheim, located in the city center. From ancient times, the place has been the main access point for ships to enter the city center of Trondheim and an essential part of the cities fish trade market. However, as time has gone by, the place has lost some of its appeal among citizens and traders. In the winter of 2013, a meeting was convened to bring forward thoughts and ideas to strengthen the importance of Ravnkloa. One idea that was put forward was to improve availability. Tourists, for instance, coming with cruise ships to Trondheim harbor, have to travel far to reach a pedestrian bridge taking them over the canal to get to Ravnkloa. One idea was then to improve the commons availability by implementing a pedestrian bridge connecting Fosenkaia and Ravnkloa. The bridge would make Ravnkloa more accessible for both the tourists and the locals.[10] However, Kystlaget Trondehim had some concerns with the installation of a new bridge in the canal as the bridge would: [22]

- Limite the range of different vessels being able to pass the canal, such as larger vessels with tall masts.
- Limite the ability to maneuver, considering that the bride would be located at the widest part of the canal.
- Isolate Fosenkaia, locking in the harbor.
- Create problems associated with the opening and closing of the bridge.
- Interfere for photographers taking photos of the historic vessels located at the harbor.

Based on these concerns, it was decided that a bridge might not be the best solution. However, some changes had to be made as the only transportation for pedestrians from Fosenkaia to Ravnkloa is a rowboat operated by Fløtmannen. The rowboat is more of a cultural monument than a reliable means of transportation. It is also limited in space and does not allow for passengers with for example bikes or wheelchairs. [11] Egil Eide, a professor at the Department of Electronics systems at NTNU and leader of Kystlaget Trondheim, proposed a solution to solve Kystlaget Trondheim's concerns and the limitations of the rowboat. The solution was a constrained autonomous shuttle ferry operating on demand by the push of a button. The ferry's capacity would room up to 12 people and be capable of carrying personal items such as wheelchairs and bicycles with a crossing time as low as 30 seconds to 1 minute.[9][8] The planned route for the shuttle ferry is seen in figure 1.2b below, and the ferry itself is seen in figure 1.2a

(a) Autonomous Shuttle Ferry[31]

(b) Transport route[8]

Figure 1.2: Autonomous shuttle ferry and Transport route

The ferry will be equipped with several different equipment and systems to ensure the safety of both the passengers and the surrounding traffic in the canal. These include an anti-collision system, cameras, sensors, and light beacons. A list of different systems and equipment that the ferry is equipped with are given in table 1.1.

Systems	**Equipment's**
Navigation System	GNSS(GPS, Galileo, Glonass), RTK and IMU
Anti-Collision system	Lidar, Radar , Optical camera (Optical 360, Stereo, and IR) and Short range radars.
Communication system	Narrowband (AIS, Data telemetry, and RTK(DGPS)) and Wideband (Video and Sensor data).
Propulsion system	4 x 4kw azimuth thrusters
Visibility system	Light beacons

Table 1.1: Autonomous shuttle ferry systems and equipment's[9][8]

A constrained autonomous ferry is defined in figure 2.2 as an unmanned ferry that is partly autonomous, having an onshore supervisor with the ability to intervene if something goes wrong. Replacing the bridge with such a ferry would eliminate the concerns regarding larger ships with high masts, the isolation of Fosenkaia, problems emerging from the opening and closing schedule, and clear sight of the historic vessels. However, other concerns arise when using constrained autonomous vessels, as this is a relatively new concept and is not as thoroughly studied as manned vessels and bridges.

One of the concerns is that if the autonomous system cannot solve a problem, then it will be up to the operator to solve it. Seeing that the operator will not be present at the ferry, it could be hard for him to analyze the situation and solve it. Another concern is the shortage of time the operator will have available, given that the ferry only takes up to 1 minute to cross the canal. If, for example, a collision was to occur, then this would have to happen within that 1 minute, which leaves the operator with very little time to react. The question then becomes, how reliable will the operator be. Will he be able to assist the passengers if the autonomous system fails to perform its tasks.

1.2 Objective

The main object of this master thesis is to investigate the human reliability of the operator. One of the major challenges that the operator is faced with is the significant probability of him misunderstanding the situation at hand or that he commits mistakes resulting in a worsening of the situation. The thesis will therefore aim to identify some of the hazards that the operator might be exposed to. What role the operator will play in those situations, and what actions he will be required to take. Finally, the operator's ability to successfully avoid a hazardous outcome will be determined.

1.3 Scope and limitations

The scope of the thesis is to identify three cases where the operator will be required to intervene. Then a task analysis will be carried out to identify the tasks that the operator should perform and what order they should be done. A human reliability analysis will then be done to identify the operator's degree of success. A detailed layout of the process is further explained in chapter 3.

One of the limitations with this thesis is that the ferry is still under construction. This means that the information that this thesis is built on, might be outdated before the final product has been made or published.

1.4 Thesis Structure Overview

The thesis starts with an introduction to what autonomy is, identifying different ways to categorize the level of autonomy in a system, then explaining some of the benefits and disadvantages of autonomous vessels in general. Chapter 3 then describes human reliability analysis, introducing some of the different methods followed by the methods that will be used for this thesis. In Chapter 4 through 6, the three operator interference scenarios are identified, where a HRA is carried out to identify the probability of success. Chapter 7 is where the results, assumption and further work are discussed and evaluated. Following is the conclusion in chapter 8.

Chapter 2

Autonomy

Figure 2.1: Autonomous vessel[13]

2.1 Definition

When a vessel is categorized as autonomous, it indicates that the vessel is capable of independently performing tasks that, if not, would require human intervention to be performed. Automation deals with the technology capable of performing tasks usually performed by humans, whereas autonomy looks at the system as a whole. The international maritime organization IMO uses the term MASS, maritime autonomous surface ships, for a vessel that falls within this category.[18]

2.2 Level of autonomy

The level of autonomy depends on the amount of work performed by the autonomous system and the potential for human intervention when necessary. For a fully autonomous operation, the system must gather all relevant information and process it automatically. Based on the information gathered, the system must also decide on relevant strategies and act on them. For a fully manual vessel, all these phases would rely on a large extent of human intervention. LOA, level of autonomy can be categorized in different ways. NFAS has come up with a 4 LOA for an unmanned ship, ranging from remote control to fully autonomous, as seen in figure 2.2. Remote control indicates that the vessel is completely controlled from an onshore location, and humans make all decisions. Automatic means that the vessel is automatically controlled from an onshore location by humans. Constrained autonomous, which is the most common and likely scenario of autonomous ships, means that the vessel can perform independently from humans. However, the system will rely on human supervision and their ability to take over the control given an emergency or in situations where the autonomous system cannot find a solution. A Fully autonomous vessel is a vessel capable of performing all aspects of the operation independent of humans, where no human supervision is present.[23]

The introduction mentioned that the ferry seen in figure 2.1 would be constrained autonomous. The ferry will be performing all tasks independently of human interaction. However, it will have an operator located at an onshore control center to supervise and intervene if needed making the ferry constrained autonomous rather than fully autonomous.

Level	Description
Remote control	Unmanned, continuously monitored and direct control from shore.
Automatic	Unmanned under automatic control, monitored from shore.
Constrained autonomous	Unmanned, partly autonomous, supervised by shore
Fully autonomous	Unmanned and without supervision

Figure 2.2: NFAS level of autonomy [23]

2.3 Benefits of autonomous vessels

There are many benefits of implementing autonomy in vessels, such as removing manned used infrastructures. These include, among others, the bride, accommodation, and deckhouse. By removing these structures, the cost will be significantly reduced, the total weight of the vessel will be lower(lowering fuel consumption and required engine power), and there will be more space for cargo increasing the potential capacity per round trip.[23]

For short-distance shipping, one of the most significant contributors to cost is the crew, which would be completely removed given a fully autonomous vessel. The cost would be significantly reduced for a constrained autonomous vessel also, as all crew onboard the vessel are replaced with onshore operators potentially monitoring several vessels. Autonomous ships are also expected to be fully battery-driven, meaning that they provide environmentally-friendly aspects, such as zero to low emission levels into the sea and air. In terms of safety benefits, it is believed that autonomous vessels will provide a higher safety level. This is based on the fact that 75 percent of maritime accidents are due to human errors resulting from the crew being fatigues or having insufficient attention levels.[14] Human errors will, however, still be a relevant error source, but at a lower degree, as the human intervention will be reduced.

For the shuttle ferry, would the implementation of autonomy mean that the cost of having an onboard crew be removed. This will then be replaced with an onshore operator who will never intervene in an optimal situation, resulting in a much lower cost. As for manned used infrastructures, the bridge would be removed, providing more room for the passengers and potential belongings and lowering the total weight of the ferry.

Chapter 3

Human Reliability Analysis

This chapter will define human reliability, followed by discussing what a human reliability analysis aims to provide. Then a method for HRA will be chosen for this thesis, where each step will be discussed in greater detail. All information provided in this chapter has been taken from the book Risk Assessment Theory, Methods, and Applications by Marvin Rausand and Stein Haugen. [2] Those places where other sources have been used, then this will be stated at the end of the paragraph.

3.1 Human Reliability

Human reliability can be defined as the probability of a person performing a task correctly. The task in question can be anything from activating a function, performing maintenance on a system, or handling equipment. [7]

3.2 Human Reliability Analysis

A Human Reliability Analysis (HRA) aims to quantify the probability of human error for the task in question and is a guiding tool for identifying weaknesses within the task and what improvements should be made to reduce the potential for human-influenced failure.[16] The HRA process can be simplified down to three main objectives:

- Identification of key human interactions
- Quantification of success and failure probability
- Alternatives for improvements

Different methods can be used when performing an HRA, such as a technique for human error rate prediction (THERP), human error assessment and reduction technique(HEART), and cognitive reliability and error analysis method(CREAM). However, the main steps of any typical quantitative HRA are:

- Step 1: Identify critical operations in which human errors could lead to an undesirable situation.
- Step 2: Task identification and breakdown into sub-tasks
- Step 3: Identification of human error modes(acting too late or too early, incorrect response), possible causal chain leading to the error, and performance influencing factors.
- Step 4: Quantification of HEP for each human error mode and then for the whole task.

3.3 THERP and HEART analysis

In this report, a combination of THERP and HEART will be used. The structure of the THERP method will be used combined with the data set provided by the HEART handbook. The HEART handbook provided different generic tasks that better fit the tasks the operator have to perform when intervening. At the same time, the THERP method was found to provide a better process of determining the probability of success. Some steps from the THERP method have been removed as they did not seem relevant for this analysis. The complete process layout which this report will be following is given in figure 3.1.

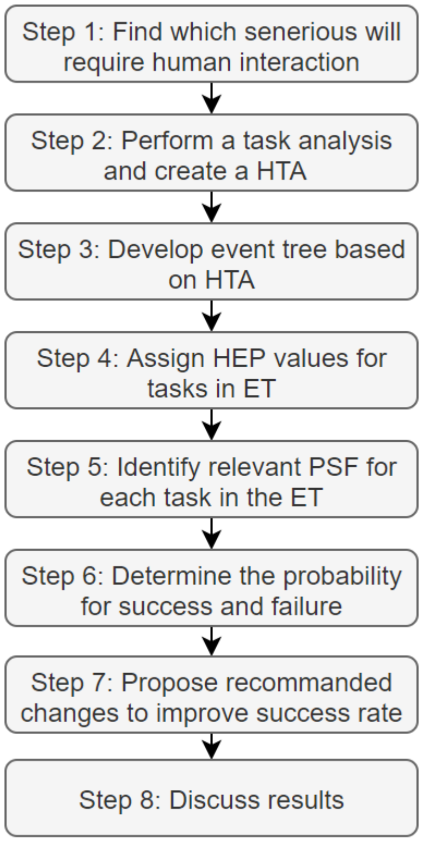

Figure 3.1: Specified HRA process

3.3.1 Step 1: Plan and prepare

Step 1 is the planning phase of the process; wherein this report, different cases have been evaluated to see if the operator will intervene or not. The autonomous system is built to handle every situation by itself, but there are situations where the operator might need to intervene. This will be either because the system cannot find a solution to a problem or because it has not noticed a problem in which the passengers will contact the operator.

3.3.2 Step 2: Perform a task analysis and create an HTA

The second step is to perform a task analysis. This will provide a visual representation of the tasks that the operator has to perform in order to achieve an intended goal. There are different methods when performing a TA, such as an HTA, hierarchical task analysis or TTA, tabular task analysis. An HTA describes the order in which tasks should be performed to achieve a specific goal. Similar to an FTA, the HTA is based on a top to bottom logic, where at the TOP, a goal is set, and below the tasks that are needed to be performed are identified.

The main structure of an HTA can be summed up in the following four steps:

- Determine the goal

- Break down the goal into individual tasks that must be performed in order to achieve the goal
- Break down the task further to include as few actions as possible
- Identify a plan

The goal can be defined as the intended accomplishment for the tasks and the desired outcome. Plans are then a description of which tasks should be performed and the order in which they should be carried out in order for the goal to be realized.

The task analysis in this thesis is constructed based on similar work, Collision avoidance on maritime autonomous surface ships [23], own judgment of required tasks to be performed, and on the available systems and equipment's onboard the ferry. Figure 1.1 shows some of the systems and equipment that the ferry will be equipped with.

3.3.3 Task 3: Develop event tree based on HTA

After making an HTA, then an event tree is produced mapping the possible sequence of events that might take place. These events will represent the tasks that the operator will perform and are created based on the HTA. Each task in the lowest level of the HTA will represent one event in the event tree where the plan will be used to identify the initial event and the sequence of events that will follow based on the success or failure of tasks in each event. The layout of a THERP event tree is different from the traditional event tree commonly used. However, there is no logical difference between the two methods, which allow for either way of drawing the event tree. Figure 3.2, shows a representation of a THERP event tree. For this thesis the traditional event tree will be used.

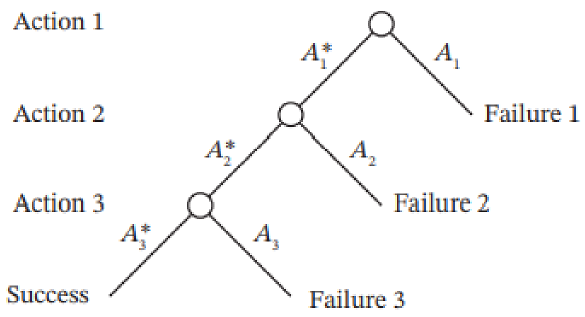

Figure 3.2: ETA THERP [2]

3.3.4 Task 4: Assign HEP values for tasks in the ET

Once the event tree has been created, HEP values will be assigned to each task performed in the different events, allowing for the probability of success and failure to be determined in step

6. Typically the HEP values will be determined based on the data table found in the THERP handbook. However, as it has been decided to use the HEART handbook for these values, table 3.3 will be used. Each task in the event tree must be compared to the generic tasks found in the HEART handbook to determine which is most closely related to the given task. The HEART handbook provides nine different generic tasks to choose from, identified by the letters A through M. Each generic task is given a HEP, referred to as human unreliability in that table. [30]

Generic task		*Proposed nominal human unreliability (5th–95th percentile boundaries)*
A	Totally unfamiliar, performed at speed with no real idea of likely consequences	0.55 (0.35–0.97)
B	Shift or restore system to a new or original state on a single attempt without supervision or procedures	0.26 (0.14–0.42)
C	Complex task requiring high level of comprehension and skill	0.16 (0.12–0.28)
D	Fairly simple task performed rapidly or given scant attention	0.09 (0.06–0.13)
E	Routine, highly practised, rapid task involving relatively low level of skill	0.02 (0.007–0.045)
F	Restore or shift a system to original or new state following procedures, with some checking	0.003 (0.0008–0.007)
G	Completely familiar, well-designed, highly practised, routine task occurring several times per hour, performed to highest possible standards by highly motivated, highly trained and experienced person, totally aware of implications of failure, with time to correct potential error, but without the benefit of significant job aids	0.0004 (0.00008–0.009)
H	Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate interpretation of system stage	0.00002 (0.000006–0.00009)
M	Miscellaneous task for which no description can be found. (Nominal 5th to 95th percentile data spreads were chosen on the basis of experience suggesting log-normality)	0.03 (0.008–0.11)

Figure 3.3: HEART generic tasks [30]

3.3.5 Task 5: Assign relevant PSF for each task in the ET

In this step, the HEP values found in step 4 will be evaluated based on performance shaping factors (PSF). These PSFs will like the HEPs be taken from the HEART handbook instead, where they are referred to as EPCs, error-producing conditions. An EPC is a factor that will increase the probability of human error. A complete list of these EPCs is given in figure 3.4, where there are a total of 38 different EPCs that could affect the final HEP. [30]

Each EPC must be assessed according to its estimated impact on the task. This is done through an Assessed proportion of effect. The proportion of effect has a value between 0 and 1. The assessed impact value of the EPC can be calculated using the following formula. The multiplier is the EPC value provided in figure 3.4.[30]

$$AssessedEffect = ((Multiplier - 1) * (AssessedProportionofEffect)) + 1 \qquad (3.1)$$

Error-producing condition		Maximum predicted nominal amount by which unreliability might change going from 'good' conditions to 'bad'
1.	Unfamiliarity with a situation which is potentially important but which only occurs infrequently or which is novel	×17
2.	A shortage of time available for error detection and correction	×11
3.	A low signal-to-noise ratio	×10
4.	A means of suppressing or overriding information or features which is too easily accessible	×9
5.	No means of conveying spatial and functional information to operators in a form which they can readily assimilate	×8
6.	A mismatch between an operator's model of the world and that imagined by the designer	×8
7.	No obvious means of reversing an unintended action	×8
8.	A channel capacity overload, particularly one caused by simultaneous presentation of non-redundant information	×6
9.	A need to unlearn a technique and apply one which requires the application of an opposing philosophy	×6
10.	The need to transfer specific knowledge from task to task without loss	×5.5
11.	Ambiguity in the required performance standards	×5
12.	A mismatch between perceived and real risk	×4
13.	Poor, ambiguous or ill-matched system feedback	×4
14.	No clear direct and timely confirmation of an intended action from the portion of the system over which control is to be exerted	×3
15.	Operator inexperienced (e.g. a newly qualified tradesman, but not an 'expert')	×3
16.	An impoverished quality of information conveyed by procedures and person–person interaction	×3
17.	Little or no independent checking or testing of output	×3
18.	A conflict between immediate and long-term objectives.	×2.5
19.	No diversity of information input for veracity checks	×2.5
20.	A mismatch between the educational achievement level of an individual and the requirements of the task	×2
21.	An incentive to use other more dangerous procedures	×2
22.	Little opportunity to exercise mind and body outside the immediate confines of the job	×1.8
23.	Unreliable instrumentation (enough that it is noticed)	×1.6
24.	A need for absolute judgements which are beyond the capabilities or experience of an operator	×1.6
25.	Unclear allocation of function and responsibility	×1.6
26.	No obvious way to keep track of progress during an activity	×1.4
27.	A danger that finite physical capabilities will be exceeded	×1.4
28.	Little or no intrinsic meaning in a task	×1.4
29.	High-level emotional stress	×1.3
30.	Evidence of ill-health amongst operatives, especially fever	×1.2
31.	Low workforce morale	×1.2
32.	Inconsistency of meaning of displays and procedures	×1.2
33.	A poor or hostile environment (below 75% of health or life-threatening severity)	×1.15
34.	Prolonged inactivity or highly repetitious cycling of low mental workload tasks	×1.1 for first half-hour ×1.05 for each hour thereafter
35.	Disruption of normal work-sleep cycles	×1.1
36.	Task pacing caused by the intervention of others	×1.06
37.	Additional team members over and above those necessary to perform task normally and satisfactorily	×1.03 per additional man
38.	Age of personnel performing perceptual tasks	×1.02

Figure 3.4: Error-producing condition [30]

3.3.6 Task 6: Determine the probability for success and failure

At this stage, the probability that the operation succeeds or fails can be determined. This is done by multiplying the probabilities in a given sequence of events to determine the probability of the corresponding end event.

3.3.7 Step 7: Propose recommended changes

After determining the probability for success, recommended changes should be proposed to allow higher success rates in the future.

3.3.8 Step 8: Discuss results

The last step is to report the findings and discuss the results found.

Chapter 4

Operator interference case 1

4.1 Operator interference scenarios

This thesis will be investigating three different scenarios where the operator will be required to intervene. These include potential collision during high traffic, man overboard, and fire emerging on the ferry. The first scenario is specified with a high traffic picture as the autonomous system should be able to avoid the collision through the use of its anti-collision system. However, given multiple obstacles in the water, the system might not be able to register all and find a safe passage.

4.2 Collision avoidance

The ferry travels from one side of the canal to the other. As its crossing the canal, a vessel is registered by the anti-collision system. The system determines that the vessel is heading straight toward the ferry and that a collision will occur if no changes in the heading are made. Unfortunately, the autonomous system cannot solve the problem as the traffic is too dense. The operator is therefore contacted through a sound alert at the SCC.

4.3 Hierarchical task analysis - Vessel on a collision course

A task analysis has been carried out to give a complete picture of the operator's tasks when exposed to a possible collision scenario. The results are shown in figure 4.1. At the top of the HTA, the main goal is presented, which is collision avoidance. The first level tasks are presented below as tasks 1 through 5; these tasks represent the set of tasks that the operator must complete to achieve the main goal, collision avoidance. The first level tasks are then further specified to identify what specifically the operator must do to allow the first level tasks to be achieved. In each cross-section, a plan is developed, which specifies the order that the tasks should be performed and the direction that the operator should go as more information becomes known.

For example, plan 0 shows the order of first-level tasks, while plans 1 through 5 the order of second-level tasks. Plan 0 indicates that the first task that the operator should perform is task 1.

Task 1, respond to distress alarm

Task 1 surrounds the operator's responsibility of responding to the distress signal that the autonomous system sends to the SCC after the vessel on a collision course is detected, and no solutions have been found. To complete task 1, the operator must first notice the alarm and then identify the cause of the alert as indicated by plan 1.

After the operator has identified the cause of the alert, then he should perform task 2.

Task 2, analyze the situation and develop strategy

Task 2 is where the operator gathers information and decides which strategy is best for preventing the collision. Plan 2 shows that the first step is for the operator to identify both vessels' speed, direction, and distance from one another. The operator should then evaluate the traffic picture in terms of the number of obstacles and what types of obstacles, such as vessels, kayaks, and buoys, that surround the ferry. Once these two tasks have been performed, then the operator must look for possible safe path scenarios using the information he has collected in the previous tasks. Rather or not the operator can locate a safe path will affect the choice that he must make in task 2.4, decide on remote control, or contact incoming vessel. If the operator can locate a means of safely avoiding the collision, then it would be best to decide on remote control. However, if no safe paths are identified, the operator must contact the incoming vessel. Failing to complete either of the tasks 2.1 - 2.2 will result in failure when attempting to locating a safe path.

Depending on this choice, the next task would be to perform task 3, remote control ship to the safe path, or task 4, contact incoming vessel, as indicated by plan 0. If the operator finds a safe path, then the next task that must be performed is task 3.

Task 3, remote control ship to safe path

Having found a safe path, the first task that the operator has to perform is to take over the control of the ferry by activating remote control. The operator should then sail the ferry clear of the hazard following the safe path identified in task 2.3.

If the collision is successfully avoided, he should withdraw from the situation as there is no further need for his assistance. On the other hand, if the operator fails to steer clear of the collision, then task 5, contact assistance, should be performed. Task 5 is described later in this section. A third scenario is that he is unable to activate remote control. If this is the case, then the operator should perform task 4 as he will be unable to remote control the ship on the safe path found.

Task 4, contact incoming vessel

Task 4 will only be performed if the operator cannot locate a safe path or if he cannot activate remote control. In such scenarios, the operator must first attempt to establish communication between the SCC and the incoming vessel and then collaborate with the captain to find a way to prevent the collision.

If the operator cannot establish communication or if they are not able to avoid the collision, then task 4.3 should be carried out as seen in plan 4. Task 4.3 is for the operator to reduce collision force. Reduce collision force refers to positioning the ferry in a way that would lower the total impact force.

Plan 0 then shows that the next step is for the operator to either withdraw himself from the situation or carry on with task 5. This will depend on rather or not the collision has been avoided. If the collision has been avoided, then the operator should withdraw and let the autonomous system retain control. However, if the collision has not been avoided, then the operator should perform task 5.

Task 5, Contact assistance

Task 5 focuses on getting the passengers medical assistance. Rather or not they need this service will not be up to the operator to decide. The operator will not have enough knowledge in this area to make this decision, and if someone is hurt, it will not be time for the operator to analyze the situation to make such a decision.

Once the emergency center has been contacted, the operator can not assist any further and should therefore withdraw himself from the situation.

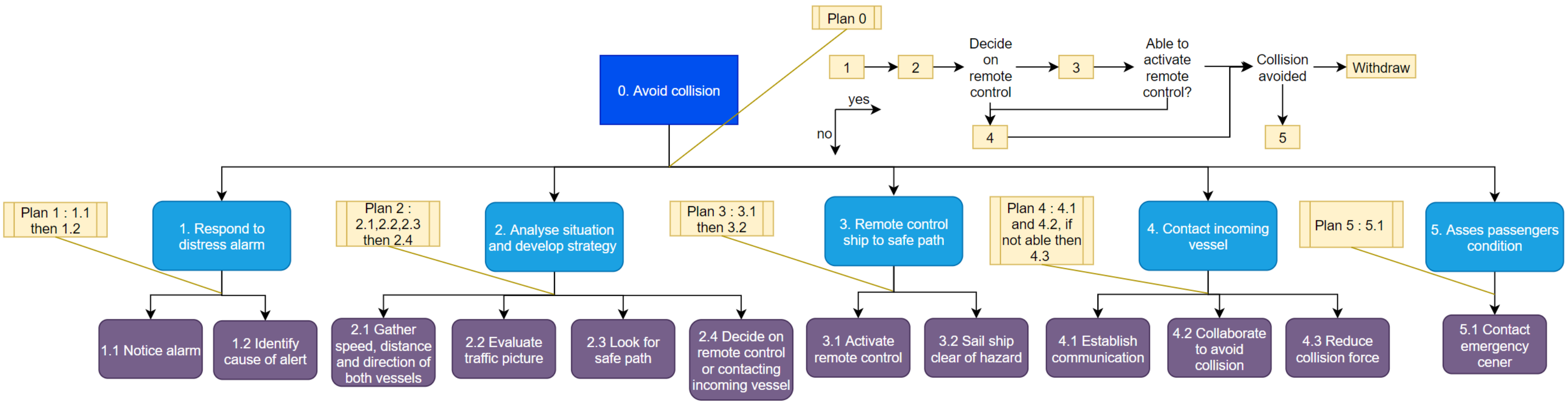

Figure 4.1: HTA - collision avoidance

4.4 Event Tree - Vessel on a collision course

The sequence of events taking place once the distress signal is sent to the SCC is seen in figure 4.3. The figure represents the event tree seen in figure 4.6 but simplified to allow it to fit on one page. Figure 4.2 shows the different end event scenarios that can occur as the operator either succeeds in performing a task or fails.

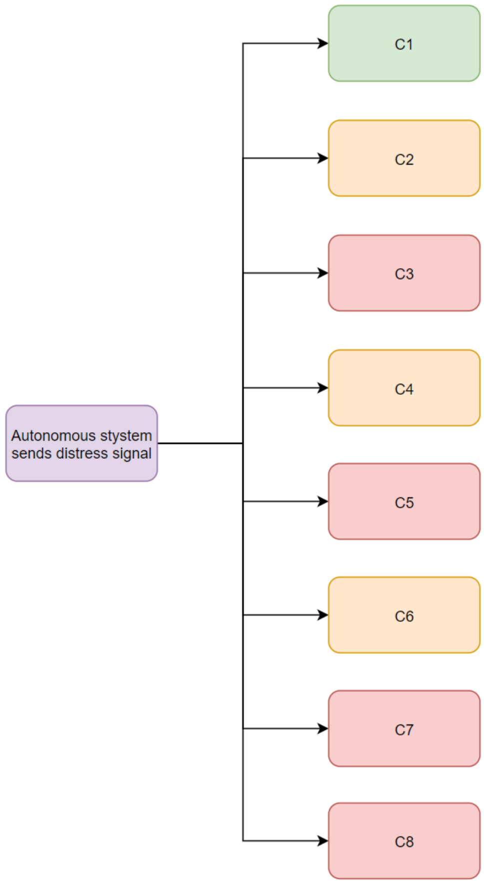

Figure 4.2: End event scenarios - collision avoidance

The end event scenarios are identified by C1 to C8, where each has been given a different color. The color represents the degree of success, where green is when the operator has fully succeeded, orange partly succeeded, and red failed completely. As seen in figure 4.3 most of the end events can be reached through different sequences of events. C1, for instance, collision avoided, can be achieved either by the operator finding a safe path and steering clear of the collision himself or by collaborating with the incoming vessel. Below the different sequences of events are explained with the resulting consequence.

End event C8

For each end event, the initiating event is the operator either noticing the sound alert sent by the autonomous system or not noticing the alert. Suppose the operator does not notice the alert. In that case, the operator fails and won't be able to act in any way to prevent the collision or get the passenger's medical assistance. This will result in end event C8; operator fails to avoid the collision, emergency center not contacted. However, if the operator does notice the alarm, then the next task is for the cause of the alarm to be identified. Failing to identify the cause will also lead to end event C8. Suppose the operator does identify that there is a vessel on a collision course towards the ferry. In that case, the operator must gather the necessary information to find a way to safely avoid the collision. The first piece of information that the operator must get is the speed of both vessels, the distance between them, and the direction in which they are heading, E2.1. Once this is done, then the traffic picture must be evaluated so that the operator has a clear understanding of the ferries' surroundings, E2.2. At this point, the operator will have enough information to allow him to look for a safe path.

End event C1-C3

Failure in either E2.1 or E2.2 will make it impossible for the operator to locate a safe path and avoid the collision. This means that if the operator cannot successfully collect both vessels' speed, distance, and direction, he won't proceed to task E2.2. In that scenario, he will directly attempt to establish communication with the incoming vessel instead, E4.1. The same goes for if the operator cannot evaluate the traffic picture, then he will not attempt to locate a safe path; instead, communication with the incoming vessel will be established. However, if the operator succeeds with both these tasks, then he will attempt to find a safe path. Failing to find a safe passage even though he has the necessary information will also result in communication with the incoming vessel to be established. However, if the operator can find a safe passage in E2.3, the operator will attempt to activate remote control, E3.1, followed by steering clear of the collision in E3.2. This will result in end event C1, collision avoided, given that he has succeeded. Failing in E3.1 will not make it possible for the operator to steer the ferry, which will result in the operator having to instead establish communication with the incoming vessel, E4.1.

On the other hand, if the operator cannot steer clear of the collision in E3.2, then it is assumed that the operator won't have enough time to contact the incoming vessel. In that scenario, the operator will have to contact the emergency center, E5.1, to ensure that the passengers get medical assistance as soon as possible following the collision. This scenario will result in end event C2, operator unable to avoid the collision; the emergency center is contacted. Failing in event E5.1 will result in end event C3, operator unable to avoid the collision, emergency center not contacted, which means that the operator has completely failed.

End event C4-C7

Failing to establish communication with the incoming vessel will make it impossible for the operator to collaborate with the captain. This means that the only thing the operator can do to ensure the passengers' safety and minimize the damage to the ferry is to reduce the collision force, E4.3. Rather the operator succeeds or not, the next task is then for the operator to contact the emergency center. Suppose the operator is able to minimize the collision force and contact the emergency center. In that case, the outcome will be end event C4, operator unable to avoid the collision, collision force reduced, emergency center contacted. If he fails to contact the emergency center, then the outcome will be C5, operator unable to avoid the collision, collision force reduced, emergency center not contacted. Failing in E4.3 and succeeding in E5.1 results in C6, and failure in E4.3 and E5.1 results in end event C7 as seen in figure 4.3.

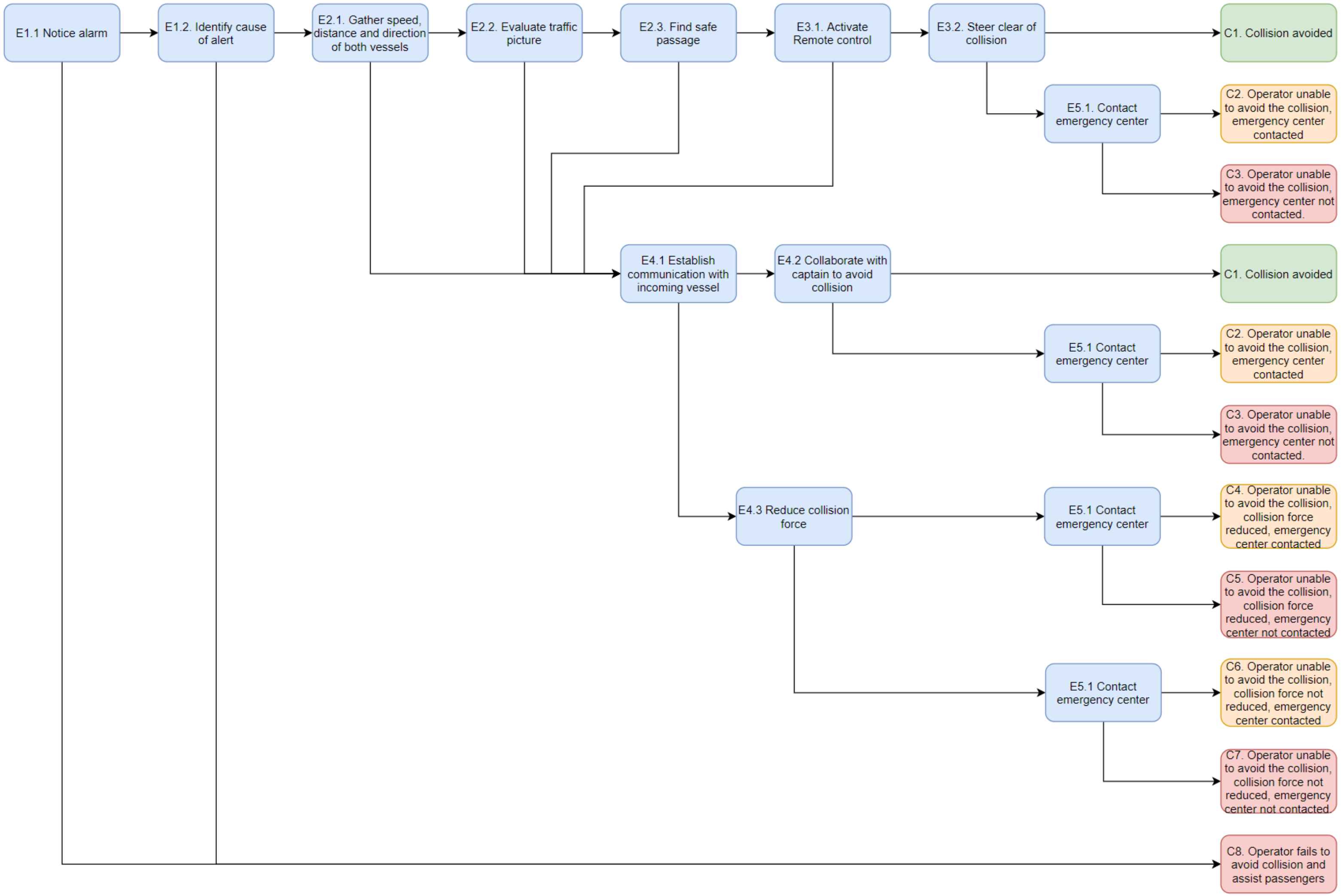

Figure 4.3: ETA - collision avoidance

Probability of each end event

The probability that either of the end events will occur can be calculated by finding the HEP for each event. The HEP will represent the probability of the NO path, meaning that the operator fails in the given event. These values are determined in the next section.

4.5 Nominal HEPs - Vessel on a collision course

This section will assign nominal HEPs to each event in the event tree, figure 4.3. The HEPs values assigned are taken from the HEART handbook. Each HEP assigned is adjusted based on relevant error-producing conditions (EPCs). All EPCs are also taken from the HEART handbook. A complete list is shown in figure 3.3 and 3.4 respectively. For every EPC, an assessed proportion of effect is determined, which estimates the given EPC's impact on the task. The proportion of effect is determined based on own judgment.

4.5.1 E1.1 Notice distress alarm

The operator's ability to notice the alarm depends on different factors such as attention level, the sound level of the alarm, and rather or not he is present. HEPs values that represent these types of failures are not easy to produce; however, looking at the task of noticing an alarm, generic tasks that are similar can be found in the HEART handbook, making it possible to find estimates of what the human error probability might look like. Generic task D in table 3.3 is defined as a fairly simple task performed rapidly or given scant attention, which is closely related to the task of noticing a distress alarm. This generic task is given a HEP of 0.09, which means that the probability that the operator will notice the alarm is 91%. It could be assumed that given that a sound alarm notifies the operator, the 91% probability of noticing the alarm might even be higher as it requires no actions on the operator's behalf, only the ability to recognize the alarm sound. However, in this thesis, the HEP value corresponding to generic task D will be used. None of the EPCs provided in the HEART handbook was seen as relevant for this task. It was considered that EPC 2, shortage of time could be relevant. However, as this task is performed instantly and since the operator is not experiencing any stress related to the limited time available, this EPC does not seem relevant for this task. The resulting HEP is, therefore:

HEP = 0.09 = 9%

4.5.2 E1.2 Identify cause of the alert

The operator's capability to act on the distress signal and identify the cause relies on his ability to understand and check the received information and how good he is at using the available cameras. It is assumed that the operator has extensive experience and practice in analyzing the received data and handling the cameras. From the HEART handbook, the generic task that mostly relates to this specific task is generic task E seen in table 3.3. Task E implies a task that is highly practiced and simple to perform. This generic task is given a HEP of 0.02.

EPC number 2, shortage of time will be relevant for this task. The time available for completing a task will, in this situation, be very low. The reason for this is how narrow the canal is. Given that the ferry's crossing time can be as low as 1 minute, any situation where a collision might occur must happen within this short interval. This means that the operator in an ideal situation will have somewhere around 1 minute to perform every task in the event tree. This leaves very little time to perform each task, which means that in this situation, collision avoidance, the effect of limited time will be very high. Given that this task is a routine task that is highly practiced and perform rapidly, the assessed proportion of effect is set to 0.5.

Another factor that can affect the HEP is the amount of information that the operator receives and that he has to analyze before finding the cause of the alert. This factor is accounted for through EPC number 8, "a channel capacity overload, caused by simultaneous presentation of non-redundant information." The assessed proportion of effect is set as relatively low, as it's believed that when the operator receives a distress signal from the autonomous system, the cause of the alert is clearly stated. The asses proportion of effect is therefore set to 0.1. The final HEP for identifying the cause of the alert is given in table 4.1.

Task	Generic Task HEP	EPC #	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#1.2	0.02	#2	11	0.5	6	**0.18**
		#8	6	0.1	1.5	

Table 4.1: HEP - Identify cause of alert

4.5.3 E2.1 Gather information on speed, distance, and direction of both vessels

The operator will have this information available as this will be collected by the autonomous system through the available equipment on board the ferry. The task can therefore be defined as fairly simple and rapidly performed. This will be something that the operator is well aware of, and the task is routine given the situation, potential collision. Therefore, the generic task used for this task is E, and the HEP is then 0.02. Again there is limited time available, and since the information gathered is provided by the autonomous system and then displayed on the operator's screen, EPC number 8 is still relevant.

The assessed proportion of effect for EPC 2, shortage of time, will be the same as the previous task. This is because the workload and difficulty level is the same, and the speed at which this task is performed is relatively fast. The assessed proportion of effect is therefore 0.5. For EPC 8, a channel capacity overload, there is a slightly higher likelihood that some mistakes can be made. However not much higher as the task is still relatively simple. For instance, the operator might misinterpret the data, switching the ferry's speed with the incoming vessel. Therefore, the assessed proportion of effect is set to 0.2. The final HEP is calculated in table 4.2.

Task	Generic Task HEP	EPC #	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#2.1	0.02	#2	11	0.5	6	**0.24**
		#8	6	0.2	2	

Table 4.2: HEP - Gather information of speed, distance and direction of both vessels

4.5.4 E2.2 Evaluate traffic picture

The process of evaluating the traffic picture builds on the use of available cameras, sensors, and GPS equipment. The GPS will be able to locate larger vessels, while the sensors will register smaller boats and kayaks. The cameras will act as security so that the operator can locate any vessels, boats, or kayaks that are not registered. This task is relatively complex as it requires the operator to locate multiple vessels and have good visualization skills to map all vessels in terms of position direction and speed. Therefore, the generic task that is most fitting is task C, a complex task that requires a high level of comprehension and skill. The human unreliability that is addressed with this generic task is 0.16. As in the two cases above both, the time aspect and the overload of available information are two important EPCs to consider. The assessed proportion of effect for the shortage of time will be very high in this task. The reason is that the operator has a high workload with very little time to do it. Based on that, the assessed proportion of effect is set at 1. The assessed proportion of effect for EPC 8 is set at 0.5. The operator has a lot more data to consider, which increases the chance of errors being made. The final HEP is given in table 4.3.

Task	Generic Task HEP	EPC #	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#2.2	0.16	#2	11	1	11	**1**
		#8	6	0.5	3.5	

Table 4.3: HEP - Evaluate traffic picture

4.5.5 E2.3 Find a safe passage

In order for the operator to locate a way to safely avoid the collision, he must be able to use the information found. Taking into account the distance between the two vessels, the speed, and the direction. He must also have in mind the surrounding traffic, so avoiding one collision does not result in another one taking place. Seeing that there are several different factors to consider, this event is categorized as fairly complex, where the operator must have a clear understanding of the situation and the surroundings.

Generic task C, a complex task requiring a high level of comprehension and skill seen in figure 3.3 is the generic task that is closest to the task of locating a safe passage. The HEP value assigned to this generic task is 0.16. Shortage of time will have a major influence on this task. EPC 10, transfer of information from task to task, will also be relevant as the operator must consider the information collected in the two previous events. EPC 8 could also affect this task.

The assessed proportion of effect for EPC 2 will be extremely high. This is because the operator will have very little time to perform a considerably complex task. As mentioned, the operator will have 1 minute to perform all the tasks, and at this point, this time will have reduced. Based on that, the assessed proportion of effect is set to 1. As for EPC 10, the assessed proportion of effect is set to 0.8 since the operator must consider both the speed, distance, and direction found in Event E2.1 and the traffic picture found in E2.2. EPC 8 is set to 0.6, just as in the previous event, as the complexity of the task is high and the amount of data to consider is large. The final HEP is given calculated in table 4.4.

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#2.3	0.16	#2	11	1	11	**1**
		#8	6	0.6	4	
		#10	5.5	0.8	4.6	

Table 4.4: HEP - Find safe passage

4.5.6 E3.1 Activate Remote control

The activation of remote control is done through the push of a button, which is a very easy task. It's most likely highly practiced, which means that the operator knows precisely which button to press. Based on this, the generic task that would be most appropriate to use here is task E, as it takes into account that the task is simple to perform, highly practiced, and performed rapidly. The only EPC that is relevant for this task is EPC 2, shortage of time. This task's assessed proportion of effect is low as the task is very simple, requiring nothing more than knowing where the button is to activate remote control. Therefore, the amount of time it takes to activate this function would be very low, and the assessed proportion of effect is consequently set to 0.2. The only reason it's even included is that the total time the operator has available is minimal. The resulting HEP is given in table 4.5

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#3.11	0.02	#2	11	0.2	3	**0.06**

Table 4.5: HEP - Activate Remote control

4.5.7 E3.2 Steer clear of collision

To steer clear of the collision, the operator must remote control the ferry using the cameras and the GPS to guide him. This task requires that the operator has a high level of skill and knowledge of remotely controlling the vessel. He must also have a high level of comprehension in dealing with the cameras as he can not himself see the ferries surroundings. Due to this, the task can be categorized as complex. A high level of skill and understanding is needed for completing the task successfully. Therefore the same generic task, task C in table 3.3 is used with a HEP value of 0.16. The time available is still limited, which makes EPC 2 relevant. Further, the need to use acquired information from earlier tasks means that some information might be overlooked or lost in the process. This corresponds to EPC number 10, the need to transfer specific knowledge from task to task without loss.

The assessed proportion of effect for EPC 2 is determined to be the same as the previous tasks that were complex. It is therefore set to 1. The operator must consider the safe path developed in event E2.3, which means EPC 10 will be relevant. It's determined that the assessed proportion of effect for EPC will be lower than in E2.3, as there is more information to consider in that task. It is therefore set to 0.5. The final HEP is given in table 4.6.

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#3.2	0.16	#2	11	1	11	**1**
		#10	5.5	0.5	3.75	

Table 4.6: HEP - Steer clear of collision

4.5.8 E4.1 Establish communication

Rather, the operator can establish communication with the incoming vessel depends both on the operator and the captain of the incoming vessel. However, the HEP value is assigned based on the operator's ability to establish communication and not rather or not the captain responds. For the operator to be successful, he must use the available communication equipment, which in this situation is the radio. Establishing communication is a relatively simple task that does not need a high level of attention and is done rapidly. What the operator has to do in order to establish communication should also be highly practiced. Based on this, the generic task used is task E. The HEP value assigned to this generic task is 0.02, and given that the operator has a shortage of time, EPC 2 is relevant. The assessed proportion of effect is set to 0.2 since the task shouldn't be much more time-consuming than activating remote control. The HEP is given in table 4.7.

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#4.1	0.02	#2	11	0.2	3	**0.06**

Table 4.7: HEP - Establish communication

4.5.9 E4.2 Collaborate with the captain to avoid collision

Successfully collaborating with the captain requires clear communication and a high level of understanding of the situation. It will involve working together to ensure that the collision does not infiltrate where both might need to maneuver their vessel and simultaneously consider the other vessels and kayaks in the surrounding area. Therefore, the operator must have the same amount of skill for the task involving finding safe passage as for those required to steer clear of the collision. The generic task used is, therefore, the same as for those two tasks. The HEP is thereby assigned the value 0.16. EPC 2 will be relevant for this task as well as EPC 10 and 16. EPC 16 is understood to involve the poor quality of information conveyed between the operator and the captain of the incoming vessel. This is considered a relevant EPC as the operator is located at the SCC, allowing for communication difficulties.

The assessed proportion of effect is set to 0.3 because the probability of this affecting HEP is not certain. EPC 2 is set to 1 as the workload is high and the time available is so limited. EPC 10 is set to 0.8, as the operator has to communicate his findings from E2.1 and E2.2. The result is given in table 4.8

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#4.2	0.16	#2	11	1	11	**1**
		#10	5.5	0.8	4.6	
		#16	3	0.3	1.6	

Table 4.8: HEP - Collaborate with captain to avoid collision

4.5.10 E4.3 Minimize collision force

To minimize the collision force, the operator must evaluate the vessel's direction and where on the ferry it will collide. Once this has been done, the operator has to assess how he can minimize the collision force, requiring a lot of experience and knowledge. The operator must also be able to remote control the ferry and make good decisions based on what he sees through the cameras and on the GPS. This makes the task complex as it requires that the operator possess a high level of skills as well as an understanding of collision forces. Generic task C in the HEART handbook is therefore used. Like in the other events, the operator will have a shortage of time, and he will also have to transfer the information found in previous tasks, direction, speed, traffic picture, and distance.

The assessed proportion of effect for EPC 2 will be one as the task is both complex and time-consuming. EPC 10 will be set to 0.8 as the operator has to transfer the same amount of information as in event E4.2. Table 4.9 shows the final HEP value.

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#4.3	0.16	#2	11	1	11	**1**
		#10	5.5	0.8	4.6	

Table 4.9: HEP - Minimize collision force

4.5.11 E5.1 Call emergency center

Contacting the emergency center is a simple task that is performed very rapidly. The operator should also have a good familiarity with what he has to do to contact them, making generic task E the most appropriate generic task to use. Time will still be an important contributing factor as the operator will not know how quickly the passengers will need medical assistance. The assessed proportion of effect is set to 0.3, as the task is more time demanding than activating remote control. However, time is not as limited as when trying to avoid the collision, which is why it was not given a higher value than in E1.2. Time is also not abundant as the passengers might require medical assistance fastly. The final HEP value is calculated in table 4.10.

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#5.1	0.02	#2	11	0.3	11	**0.08**

Table 4.10: HEP - Call emergency center

4.5.12 HEPs summarized

Task	Generic HEP
Notice distress alarm	HEP = 0.09 = 9%
Identify cause of alert	HEP = 0.18 = 18%
Gather information of speed, disance & direction	HEP = 0.24 = 24%
Evaluate traffic picture	HEP = 1 = 100%
Find safe passage	HEP = 1 = 100%
Activate remote control	HEP = 0.06 = 6%
Steer clear of collision	HEP = 1 = 100%
Establish communication	HEP = 0.06 = 6%
Collaborate with captain to avoid collision	HEP = 1 = 100%
Minimize collision damage	HEP = 1 = 100%
Call emergency center	HEP = 0.08 = 8%

Table 4.11: HEPs summarized - collision avoidance

4.6 Probability of succeeding

So far, the HEP of each task that the operator has to perform has been established. This allows for the probability of success and failure to be determined for each task. Multiplying these probabilities together for a given sequence of events will then provide the probability for the corresponding end event. This process can then be repeated for every single scenario using excel. The result is shown in figure 4.6.

The results show that only five out of the eight different end events could occur. With the most plausible outcome being C2, operator unable to avoid the collision, emergency center contacted. Note from earlier that C1 being green means that the operator has completely succeeded. Whereas C2, C4, and C6 being orange mean that the operator has only partially succeeded, and C3, C5, and C7 are red, meaning that the operator has completely failed. This means that the operator won't be able to succeed completely since C1 is not a possible end event. The only end events that can occur are C2, C3, C6, C7, and C8, where none includes the scenario where the operator is able to avoid the collision. Figure 4.4 shows the added probability for the operator's degree of success.

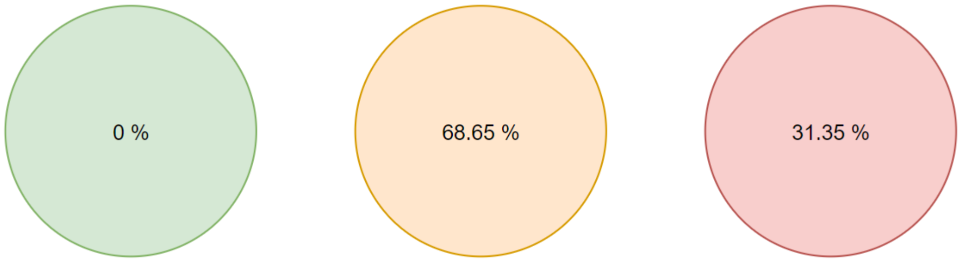

Figure 4.4: Success rate - collision avoidance

The figure shows that there is a 68.65% chance that the operator will be able to partially succeed and a 31.35% chance that he will completely fail. Interestingly, however, is that in every outcome where the operator partially succeeds, he is only able to contact the emergency department. The operator is not able to avoid the collision by steering clear of it or by cooperating with the captain. And he is also not able to minimize the collision force. This means that every task the operator performs after identifying the cause of the alert until contacting the emergency department is a waste of time. Rather he performs these tasks or not, the outcome will be the same.

Another interesting factor to consider is the large effect that limited time has on the operator's ability to perform a task successfully. The largest contributing factor for the high HEP values is EPC 2, shortage of time. However, it is also evident that the operator's limited time to perform his tasks is not the only factor preventing him from succeeding. This can be seen in figure A.1.1 given in appendix A, where the effect of removing EPC 2 was calculated. The results show that even if the operator had more time to perform the tasks, he would still not be able to avoid the collision. However, he would have a higher chance of partially succeeding as he would be able to contact the emergency center more often, which can be seen in figure 4.5.

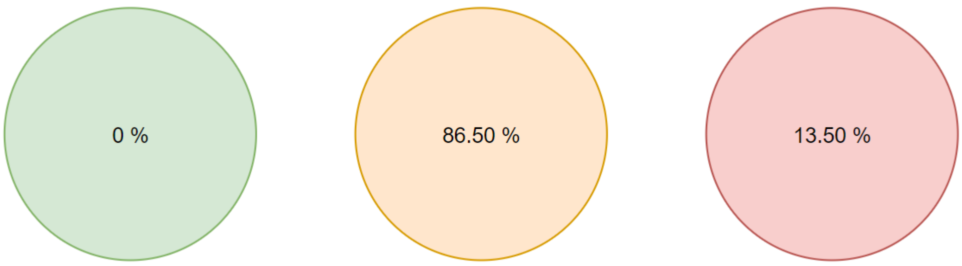

Figure 4.5: Success rate, EPC 2 removed - collision avoidance

Given that the operator is provided with more time, then the only factor that keeps him from successfully preventing the collision from infiltrating is EPC 8 and 10—being able to transfer information from one task to another and being given too much data at once. However, the problem is that the canal is only as wide as it is. This means that if a collision occurs, it will occur within that 1 minute it takes for the ferry to travel across the canal. Since the total time available will always be at most 1 minute, there isn't much that can be done to provide the operator with more time to perform all his tasks. Therefore, the only way the operator will have more time for each task is if the total number of tasks he has to perform was reduced.

Since the operator won't be able to assist in avoiding the collision, it could be better that he contacted the emergency center instantly instead. The thought behind this is that he would have more time to successfully perform this task. This could arguably be enough time that the effect of limited time could be removed. This would, as seen above, increase the chance that he partially succeeds, or in that scenario, completely succeeds. Reducing the tasks that he should perform down to noticing the alert, identifying the cause, and contact the emergency center, would result in a probability of succeeding at 86.5%. This would mean a 17.85% higher chance of being able to contact the emergency center as opposed to 68.65% if he attempts to avoid the collision, which he won't be able to do anyway. The supporting calculations are given in appendix A, figure A.2.1. Reducing the tasks any further would not be possible as the operator has to notice the alarm and understand why it was sent to be able to know whom he should contact or if it's needed at all.

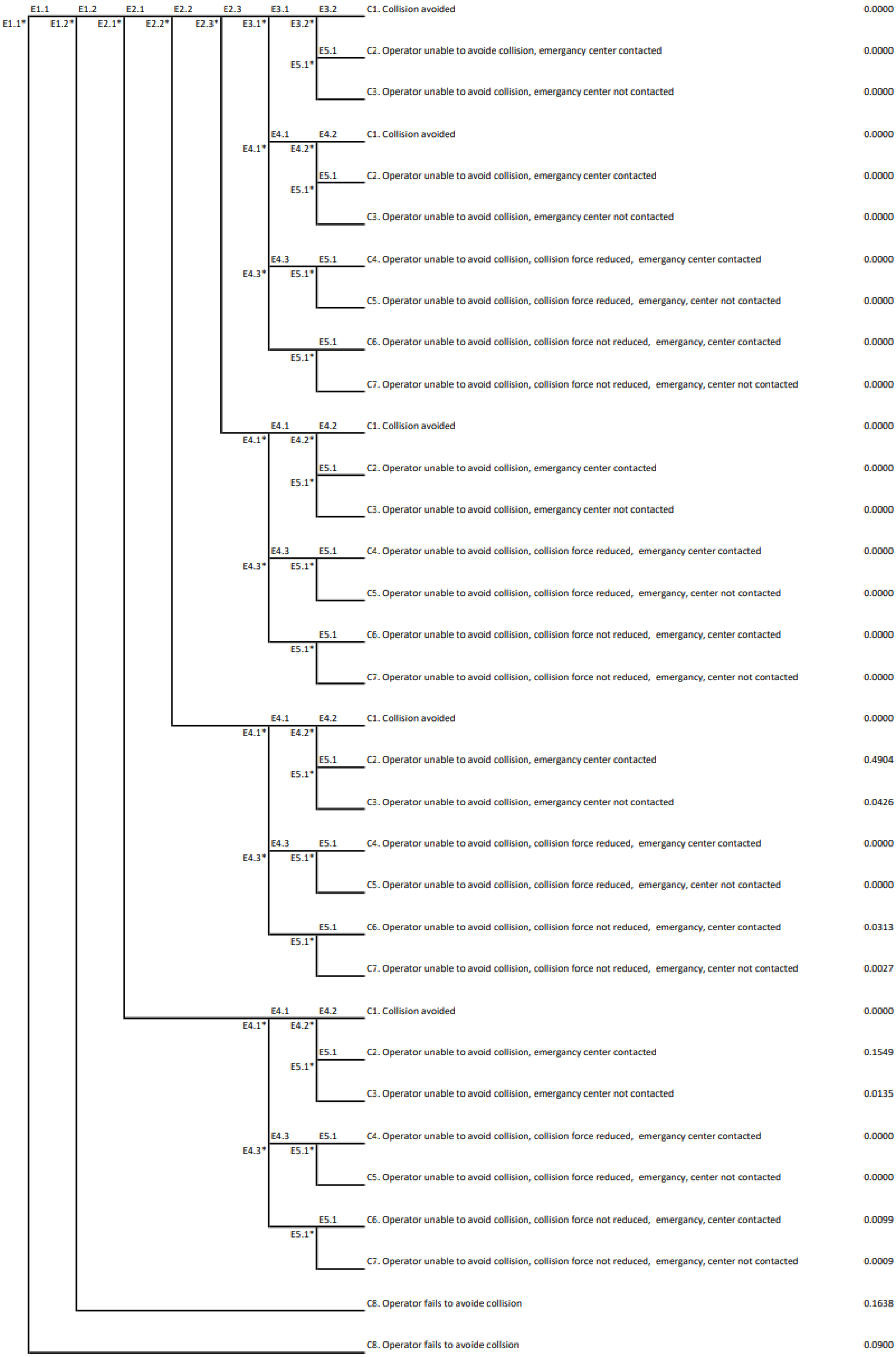

Figure 4.6: End Event probabilities - collision avoidance

4.6.1 Recommended changes

Three main factors prevent the operator from being able to avoid the collision. The shortage of time, transferring information from one task to another, and an overload of information being displayed at once. Creating more time isn't a possibility; the canal is narrow, and the passage time is only about a minute long. This doesn't allow for enough time to be saved. However, the procedure could be changed, where the autonomous system doesn't leave the port before confirming with the operator that the coast is clear. This would provide the operator with more time to analyze the canal and prevent any collisions from occurring. However, making such a change to the procedure would reduce the level of autonomy from constrained autonomous to somewhere closer to automatic in accordance to the IMO level of autonomy, figure 2.2.

The other two factors, transfer of information and display of information, could more easily be taken care of by better software. Having well-designed software that uses clear and well-designed layouts would reduce the chance of information found in one task being lost in later tasks. It could also reduce the amount of non-redundant information being shown to prevent the operator from being overloaded by too much information that might not be important in that specific situation. This would decrease the HEP for some tasks, but not enough for the operator to be able to avoid the collision as limited time has too big of an effect.

Chapter 5

Operator interference case 2

5.1 Fire emerging onboard ferry

The second scenario investigated is when a fire emerges on board the ferry. The ferry is similar to the previous case traveling from one side of the canal to the other when a fire suddenly develops onboard the ferry. The autonomous system detects the fire and responds by sending a distress signal to the SCC. The primary goal for the operator will be to assist the passengers in extinguish the fire or evacuate. The operator will have to evaluate the situation and choose the option most likely to ensure the safety of the passengers.

5.2 Hierarchical task analysis - Fire emerging onboard

Figure 5.1, illustrates the hierarchical task analysis developed for this scenario, where the primary goal is, as stated, to extinguish the fire or evacuate the passengers. Tasks 1 through 5 are the first-level tasks that the operator must complete to achieve the goal. Below these tasks are the second-level tasks that specify what the operator has to do in each of the first-level tasks. For example, plan 0 indicates that the first task that the operator must carry out is task 1.

Task 1, Respond to distress alarm

The first task of this interference scenario is the same as for collision avoidance. After the autonomous system has sent the distress signal to the SCC, plan 1 indicates that the operator first has to perform task 1.1, which is to notice the alarm. Once the operator has noticed the alarm, the cause of the alert has to be identified.

After completing tasks 1.1 and 1.2, the next step is for the operator to perform task 2.

Task 2, Analyse situation and develop strategy

Task 2 is when the operator gathers relevant information and decides whether it will be safer for the passengers to attempt to take out the fire or evacuate the ferry. For the operator to make this decision, vital information such as the location of the fire, size, and source has to be established. Plan 2 then shows that the operator's next task is to identify how to extinguish the fire safely. Based on whether the operator can complete these tasks and on the information he has collected, a decision must be made to extinguish the fire or evacuate the ferry.

Plan 0 shows that if the operator decides that extinguishing the fire is the best option, then the next task that the operator should perform is task 3. However, if the operator decides that it's not safe to attempt to put out the fire, the operator should perform task 4.

Task 3, Extinguish fire

Having decided that the best option is to extinguish the fire, the first task that the operator must carry out is to establish communication with the passengers. Once the operator can communicate with the passengers, task 3.2 should be carried out. Task 3.2 is for the operator to cooperate with the passenger to put out the fire. It is, however, not given that the operator will be able to establish communication with the passenger or that they will be able to cooperate. Plan 0 shows what the response of the operator should be in each of these two scenarios. If the operator cannot establish communication, he should move straight to task 5 since task 4 also requires the operator to communicate with the passengers. Task 5 is explained later in this section. On the other hand, if the operator fails to cooperate with the passenger to put out the fire, task 4 should be carried out even though it was decided that the safest option is for the fire to be extinguished.

Task 4, Evacuate passengers

Having decided that it's not safe to attempt to put out the fire, the operator needs to establish communication with the passengers. If, however, the operator could not collaborate with the passengers and, for that reason, has decided to evacuate. Then this task is already performed, and the operator can go straight for task 4.2. Once communication is established, the operator's next task is to inform the passengers of the evacuation procedure. The operator must then remote control the ferry away from the passengers and any boats and kayaks in the area. If the operator cannot perform any of the tasks 4.1 - 4.3 successfully, the operator should go straight to task 5. The operator should also perform task 5 if he succeeds, but not before completing task 4.1 - 4.3.

Task 5, Contact assistance

Task 5 should either be performed when the operator has succeeded in putting out the fire, when the operator has evacuated the passengers or if the operator fails and can not assist the passengers any further. The operator should then first contact the fire station, followed by calling the emergency center. Calling the fire station might result in the emergency center being contacted automatically, but if this is not the cause, the operator must contact them as well.

There is nothing more the operator can do at this stage, and he should therefore withdraw from the situation and let the fire department and emergency department handle the situation.

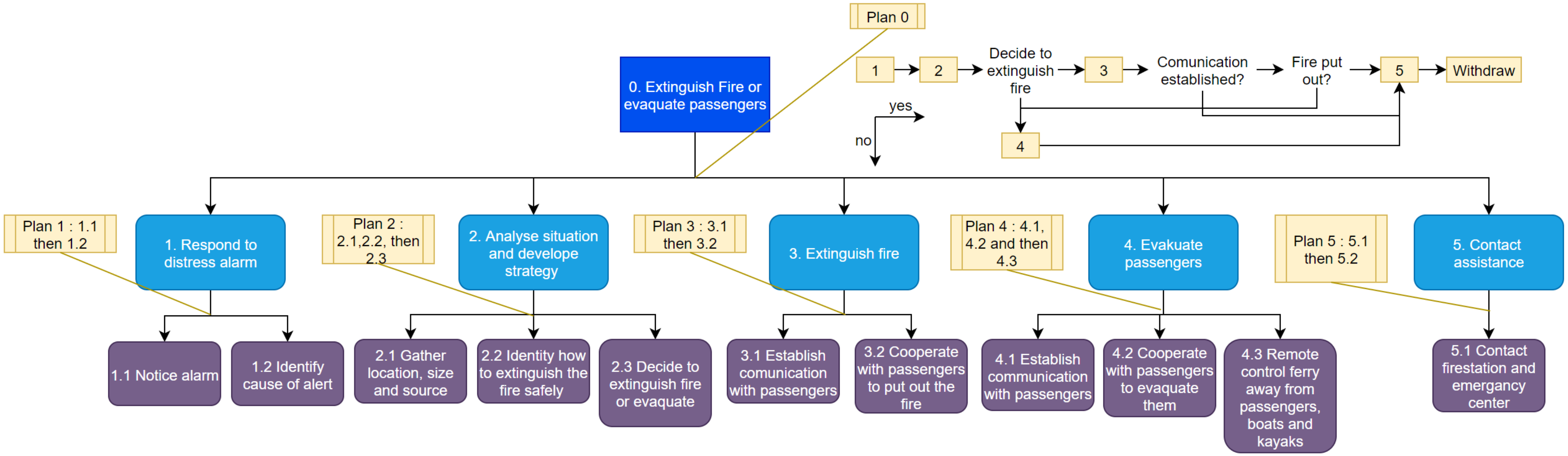

Figure 5.1: HTA - fire emerging

5.3 Event Tree - - Fire emerging onboard

Figure 5.3 illustrates the sequence of events taking place after the autonomous system sends a distress alert to the SCC. The event tree is created from the HTA seen in figure 5.1, where each event corresponds to the second level tasks performed by the operator. The event tree has some simplification in the layout to allow it to fit within one page. The full event tree with the correct layout is given in figure 5.7. From the event tree in figure 5.3, 11 different end events are given in 3 different colors, these are illustrated in figure 5.2. Green corresponds to the operator succeeding completely, orange to partial success, and red to complete failure.

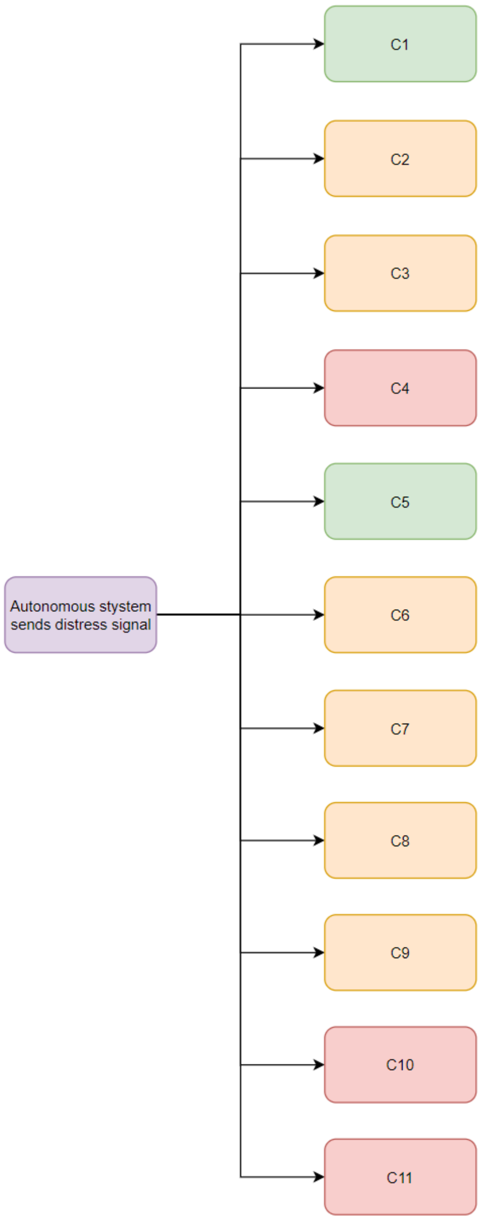

Figure 5.2: End events scenarios - fire emerging

Eleven different outcomes can happen depending on the operator's ability to perform a task successfully. It must also be noted that these end events are based on whether the operator can complete a task successfully and not on rather the passengers can act based on their intuition. For example, in end event C10, the operator fails to evacuate the passengers and is unable to contact the fire department and the emergency center. This end event does not take into account; whether the passengers can evacuate themself or contact the fire department and the emergency center. This information is irrelevant in this thesis as it aims to look at human errors made at the SCC.

End event C11

The sequence of events leading up to the end events C1-C11 starts at the initiating event E1.1, notice distress alarm. The operator first has to notice the distress signal sent in the form of an alarm sound at the SCC. From this, there are two different outcomes. Either the operator notices the alert and then moves on to event E1.2, identifying the cause, or he does not notice the alarm, which results in end event C11, operator fails to assist passengers. Given that the operator does notice the alarm, then there are two new potential outcomes, either he is able to identify the cause of the alert, or he is not. If he fails, then the operator will also fail to assist the passengers, C11. However, suppose the operator is successful and can identify the cause through analyzing the information sent by the autonomous system or through the cameras. In that case, the next event is E2. 1.

End event C1-C2

Event E2.1 is where the operator gathers relevant information, vital for him finding a way to extinguish the fire safely. The information that he has to gather is the location of the fire, size, and source. If the operator fails to gather this information, he won't be able to identify how to extinguish it, which results in the decision to evacuate the ferry. However, if he succeeds, then the next event is E2.2, where the operator attempts to identify how to extinguish the fire safely. Rather the operator fails or not, the next event is for the operator to establish communication with the passengers, E3.1 and E4.1. If he fails in event E2.2, then he will evacuate the passengers and move on to event E4.1. But if he succeeds, then the next event is E3.1, where he will establish communication with the passengers to cooperate with them to put out the fire safely, E3.2. If the operator fails to cooperate with the passengers to put out the fire, he will try to evacuate them instead, E4.2.

Given that the operator has succeeded and the fire is extinguished, then the fire department and the emergency center will be contacted, E5.1. This will result in end event C1; fire extinguished, fire department, and emergency center contacted. The emergency center will be contacted so that anyone that is injured will get attended to. Even though the fire is put out, the fire department is also contacted. This is done so that the cause of the fire can be identified and to ensure new fires do not develop. If the operator fails in E5.1, then the end event will be C2, fire extinguished, but the fire department and emergency center are not contacted. This end event is partially successful since the operator has extinguished the fire, but not a complete success as he failed to contact the fire department and emergency center.

End event C3-C4

Failing to establish communication with the passengers, E3.1 and E4.1, will result in the operator not being able to assist the passenger in putting out the fire. It will also prohibit him from assisting them in evacuating as well. In that scenario, the operator will contact the fire department and the emergency center directly. This will result in one out of two end events. Either the operator is able to contact the fire department and the emergency center resulting in end event C3, or he will fail, which will result in end event C4. End event C3 will be a partial success, while C4 will be a complete failure.

End event C5-C8

Suppose it has been decided that the passengers should be evacuated because of a failure in either event E2.1 or E2.2. In that case, the following event will be the operator attempting to establish communication with the passengers. However, if the operator fails to cooperate with the passengers in even E3.2, then communication has already been established, and the next event is then E4.2, cooperate with passengers to evacuate them. If he succeeds and the passengers are evacuated, then the operator should remotely control the ferry away from the passengers and any boats or kayaks in the area. He will then contact the fire department and emergency center, resulting in end event C5, passengers are evacuated, the ferry is out of harm's way, and both the fire department and the emergency center are contacted. If he fails to contact the fire department and the emergency center, then the end event will be C6. Failing to remote control the ferry out of harm's way in event E4.3 will either result in end event C7 or C8, depending on rather or not he succeeds in event E5.1.

End event C9-C10

Failure in event E4.2 will not allow the operator to assist the passengers in evacuating. At this point, the operator should contact the fire department and the emergency center so that they can assist them once they get there, E5.1. This will result in end event C9, operator fails to evacuate passengers, but fire department and emergency center are contacted. However, if he fails in event E5.1, then the end event will be C10; the operator fails to evacuate the passenger and is not able to contact the fire department and emergency center, which means that he has completely failed.

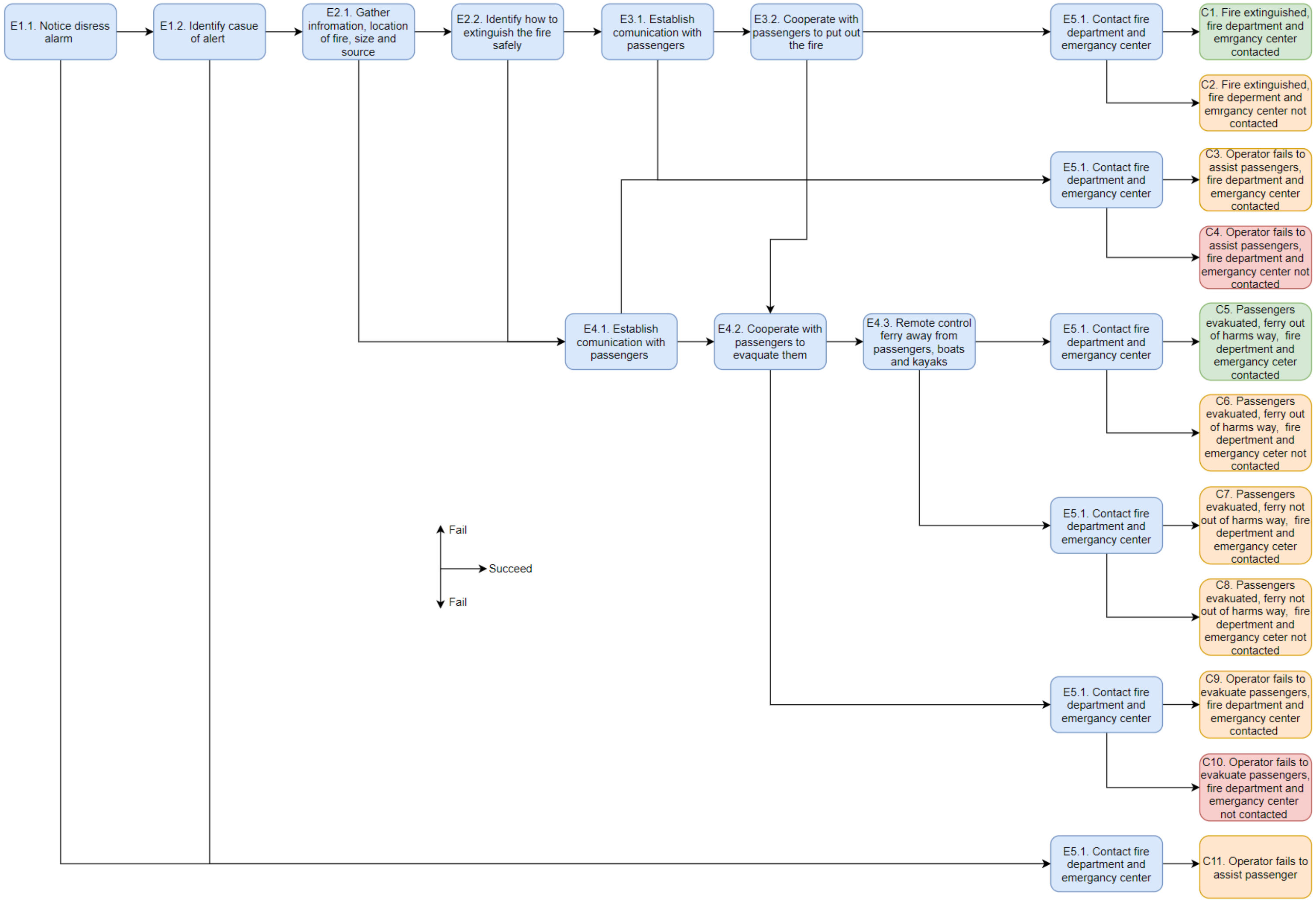

Figure 5.3: ETA - fire emerging

5.4 Nominal HEPs - Fire emerging onboard

Below each event in figure 5.3 are listed, where generic tasks are assigned to each event together with nominal HEPS. The generic tasks used are as for the previous case taken from the HEART handbook, figure 3.3. All EPCs are also from the HEART handbook, figure 3.4. Some of the events are identical to the previous case but will be repeated to prevent going back and forth.

5.4.1 E1.1 Notice distress alarm

Noticing the alarm requires no specific skill; it's not complex, and it's not a highly practiced task. It is a simple task that happens instantly, which corresponds to generic task D. Task D has a HEP of 0.09. The extra probability of error that comes with the limited time available is not relevant because the operator is not aware that time is limited. The total HEP value is, therefore:

HEP = 0.09 = 9%

5.4.2 E1.2 Identify cause of alert

Since the cause of the distress alert is a fire, it is assumed that the autonomous system has detected this through the fire detectors. It's also assumed that the operator has extensive training in analyzing the data received promptly and has practiced identifying reasons for the different scenarios where a distress signal is sent. Based on this, the task can be categorized as a simple and a rapid task that is highly practiced. This means that generic task E would be the one that is most closely related to this specific task, with a HEP of 0.02. Lack of time will be a factor that will affect the operator's ability to complete the task. Time is a factor because the ferry is so small that if the fire intensifies, the passengers will not have anywhere to occupy themselves, resulting in them getting burned very quickly. Based on EPC number 2, shortage of time will be a relevant factor affecting the HEP. The amount of information that the operator will have available at any given time can also contribute to errors being made, which is accounted for through EPC number 8. However, since the fire is detected through the fire detectors, the autonomous system will be able to provide the exact reason for the distress alarm clearly to the operator.

Due to this, the assessed proportion of effect that EPC number 8 will have on the HEP is determined to be very low and is set at 0.1. EPC 2, shortage of time is set to 0.3. The reasoning behind this is that the operator will have limited time to perform all the tasks, but it will not be as low as for collision avoidance, where the operator only has about 1 minute to act. It is believed that the fire will take more time than that to intensify to a dangerous size, given that the fire detector is able to detect the fire at an early stage. The final HEP is given in table 5.1

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#1.2	0.02	#2	11	0.3	4	**0.12**
		#8	6	0.1	1.5	

Table 5.1: HEP - Identify cause of alert

5.4.3 E2.1 Gather information, location of fire, size, and source

Gathering this information will rely on the operator's ability to evaluate the situations from what he can see through the cameras. However, the operator might be given error or failure messages of different components on the ferry by the system, which will help identify the location and source of the fire. This means that most of the information gathered will rely on the operator using the cameras and evaluating what he can see. Using the cameras isn't that complex, and identifying the location and size of the fire should not be very time-consuming. The only complex part of this task will be to identify the cause of the fire, which, if identified, will be primarily based on failure messages that he receives from the system. Based on that, it is determined that the most fitting generic task is task E. This task has a HEP of 0.02. EPCs relevant for this task include the shortage of time available for the operator to gather the information, x11. Having too much information available could also contribute to errors being made. EPC number 8 relates to the overload of available information, x6.

The assessed proportion of effect that the shortage of time will have on this task is medium to low. The thought behind this assumption is that the task is not very complex but will take some time. However, time is something that the operator does not have, which is why the proportion effect is set to 0.4. Again somewhat lower than in event E2.1 from the collision avoidance case, but this is because the operator will have a little more time to perform the tasks than in that situation. As for EPC 8, the assessed proportion of effect is set to 0.1. A relatively low number because the operator will mainly get his information from what he can see through the cameras. The final HEP is calculated in table 5.2

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#2.1	0.02	#2	11	0.4	5	**0.15**
		#8	6	0.1	1.5	

Table 5.2: HEP - Gather information, location of fire, size and source

5.4.4 E2.2 Identify how to extinguish the fire safely

The operator's ability to find a way to extinguish the fire safely relies on experience, knowledge of different types of fires, and how well he can use the information he has gathered. The only way the fire can be extinguished using available equipment is a fire extinguisher. However, because the ferry is so small, the passengers might be in too big a danger if they attempt to, so determining a way to do it safely is what makes this task complex. Therefore, the task is determined to be complex, which makes generic task C the most fitting choice, HEP 0.16. The operator having to use the information found in previous tasks creates room for mistakes as some information might be forgotten or not thought of in the heat of the moment. EPC number 10 relates to this, x5.5. The shortage of time also increases the chance for error, x11.

The assessed proportion of effect for EPC 10 isn't that big, as there isn't much information to transfer from the previous task. This is why the proportion of effect is set to 0.3, not irrelevant but not that great. However, shortage of time will influence this task more, as the operator will be stressed to make a fast decision which can affect his ability to complete the task successfully. EPC 2 is therefore given a proportion effect of 0.8. The final HEP is calculated and presented in table 5.3

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#2.2	0.16	#2	11	0.8	9	**1**
		#10	5.5	0.3	2.35	

Table 5.3: HEP - Identify how to extinguish fire safely

5.4.5 E3.1 and E4.1 Establish communication

Establishing communication with the passengers does not rely on the passengers in any way. The operator just has to activate the speakers and microphones on the ferry allowing them to communicate. This is a simple task, and the operator should be well aware of what to do in order to activate them. Generic task E is, therefore, the task that is best suited in this situation. The only EPC that will be relevant here is the time factor EPC number 2.

The assessed proportion of effect will be very low for this task, as establishing communication is not time-consuming, and limited time won't have a massive effect on whether the operator can establish communication. Its therefore given an assessed proportion of effect at 0.2. Table 5.4 shows the end result.

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#3.1 & #4.1 Establish communication	0.02	#2	11	0.2	3	**0.06**

Table 5.4: HEP - Establish communication

5.4.6 E3.2 Cooperate with passengers to put out the fire

The cooperation between the operator and the passenger demands clear and easily understood directly from the operator. The operator must be able to communicate with the passenger in a way that allows the passenger to understand what they have to do, as any miss understanding could be severe. This is therefore not a simple task, and given the limited time available, the task is determined to be complex. The generic task C is therefore chosen, making the HEP 0.16. The limited time mentioned increases the probability for error, and the requirement of using information from previous tasks further increases the probability of error to some extent. The fact that the operator is handling the situation from the SCC could result in poor communication between the operator and the passengers, which is accounted for through EPC number 16.

The assessed proportion of effect for EPC 2 is thought to be relatively high in this task. The operator will have limited time to cooperate with the passengers, and this will influence the operator's ability to assist the passenger in extinguishing the fire. The proportion effect is therefore set to 0.8 for EPC 2. EPC 16 is set at a low to medium level, 0.3, because the effect of the operator being located at the SCC on his ability to communicate well is not that clear. EPC 10 is given an assessed proportion of effect at 0.5, an increase from event E2.2. The reason is that the operator will, at this point, have found a way to extinguish the fire safely, and how he will do this has to be transferred over to this task. The final HEP value is presented in table 5.5

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#3.2	0.16	#2	11	0.8	9	**1**
		#10	5.5	0.5	3.25	
		#16	3	0.3	1.6	

Table 5.5: HEP - Cooperate with passengers to put out the fire

5.4.7 E4.2 Cooperate with passengers to evacuate them

The process of informing the passenger of what to do when evacuating is a task that is highly practiced. It relies on step-by-step directions given by the operator that will vary somewhat depending on the situation. Rather this is a complex task that could be debated, but since the time is so limited, this information has to be given fast without being conveyed poorly. Due to this, the task has been categorized as complex, and as a result, generic task C is chosen. The operator has, as mentioned, a short amount of time to evacuate the passengers, which increases the HEP, EPC 2. He also has to transfer information from previous tasks to determine the best evacuation plan, EPC 10. The fact that the operator is handling the situation from the SCC and that he has limited time available will increase the probability form information being conveyed poorly, EPC 16.

The assessed proportion of effect will be the same as in event E4.2 for EPC 2 and 16. However, the operator has not been able to identify a means of extinguishing the fire safely, which means he does not need to transfer this information to this task. Therefore, EPC 10 is given an assessed proportion of effect at 0.3, just like in event E2.2. The total HEP for this task is given in table 5.6

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#4.2	0.16	#2	11	0.8	9	**1**
		#10	5.5	0.3	2.35	
		#16	3	0.3	1.6	

Table 5.6: HEP - Cooperate with passengers to evacuate them

5.4.8 E4.3 Remote control ferry away from passengers, boats, and kayaks

For the operator to safely control the ferry away from the passenger, boats, and kayaks, several different tasks must be done. First, the operator must activate remote control; then, he must have already communicated to the passengers in which directions they should be swimming. He must then evaluate the traffic picture and afterward steer the ferry, only having cameras and GPS available to know where to sail. All this makes the task complex and relies on the operator having a lot of experience and skills. Generic task C is, therefore, the one that most closely resembles this specific task. Again there is limited time available to get the ferry out of harm's way, as the fire might escalate and become more dangerous EPC 2. There is also the need for the operator to "transfer specific knowledge from task to task without loss," which further increases the HEP, EPC 10.

The effect of EPC 2 on this task will be significant as the operator will have very little time to perform a set of different actions to be able to remote control the ferry away from the passengers and potential boats and kayaks in the area. The assessed proportion of effect for EPC 2, in this case, is therefore given a value of 1. The operator will also have to transfer information such as the direction in which the passengers are swimming and the current traffic picture. This EPC is therefore given an assessed proportion of effect of 0.6. The resulting HEP is given in table 5.7

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#4.3	0.16	#2	11	1	11	**1**
		#10	5.5	0.6	3.7	

Table 5.7: HEP - Remote control ferry away from passengers, boats, and kayaks

It is assumed in this event that the operator has activated remote control and is evaluating the traffic picture as he is about to remote control the ferry away. This is a simplification made to make the event tree a little smaller. However, the effect isn't that big as the probability of succeeding, either way, is equal to 0.

5.4.9 E5.1 Contact fire department and emergency center

Contacting both the fire department and emergency center is a simple task that requires no particular type of skill. The process is simple and well known to the operator, making generic task E most fitting. However, the operator will have limited time to contact them as the passengers might be in instant need of medical assistance, which further increases the chance of errors, EPC 2. The assessed proportion of effect is set at 0.3, slightly higher than in events E3.1 and E4.1 because contacting the emergency center is more time-consuming. The resulting HEP is given in table 5.8.

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#5.1	0.02	#2	11	0.3	11	**0.08**

Table 5.8: HEP - Contact fire department and emergency center

HEPs summarized

Task	Generic HEP
Notice distress alarm	HEP = 0.09 = 9%
Identify cause of alert	HEP = 0.12 = 12%
Gather information, location of fire, size and source	HEP = 0.15 = 15%
Identify how to extinguish fire safely	HEP = 1 = 100%
Establish communication	HEP = 0.06 = 6%
Cooperate with passengers to put out the fire	HEP = 1 = 100%
E4.2. Cooperate with passengers to evacuate them	HEP'= 1 = 100%
Remote control ferry away from passengers, boats, and kayaks	HEP = 1 = 100%
Contact fire department and emergency center	HEP = 0.08 = 8%

Table 5.9: HEPs summarized - fire emerging

5.4.10 Probability of succeeding

The probability of success has been calculated in excel, and the results are presented in figure 5.7. Out of the 11 different possible outcomes, only five can occur. These include end events C3, C4, C9, C10, and C11. Neither of the scenarios includes the operator being able to extinguish the fire or evacuate them; however, the operator is able to contact the emergency department the majority of the time. The outcomes where the operator partially succeeds and fails have been added to display the overall probability picture. The results are seen in figure 5.4.

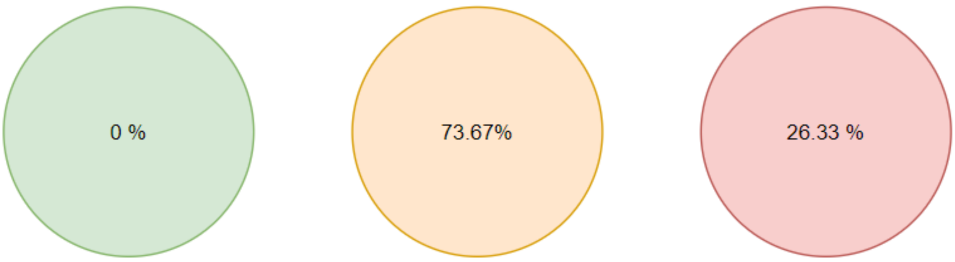

Figure 5.4: Success rate - fire emerging

The results show that the operator will be able to partially succeed 73.67% of the time but that he won't completely succeed. In the remaining 26.33 % of the time, the operator will fail to assist the passengers in any way. Similar to the collision case, the operator is only partially succeeding because he has been able to get hold of assistance. Neither of the partial success scenarios includes the operator either extinguishing the fire or evacuating the passengers. This means that the operator should focus on getting the passengers assistance as soon as possible instead of attempting to resolve the situation himself. Shortening the number of tasks that he has to perform would give him more time to perform each task, possibly enough time to remove the time factor. The result would then be a partial success chance of 86.5% as opposed to the 73.67% that he otherwise would have, as seen in figure 5.5. Since the number of tasks is reduced to notice alarm, identify the cause, and contact assistance, it is not strange that the probability of success is the same in this case and the collision avoidance case.

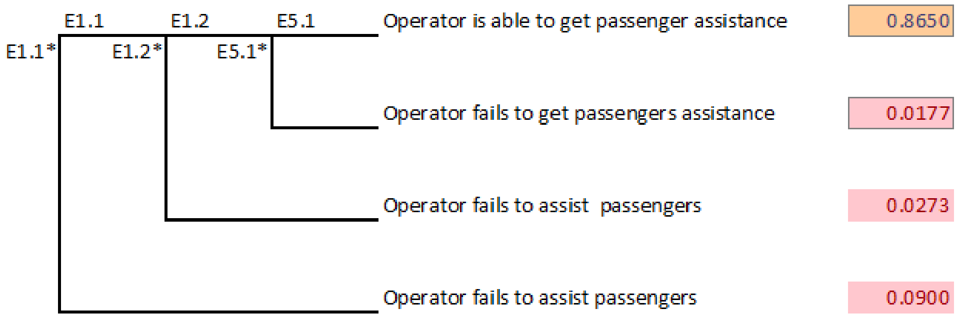

Figure 5.5: Event tree, tasks reduced - fire emerging

Without cutting the number of tasks that the operator has to perform, it's hard to find a way to increase the amount of time the operator has to perform the tasks. However, without more time, the operator won't be able to do any more than getting the passenger's assistance. This means that even though changes are made to improve the operator's ability to transfer information from one task to another and reduce non-redundant information. The operator won't succeed any more than to contact the fire department and emergency department. However, if the operator was somehow provided with more time, to the point that the shortage of time factor could be completely removed. Then this would allow the operator to be able to succeed completely. Figure 5.6, shows the significant effect that time has on the operator's success rate.

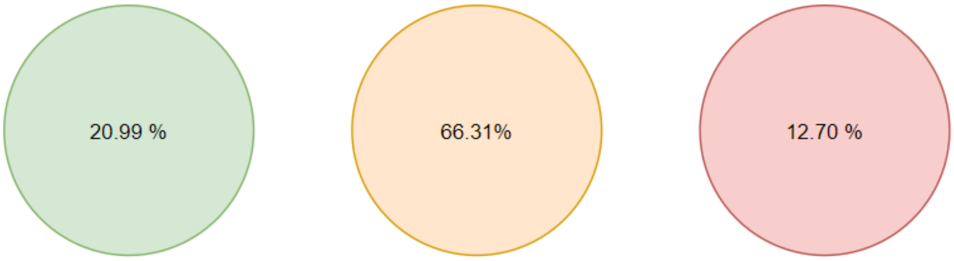

Figure 5.6: Success rate, EPC 2 removed - fire emerging

Removing the time factor would result in the operator having a 20.99 % chance of completely succeeding. This includes the probability that he either is able to evacuate the passenger and contact the two departments or extinguish the fire and contact the two departments. The calculations made to support this statement are shown in figure B.1.1 in appendix B. The result could even be higher given that changes were made to reduce the proportion effect of the other EPCs.

However, given that no changes are made, the operator should not attempt to assist the passengers in putting out the fire or evacuating as there is a 0% chance that he will succeed. Instead, he should get the passenger's assistance instantly after understanding what is going on, which will increase his probability of succeeding by 12.83%. However, if the operator is provided with more time, it would be possible for the operator to assist further, which would be the ideal scenario.

5.4.11 Recommended changes

The installation of automatic fire extinguishers would allow the operator to activate this function from the SCC. That would increase the probability that the fire gets extinguished and, therefore, the probability that he succeeds.

The same changes to the software recommended in the collision avoidance case would also be relevant in this case.

Figure 5.7: End event probabilities - fire emerging

Chapter 6

Operator interference case 3

6.1 Passenger fallen overboard

The third scenario investigated is when one of the passengers falls overboard. The operator again is contacted through a distress alarm. Different from the previous scenarios, the distress signal is not sent by the autonomous system. In this case, the passengers have pressed an emergency button to get in contact with the operator. It is assumed in this situation that there is always more than one person using the ferry at a given time to allow for collaboration between the operator and the passengers. In the situation that only one person uses the ferry and falls overboard, the operator will not be contacted as the system won't be able to detect if someone has fallen overboard.

6.2 Hierarchical task analysis - Passenger fallen overboard

The operator's primary goal is to assist the passenger who has fallen overboard to get back on board. The tasks that the operator will have to perform to achieve this goal are given in figure 6.1. Plan 0 indicates the order in which the tasks are performed, starting with task 1.

Task 1, Respond to distress alarm

The first task is for the operator to respond to the distress alarm that the passengers have sent. Plan 1 indicates that the operator will first have to notice the alarm. Once the alarm is noticed, then the operator must establish communication with the passengers to then be able to identify why the passengers have contacted the SCC. However, it is assumed that since the passengers have contacted the operator, then communication is instantly established as the system will automatically activate the speakers and the microphones.

Once the operator is aware of the situation, the operator needs to analyze the situation.

Task 2, Analyse situation

The operator will analyze the situation by performing task 2.1 followed by task 2.2. Task 2.1 indicates that the operator must first locate the passenger that has fallen overboard. Once the location of the passenger is identified, then the operator should perform task 2.2. Task 2.2 states that the passenger's state should be evaluated in terms of conscious or unconscious.

The state of the passenger will determine how the operator will proceed. If the passenger is conscious, the operator will carry on with task 3, assisting the passenger in getting back on board. However, if the passenger is not conscious, the operator must assist the passengers on the ferry to retrieve the unconscious person. The distinction here is that if the passenger is unconscious, he won't be able to cooperate, and by that, the task load will increase.

Task 3, Assist passenger in getting back on board

In order for the operator to assist, he first has to take command over the ferry. The operator, therefore, has to activate remote control, 3.1. Once the operator controls the ferry, he has to stop the ferry from sailing or drifting away from the passenger as there might be strong currents in the canal, 3.2. Plan 3 then indicates that the last task is for the operator to cooperate with the passengers in assisting the person in the water to get back on board.

Once the operator has performed all sub-tasks of task 3, then the operator should perform task 5.

Task 4, Get the unconscious passenger on board the ferry

Like in task 3, the operator must first get control over the ferry, which is achieved by activating remote control. Then, since the person fallen overboard is unconscious, the operator has to remote control the ferry towards the person, positioning the ferry's bow next to him, task 4.2. The operator then has to cooperate or instruct the passengers on the ferry to pull the person back on board from the bow, task 4.3.

Once the passenger is safely located onboard the ferry, the operator should perform task 5.

Task 5, Contact assistance

Contacting assistance implies that the operator should contact the emergency center to assess the passenger and treat him if necessary once they get to the site. The operator should also contact the coast guard if he cannot assist the passenger back on board.

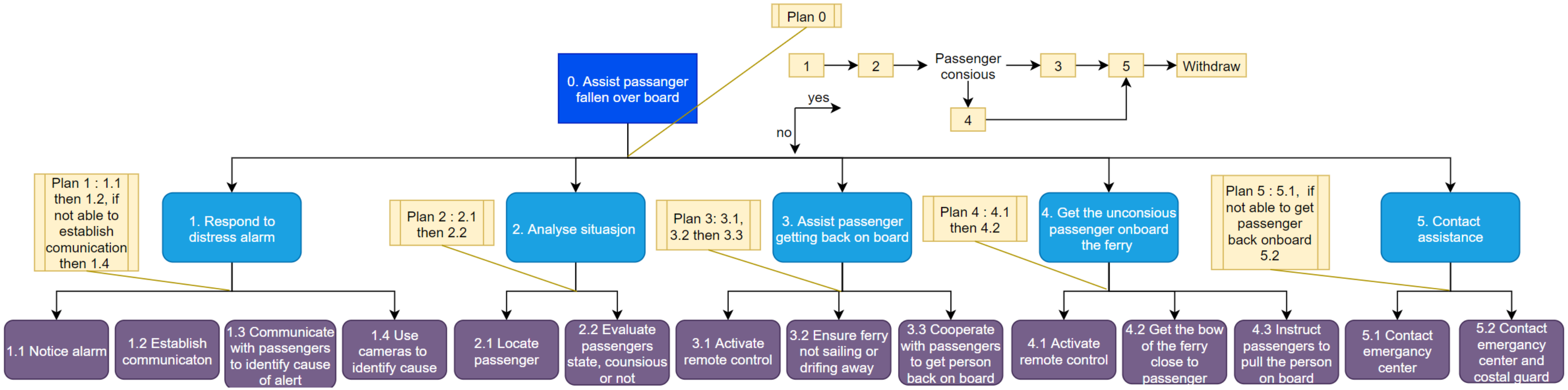

Figure 6.1: HTA - man overboard

6.3 Event Tree - Passenger fallen overboard

The sequence of events taking place from the operator's perspective once the passengers have alerted the SCC is shown in figure 6.3. The event three is built-in correspondence to the HTA shown in figure 6.1. A total of 5 different outcomes were found to possibly occur depending on rather the operator succeeds in performing his tasks or not. These are identified by C1 to C5, as shown in figure 6.2 with distinctive colors representing the degree of success. Some of the end events are the same even though the sequence of events is different since the overall outcome is similar. For instance, whether the passenger is conscious or not will not affect the outcome, as long as he is safely located onboard the ferry and the emergency department has been contacted. The outcome will for both these events be C1.

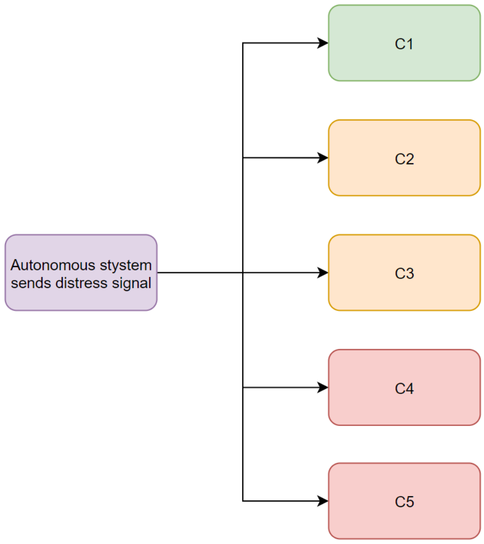

Figure 6.2: End events scenarios - man overboard

As in the other 2 cases, the end event does not consider passengers taking the initiative to either help the person fallen overboard or contact the emergency department. The end events are only based on rather the operator has completed his tasks correctly. Below the different directions that the situation may take are shown to illustrate how the different end events can be reached.

End event C5

As seen in figure6.3, the initial event is the operator noticing the alarm or not. If the operator does not notice the distress alarm, then the operator will immediately fail, as he will not be able to assist the passenger fallen overboard. This will result in end event C5; the operator fails to assist the passenger. End event C5 will also occur if the operator cannot identify the cause of the alert since he won't know what's wrong and why he was contacted.

For the operator to identify the cause of the alert, he will have to communicate with the passengers since the autonomous system will not know why the passengers contacted the operator.

If the operator can identify the alarm's cause, he will move on to event E2.1.

End event C1-C4

E2.1 is where the operator has to locate where the person who has fallen overboard is. Again, if the operator cannot locate the passenger, he will not be able to assist him. In that situation, the operator should contact the emergency department and the coastal guard immediately so they can attempt to assist him. Depending on rather the operator succeeds, the outcome will either be event C3 or C4. End event C3 means that the operator has failed to assist the passenger in getting back on board the ferry. However, he has contacted the emergency department and coastal guard, which corresponds to a partial success. Whereas C4, the operator is not able to do either of these tasks and has thereby completely failed.

If the operator can locate the passenger, he will evaluate the passenger's state, in terms of conscious or unconscious, E2.2. If he is unsuccessful, then he will assume that the passenger is unconscious. If he is successful, then depending on the verdict, he will either move on to E3.1 or E4.1. In both events, E3.1 and E4.1, the operator will activate remote control, but the following events will change depending on the passenger's state. Suppose the operator fails to activate remote control in either E3.1 or E4.1. In that case, it is determined that he will not be able to assist the passenger in getting back on board, as future tasks will require him to have remote control over the ferry. This will mean that the operator has to contact the emergency department and the coastal guard immediately. The resulting end events will thereby be C3 and C4. Given that the passenger is conscious and the operator has activated remote control, the next event is E3.2.

The operator will have to ensure that the ferry does not sail or drift away from the passenger. This will require the operator to stop the ferry from sailing towards the quay and remote control the ferry towards the passenger as the current will take him in the canal. If the operator cannot do this, then the passenger will be pulled too far away from the ferry. This will not allow the operator to assist him in getting back on board. The operator will thereby have to contact the emergency department and coastal guard instead. Again this will result in end event C3 or C4. Suppose he can ensure that the ferry does not sail or drift away from the passenger, then the next event will be E3.3. The operator will cooperate with the passengers on board the ferry to get the person who has fallen overboard back onboard. The operator will then instruct them to throw the lifebuoy and pull him back toward the ferry and help him to get onboard. If the operator fails to collaborate with the passengers, he will contact the emergency department and coastal guard, C3 and C4.

If he succeeds and the passenger is safely onboard the ferry, he will only contact the emergency department. Since the passenger is safely onboard the ferry, there is no need for the coastal guard. However, the emergency department should be contacted to assess the passenger and potentially treat him if necessary. The resulting end event will be C1 or C2. C1, the passenger is safely onboard, and the emergency center is contacted, which means that the operator has completely succeeded. C2, the passenger is safely onboard the ferry, but the operator has not contacted the emergency department, and thereby he has only partially succeeded.

End event C1-C4 passenger unconscious

If either the passenger is determined unconscious or the operator fails to determine the passenger's state and assumes he is unconscious. The next event is E4.1, activate remote control. Failing to activate remote control will result in end events C3 or C4, as mentioned above. However, if he succeeds, then the operator will have to get the ferry positioned so that the ferry's bow is close enough to the man overboard so that the passengers will be able to pull him back on board, E4.2 and E4.3. On the other hand, suppose the operator fails to perform either of these tasks. In that case, he will not be able to assist the passenger, and he should therefore contact the emergency center and the coastal guard immediately. This will also result in either end event C3 or C4. On the other hand, if he succeeds and the passenger is safely located on the ferry, he will only contact the emergency center. The resulting end event will thereby be C1 or C2 depending on whether he can contact the emergency department or not.

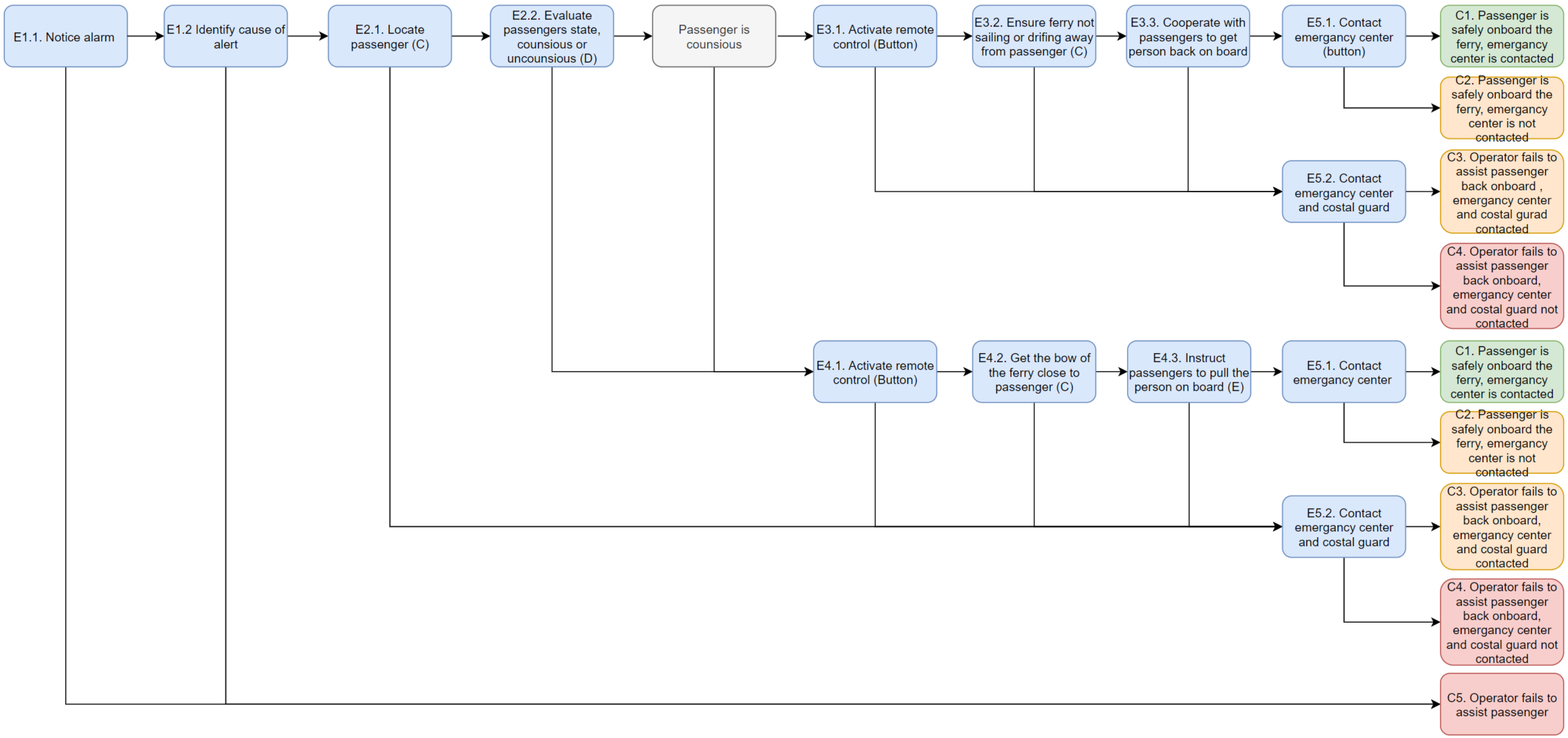

Figure 6.3: ETA - man overboard

6.4 Nominal HEPs - - Passenger fallen overboard

6.4.1 Notice alarm

As explained in the other two cases, the operator performs a reasonably simple task, which corresponds to generic task E. Generic task E has a HEP of 9%, which then results in a 91% chance of succeeding. No EPC in the HEART handbook is relevant for this task.

HEP = 0.09 = 9%

6.4.2 Identify cause of alert

Identify the cause of the alert will rely on the communication between the operator and the passengers. It's a simple task requiring the operator to listen to the passengers as they explain the situation. Generic task D could therefore be a fitting choice as it specifies a simple task that is performed rapidly. Generic task E could also be a fitting choice, but it specifies that the task is highly practiced. This report will assume that the operator has practiced communicating with people efficiently and is able to ask specific questions that allow the passengers to communicate the problem clearly. Therefore generic task E will be the most appropriate choice. The operator will have limited time to act since the passenger that has fallen overboard might drown or get caught by the current and drift away. If the passenger is conscious, then the operator will have more time to act than if the passenger is unconscious. However, at this stage, that will be hard to determine. In either of those cases, it will be assumed that the operator will have more time than in the collision avoidance case but still limited enough to account for EPC 2. In the other two cases, EPC 8 has also been included. However, in this case, the operator's ability to identify the cause of the alert depends on the passengers rather than information provided by the autonomous system. Due to this, this EPC will not affect the HEP.

The assessed proportion of effect for this task will be set at 0.4, as the operator will have limited time to perform the task. But he will, however, be performing a relatively simple task that is not extremely time demanding, which is why it is not set to 1. The resulting HEP is given in table 6.1

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#1.2	0.02	#2	11	0.4	5	**0.1**

Table 6.1: HEP - Identify cause of alert

6.4.3 Locate passenger

Locating the passenger requires the operator to have good familiarity with the different cameras available and a high level of skill when operating them. Spotting a person in the water through these cameras can be challenging, making the task complex. However, seeing that the operator is able to communicate with the passengers on board, they might be used by the operator to identify the passenger's location easier. Generic task D is, therefore, the best option. The HEP is thereby 0.09. It is assumed that this type of task is something that the operator hasn't practiced a lot, making generic task D a more reasonable choice than E. The only EPC that will be relevant for this task is EPC 2. The assessed proportion of effect for this EPC is set to 0.5, as the task is not very time-consuming but more demanding than the previous task. The final HEP value is given in table 6.2

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#2.1	0.09	#2	11	0.5	6	**0.54**

Table 6.2: HEP - Locate passenger

6.4.4 Evaluate passengers state, conscious or unconscious

The passenger's state is quickly evaluated by seeing if he responds when talked to or if he is moving. If the passenger does not respond or move, it should be assumed that he is not conscious. This can be evaluated fast, and it's relatively simple to evaluate. Therefore generic task D is the most fitting choice from the HEART handbook. Even though the task is simple and performed rapidly, the operator will have limited time. However, the assessed proportion of effect is seen as low in this case, as this will be an immediate decision that the operator has to make. Therefore, the proportion of effect is set to 0.3, as the limited time could make the operator assess the situation too fast and make the wrong assumption. The calculated HEP is given in table 6.3.

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#2.2	0.09	#2	11	0.3	4	**0.36**

Table 6.3: Evaluate passengers state, conscious or unconscious

6.4.5 Activate remote control

The operator will have practiced remote controlling the ferry numerous times. This implies that he knows precisely how to activate the function, and the task can therefore be assumed to be highly practiced. The activation itself is not a complex task and can be done relatively fast, which means that generic task E is the most appropriate choice. The operator will have limited time to complete the task, which means that EPC 2, shortage of time, will still be relevant. However, the assessed proportion of effect will be low as the task is both simple and performed rapidly. Based on that, it's set to 0.2. Reuslts are given in table 6.4.

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#3.1 & #4.1	0.02	#2	11	0.2	3	**0.08**

Table 6.4: Activate remote control

'

6.4.6 Ensure ferry not sailing or drifting away from passenger

This is a complex task as it requires the operator to control the ferry through the available cameras remotely. He will also have to evaluate the strength of the current, as this will affect the forces acting on the ferry and how fast the passenger will be dragged away. Generic task C is therefore chosen with its HEP value of 0.16. The EPCs that are relevant in this task are EPC numbers 2 and 8. The operator will have a shortage of time as the passenger will be taken by the current instantly. The longer it takes for the operator to act, the further away the passenger will be and the higher the likelihood is for him drowning. EPC 8, a channel capacity overload, is also relevant as the operator will have a lot of non-redundant information available when evaluating the current, keeping track of the passenger, and steering the ferry.

Since this task is both complex and time-consuming, a shortage of time will significantly affect the operator's ability to perform the task successfully. The assessed proportion of effect for EPC 2 is therefore set to 0.8. Evaluating the current while steering the ferry and keeping track of the passenger will mean that non-redundant information can cause the operator to get confused with which data is relevant and which is not. This is likely to cause problems, and therefore the assessed proportion of effect for EPC 8 is set to 0.5. Table 6.5, shows the final HEP value.

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#3.2	0.16	#2	11	0.8	9	**1**
		#8	6	0.5	3.5	

Table 6.5: Ensure ferry not sailing or drifting away

6.4.7 Cooperate with passengers to get person fallen overboard back on board

This task is determined to be complex as it involves the operator being able to cooperate with the passengers, steer the ferry and keep track of the person in the water at the same time. The task isn't necessarily very time-consuming, but it could be. Generic task C is therefore thought to be the most fitting choice. HEP = 0.16. The EPCs that will be relevant to this task are EPC 2, 10, and 16. The assessed proportion of effect concerning EPC 2 is set to 0.8. A high number as the operator will be performing a complex task that will most likely be relatively time-consuming compared to the time available. EPC number 8 will be set to 0.3 as there isn't that much information that the operator has to transfer from previous tasks besides the location and physical state of the person in the water. For EPC 16, the assessed proportion of effect will be set to 0.3 as in the other two cases. Table 6.6 shows the final HEP.

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#3.3	0.16	#2	11	0.8	9	**1**
		#8	6	0.3	2.5	
		#16	3	0.3	1.6	

Table 6.6: HEP - Cooperate with passengers to get person fallen overboard back on board

6.4.8 Get the bow of the ferry close to passenger

The task involves the operator steering the ferry close enough to the unconscious passenger allowing the people onboard the ferry to pull the passenger back onboard. This task is seen as complex as it requires the operator to have a relatively high level of skill when it comes to steering the ferry remotely and accounting for the current. The danger with this task is that the operator could hit the passenger, hurt him, or push him underwater. The generic task chosen for this task is therefore task C, HEP = 0.16. The EPCs that will affect the HEP are thought to be the same as Ensuring the ferry is not sailing or drifting away. This is because the task that the operator is faced with a more or less the same. However, seeing that the passenger is unconscious in this situation, then time will be even more limited, and therefore the assessed proportion of effect for EPC 2 will be set to 1. The effect of EPC 8 is seen to be equal and is set to 0.5. The resulting HEP is given in table 6.7.

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#4.2	0.16	#2	11	1	11	**1**
		#8	6	0.5	3.5	

Table 6.7: Get the bow of the ferry close to passenger

6.4.9 Instruct passengers to pull the person back on board

This task involves cooperating with the passengers and instructing them to pull the passenger back on board once the operator has positioned the ferry close enough. Cooperating with the passengers on the ferry is seen as a complex task, as the operator has to keep the ferry steady, keep track of the passenger in the water, constantly evaluating the current, and at the same time communicating with the passengers. This task is very similar to the task performed in event E3.3, which means that the same EPCs will be relevant for this task. Therefore, the generic task that is chosen for this task is task C. However, as the passenger is unconscious, the assessed proportion of effect for EPC 2 will be one compared to 0.8 since the operator will have to act faster. For EPC 10 and 16, the assessed proportion of effect will, however, be the same. The fianl HEP is seen in table 6.8.

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#4.3	0.16	#2	11	1	11	**1**
		#8	6	0.3	2.5	
		#16	3	0.3	1.6	

Table 6.8: Instruct passengers to pull the person back on board

6.4.10 Contact emergency center

Contacting the emergency department is an easy task requiring a low level of skill, and it is believed to be routine in such situations. Based on that, the generic task E is chosen with a HEP of 0.02. The only EPC that will affect the performance of this task is EPC 2. The assessed proportion of effect on this EPC is set to 0.3 since the task does not take much time to perform and is not a complex task for the operator to perform. Final HEP is given in table 6.9.

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#5.1	0.02	#2	11	0.3	4	**0.08**

Table 6.9: Contact emergency center

6.4.11 Contact emergency center and coast guard

Contacting the emergency center and the coast guard is assumed to be the same as only contacting the emergency center. The effect of EPC 2 could arguably be a little bigger; however, in this thesis, it's assumed to be equal. The final HEP is seen in table 6.10

Task	Generic Task HEP	EPC#	Multiplier	Assessed Proportion of Effect	Assessed Effect	Final HEP
#5.2	0.02	#2	11	0.3	4	**0.08**

Table 6.10: Contact emergency center and coast guard

6.4.12 HEPs summarized

Task	Generic HEP
Notice alarm	HEP = 0.09 = 9 %
Identify cause of alert	HEP = 0.1 = 10%
Locate passenger	HEP = 0.54 = 54%
Evaluate passengers state, conscious or unconscious	HEP = 0.36 = 36%
Activate remote control	HEP = 0.08 = 8%
Ensure ferry not sailing or drifting away from passenger	HEP = 1 = 100%
Cooperate with passengers to get person fallen overboard back on board	HEP = 1 = 100%
Get the bow of the ferry close to passenger	HEP = 1 = 100%
Instruct passengers to pull the person back on board	HEP = 1 = 100%
Contact emergency center	HEP = 0.08 = 8%
Contact emergency center and coast guard	HEP = 0.08 = 8%

Table 6.11: HEPs summarized - Man overboard

6.4.13 Probability of succeeding

The probability of each end event occurrence is given in figure 6.7. Out of the five different possible outcomes, two were found to not be possible in neither of the scenarios where it found that the operator was able to assist the passenger back onboard the ferry. Meaning that end events C1 and C2 had a zero percent chance of occurring. Consequently, the operator will not be able to succeed completely, which can be seen in figure 6.4, where there is a zero percent chance for the green scenario being the outcome.

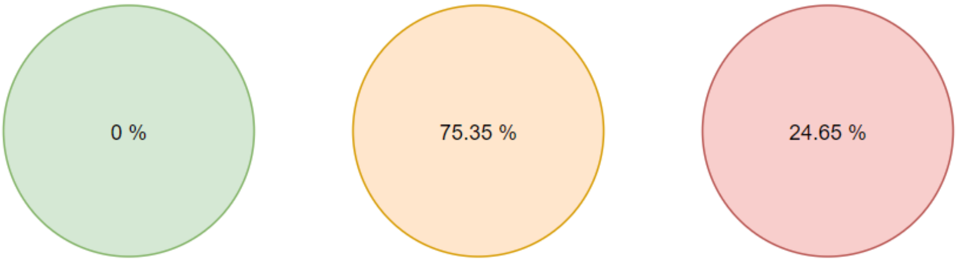

Figure 6.4: Success rate - man overboard

One important detail to highlight is that the Conscious, Not conscious events in figure 6.7, are given a 50% chance of occurring. That number was used as the actual probability of each event was uncertain. This simplification was made as the probability of the passenger being unconscious or conscious is not relevant in relation to the operator being able to perform his tasks. That being said figure 6.4, shows that the added probability for complete success is zero, the probability of a partial success is 75.35%, and the probability for a complete failure is 24.65%. That means that the operator will be able to partially complete his tasks the majority of the time. However, looking at figure 6.7, the end event that this partial success probability is composed of is C3. The operator is not able to assist the passenger in getting back on board but is able to contact the emergency center and the coast guard. That is more or less the same outcome as in the other two cases. The operator cannot solve the situation himself but can contact assistance with more experience.

Again, it seems that time is the most significant contributing factor to the operator not fully succeeding. Not only because time is so limited but also because of the major effect that time has on the HEP. For example, EPC 2, shortage of time, can, if the assessed proportion of effect is set to 1, be as high as 11. That is almost twice as high as all the other EPC used in this thesis, which means finding a way to provide the operator with more time is of the uttermost importance. The effect of removing the time factor has been calculated and is presented in figure C.1.1, in appendix C.

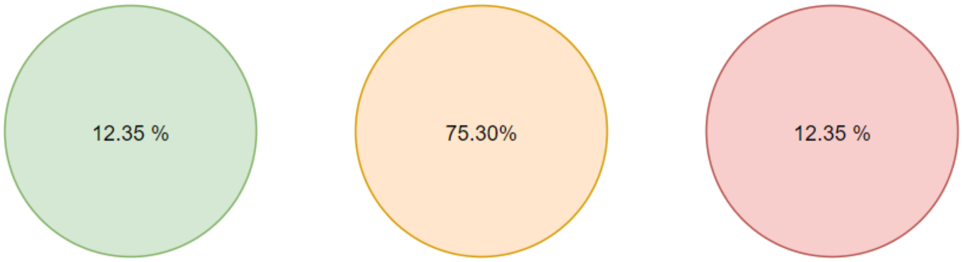

Figure 6.5: Success rate, EPC 2 removed - man overboard

Figure 6.5 shows that by removing EPC 2, the probability of a complete success increases from 0% to 12.35%, while the probability of failure is reduced from 24.65% to 12.35%. The probability for partial success does, however, seem almost unchanged. This shows that even though the effect of EPC 2 is removed, the operator still doesn't have a good chance of solving the problem himself. However, it does increase the probability that the operator does not completely fail from 75.35% to 87.65%. If further changes were made to reduce the effect of the other EPCS or to remove them completely, then this number would increase somewhat more.

It is, however, not that many changes that can be made to increase the amount of time the operator has. This has been discussed in the other two cases as well, which is why it might be more ideal for the number of tasks to be reduced instead. The effect would possibly, as mentioned earlier, be that the shortage of time could be removed. The effect would then be an 87.4 % chance that the operator partially succeeds and a 12.6 % chance that he fails. The results are displayed in figure 6.6.

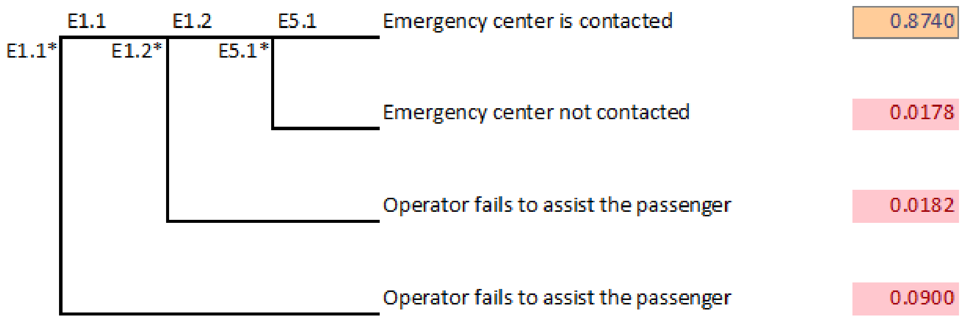

Figure 6.6: End event, tasks reduced - man overboard

So if it is possible to find a way to increase the time the operator has available, then it would be better for the operator to attempt to assist the passenger. However, if that is not possible, he should instead attempt to get the passengers' professional assistance instantly. This will then decrease the probability of failure by approximately 50%.

6.4.14 Recommended changes

Many changes can be made to reduce the probability that of this situation occurring. However to improve the operator's success rate can be more problematic. As for EPC 10 and 8, the same changes as mentioned in the collision avoidance case could be implemented.

When it comes to the time factor, EPC 2, then there are fewer improvements that can be made. However, one improvement would be to install a sensor capable of recognizing a person as a passenger. Then if someone falls overboard, the sensors would be capable of determining that this is not a swimmer or an obstacle but a passenger that has fallen over board. The complexity of such a sensor is beyond the scope of this paper. However, if such a sensor is possible to install, this would increase the time available somewhat as the sensors' response time would be much higher than that of the passengers on board the ferry.

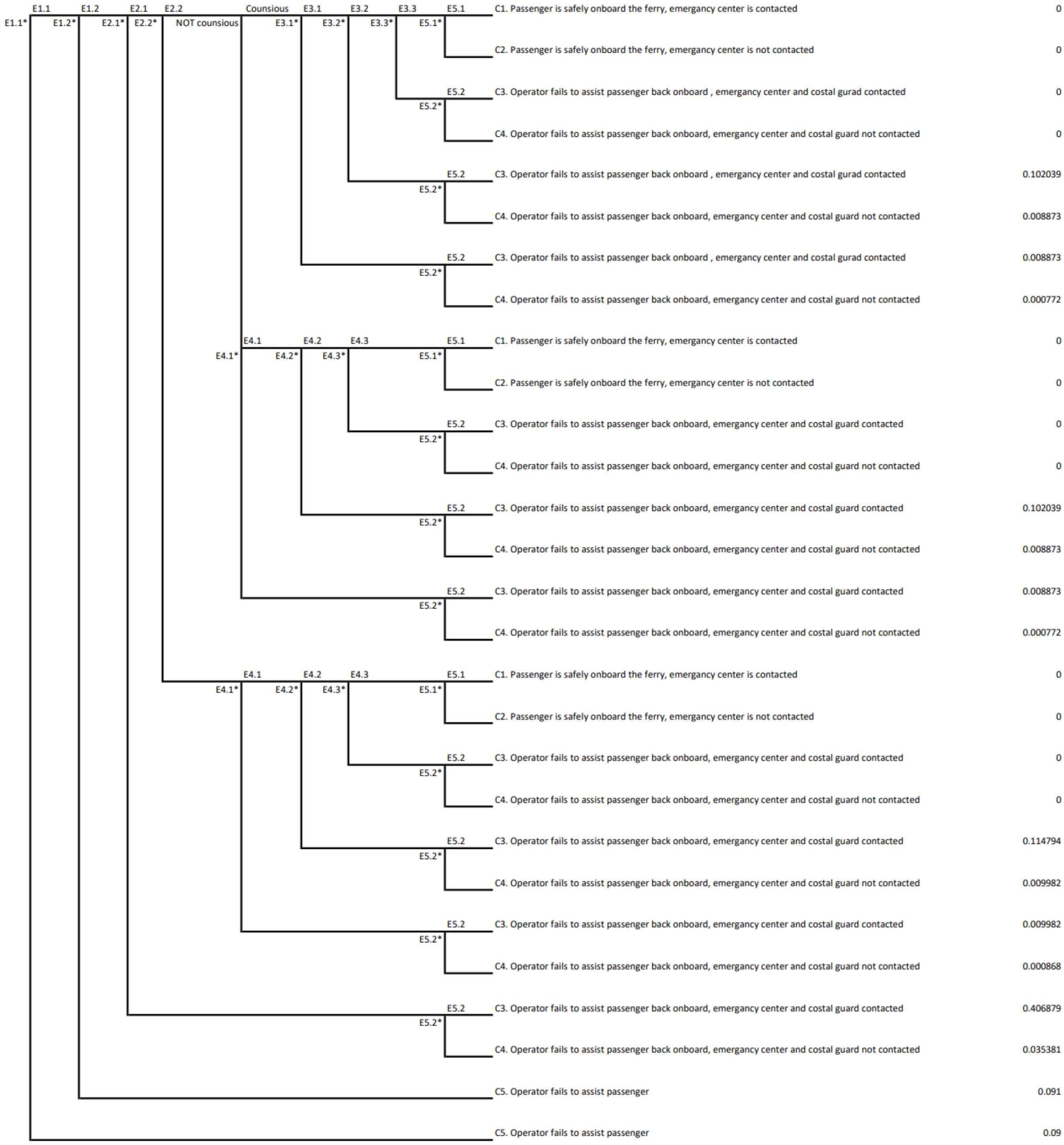

Figure 6.7: End event probabilities - man overboard

Chapter 7

Discussion

7.1 Results

In all three cases looked into, the operator was never able to resolve the problem. What was evident is that time was the most significant contributing factor to the operator failing completely. By removing this EPC, the probability of failing more than halved in two of the cases and approximately halved in the last one. However, in the first case, collision avoidance, the operator was still not able to fully succeed and thereby avoid the collision. This was, however, mainly due to the assessed proportion of effect of the other EPCs, which could have been done something about if changes are made to the display of information. In the other two cases, however, the operator was able to completely succeed given the removal of EPC 2. The major problem that was found was nonetheless the fact that it would not be possible to provide the operator with more time to perform each task, which then makes it impossible for the operator to succeed completely. Based on that, it was found that the removal of all tasks between identifying the cause of the alarm until contacting for assistance would be the most reasonable decision. Doing that would provide the operator with more time to perform each of the remaining tasks and thereby decrease the probability of failure.

7.2 Assumptions and limitations

Through the development of this thesis, assumptions have been made. These assumptions might have been wrong, which then will have had a negative impact on the results. For instance, it was assumed that by reducing the number of tasks, the operator would be left with enough time to complete each task without the effect of EPC 2 being significant. Rather this is a reasonable assumption or not, has not been evaluated. Several other assumptions have also been made, such as which tasks the operator should perform and the assessed proportion of effect that the EPC has on the different tasks.

As for the task analysis, every task that the operator has to perform in the three different cases is based chiefly on own judgment. This leaves room for errors as the actual procedure created by the developer might be very different. For the human error probabilities determined for each task, the limitations lay within the method. The HEART metode relies primarily on expert opinions and the users' ability to determine the most fitting generic task with corresponding EPCs, as well as his ability to determine the appropriate assessed proportion of effect. This leaves room for different opinions, which then results in different outcomes. Therefore the results gotten in this thesis might differ depending on the person, and will to a large extent, rely on extensive experience for optimal results.

One of the most significant limitations in this thesis is, as mentioned in the introduction, the fact that the ferry is under development. Changes are constantly being made, which changes both the ability of the autonomous system and the tasks required to be performed by the operator. One of the changes that were made was the implementation of fire extinguishers in each compartment under the deck—these work by being automatically activated as the temperature in a compartment increases above a certain amount. The implementation of these will affect the task analysis made in the fire case. However, as this information became known during a visiting tour of the ferry after the report was finalized, this has not been accounted for in this thesis.

7.3 Further work

It is suggested that for further work, the reliability of the operator is to be re-evaluated after all details of the ferry have been determined. This will allow for a complete HRA to be performed that represents a more realistic representation of the operator's success rates.

Another factor to consider is to which extent the operator will be intervening. As all capabilities of the autonomous system are not completely clear, it can be hard to determine the role the operator will play and to what extent he will be intervening. Having this clearly defined before performing the task analysis could increase the accuracy of the HRA.

Lastly, it could be interesting to see if using different methods for HRA would result in completely different outcomes.

Chapter 8

Conclusion

A human reliability analysis, HRA, has been carried out to determine the reliability of the operator in an emergency. Three different cases where the operator would have to intervene were chosen to be investigated. These include the ferry being on a collision course towards another vessel, a fire emerging on board the ferry, and third, one of the passengers falling overboard.

The results were found to be negative in the sense that the operator would not be a reliable source of protection in emergencies. The operator was not able to resolve the situation or to get the passengers out of harm's way. The only reliable task that the operator was able to perform was to notice the distress signal, identify the cause, and get in contact with assistance, such as the fire and emergency department.

In each of the three cases, limited time was determined to be the most significant contributing factor to lower reliability. It was found that by removing the effect of limited time on the operator's ability to perform a task successfully, he would in two out of the three cases be able to successfully solve the hazardous situation. However, each of the three cases contains problems that require fast-paced decisions and actions to be taken instantly. The result is then a very short interval for the operator to act and solve the situation.

All things considered, it was found that the removal of tasks that the operator was not able to perform successfully would provide the operator with more time to perform the remaining tasks. This would, in each case, improve the operator's reliability for successful performance.

Based on the results, it was concluded that operators' roles in emergencies should be minimal. The operator is put into a difficult scenario with very low time acquiring situational awareness and acting. The probability that the operator is able to complete all his tasks successfully were found to be zero, and the probability for partial success was 100% composed of the operator being able to contact for assistance only. Therefore, it is determined that the operator's role should be set to monitor the situation and contact specialized assistance instantly. This will result in the operator having more time to perform his tasks and decrease failure by 50% or more.

References

[1] Anne Sophie Ness Tord Tørressen Spencer Dugan. *Risk Analysis and Safety Management in MaritimeTransport*. 2019.

[2] Marvin Rausand Stein Haugen. *Risk Assessment Theory, Methods, and Applications*. John Wiley & Sons, Inc, 2020.

[3] Tord-eskil Hannevik Tørressen. *Big Orange XVIII Barrier Failures and Barrier Management*. 2020.

[4] Bergensentrum. *Beffen – Bergen kystkultursenter*. URL: https://www.bergensentrum.no/bedrift/beffen/.

[5] Atle Bjørnar Bratset. *Sundbåtselskapet søker ny daglig leder*. URL: https://www.ksu247.no/sundbatselskapet-soker-ny-daglig-leder.

[6] Morten Breivik. *Autoferry*. URL: https://www.ntnu.edu/autoferry.

[7] DrEduardo Calixto. *Human Reliability*. URL: https://www.sciencedirect.com/topics/engineering/human-reliability.

[8] Egil Eide. *MilliAmpère – Norges første førerløse ferje*. URL: https://www.sdir.no/globalassets/sjofartsdirektoratet/fartoy-og-sjofolk---dokumenter/ulykker-og-sikkerhet/sjosikkerhetskonferansen-2018/sjosikkerhetskonferansen_2018_foredrag_1_25_egil_eide.pdf.

[9] Egil Eide. *The Development of an Autonomous Shuttle Ferry in Trondheim*. URL: https://www.ntnu.edu/documents/1278511297/1282174090/6_sess2-Eide.pdf/8314c17e-e17f-4fb4-a006-118519984c5e.

[10] EnBlaaTraad. *Revitalisering av Ravnkloa, parallelloppdrag*. URL: http://xn--enbltrd-hxac.no/ravnkloa-parallelloppdrag/.

[11] hjerteplanen. *Bro ved Ravnkloa*. URL: http://hjerteplanen.no/prosjekter/hjertepromenaden/bro-ved-ravnkloa/.

[12] Erik Holand. *Hvordan bruke 20 millioner paa ny elferje når jolbjorn II kan elektrifiseres for en brokdel*. URL: https://www.agderposten.no/okategoriserade/hvorfor-bruke-20-millioner-pa-ny-elferje-nar-kolbjorn-iii-kan-elektrifiseres-for-en-brokdel/.

[13] MARIUS KNUTSEN. *Plans for an autonomous world first*. URL: https://maritimecleantech.no/2020/06/02/plans-for-an-autonomous-world-first/.

[14] Malcolm Latarche. *What are the benefits of adopting autonomy technology for the maritime industry?* URL: https://shipinsight.com/articles/what-are-the-benefits-of-adopting-autonomy-technology-for-the-maritime-industry/.

[15] minbox. *CONTINGENCY PLAN FOR MAN OVERBOARD*. URL: http://marineinbox.com/marine-exams/contingency-plan-for-man-overboard/.

[16] Nopsema. *HUMAN RELIABILITY ANALYSIS*. URL: https://www.nopsema.gov.au/resources/human-factors/human-reliability-analysis/#:~:text=The%5C%20concept%5C%20of%5C%20Human%5C%20Reliability,error%5C%20for%5C%20a%5C%20given%5C%20task.

[17] Sondre oeie. *Study of the risks and regulatory issues of specific cases of MASS – Part 1*. URL: http://www.emsa.europa.eu/emsa-documents/latest/item/3892-safemass-study-of-the-risks-and-regulatory-issues-of-specific-cases-of-mass.html.

[18] Oernulf Jan Roedseth. *DEFINING SHIP AUTONOMY BY CHARACTERISTIC FACTORS*. URL: https://sintef.brage.unit.no/sintef-xmlui/bitstream/handle/11250/2599931/Rodseth_etal15653.pdf?sequence=1&isAllowed=y.

[19] CIAOTECH Srl. *EU to finance autonomous shipping initiative for european waters*. URL: https://www.onthemosway.eu/eu-to-finance-autonomous-shipping-initiative-for-european-waters/.

[20] Marvin Rausand Stein Haugen. *Risk Assessment 9. Preliminary hazard analysis*. URL: https://www.ntnu.edu/documents/624876/1277591044/chapt09-pha.pdf/8c56b9d5-2863-4a55-a621-562e7c5456da.

[21] Tore Stensvold. *Nå seiler Moss-Horten-ferga autonomt på de fleste turene*. URL: https://www.tu.no/artikler/na-seiler-moss-horten-ferga-autonomt-pa-de-fleste-turene/501412?fbclid=IwAR3rlq_7Hviplou3nxAXQtOKSTZh7ruOW D4zBYD4.

[22] Kystlaget Trondhjem. *Levende - eller død - Kanalhavn?* URL: http://www.kystlaget-trh.no/wp-content/uploads/2014/03/Kystlaget-Trondhjem-Broplan-Ravnkloa-2014-03-21.pdf.

[23] Ingrid Bouwer Utne. *Collision avoidance on maritime autonomous surface ships Operators tasks and human failure events*. URL: https://www.sciencedirect.com/science/article/pii/S0925753518312669?via%5C%3Dihub.

[24] Ingrid Bouwer Utne. *Risk, risk analysis and risk modeling*. URL: https://learn-eu-central-1-prod-fleet01-xythos.content.blackboardcdn.com/5def77a38a2f7/6099334?X-Blackboard-Expiration=1606856400000&X-Blackboard-Signature=lfovna20L57IFVsGc%5C%2BJ15C7UASTsfvjDYJ4B2nnfe
5C%3D&X-Blackboard-Client-Id=303508&response-cache-control=private%5C%2C%5C%20max-age%5C%3D21600&response-content-disposition=inline%5C%5C%5C%3B%5C%20filename%5C%2A%5C%3DUTF-8%5C%27%5C%27Lecture%5C%2520-Overview%5C%2520risk.pdf&response-content-type=application%5C%2Fpdf&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Date=20201201T150000Z&X-Amz-SignedHeaders=host&X-Amz-Expires=21600&X-Amz-Credential=AKIAZH6WM4PL5M5HI5WH%5C%2F20201201%5C%2Feu-central-1%5C%2Fs3%5C%2Faws4_request&X-Amz-Signature=899c9e9e455eecc1c33f08be17ccd5

[25] Vanderley de Vasconcelos. *FN-CURVES: PRELIMINARY ESTIMATION OF SEVERE ACCIDENT RISKS AFTER FUKUSHIMA*. URL: https://inis.iaea.org/collection/NCLCollectionStore/_Public/47/017/47017692.pdf.

[26] Wikipedia. *Beffen*. URL: https://no.wikipedia.org/wiki/MF_%5C%C2%5C%ABBeffen%5C%C2%5C%BB.

[27] Wikipedia. *International Regulations for Preventing Collisions at Sea*. URL: https://en.wikipedia.org/wiki/International_Regulations_for_Preventing_Collisions_at_Sea.

[28] Wikipedia. *Kolbjorn III*. URL: https://no.wikipedia.org/wiki/MF_%5C%C2%5C%ABKolbj%5C%C3%5C%B8rn_III%5C%C2%5C%BB.

[29] Wikipedia. *Sundbåten*. URL: https://no.wikipedia.org/wiki/Sundb%5C%C3%5C%A5ten.

[30] Williams. *Human Error Assessment Reduction Technique (HEART)*. URL: https://www.epd.gov.hk/eia/register/report/eiareport/eia_2242014/EIA/app/app12.10.pdf.

[31] Zeabuz. *NTNU and the milliAmpere ferries*. URL: https://zeabuz.com/miliampere/.

Appendix A

Success and failure calculations - Collision

A.1 Collision avoidance - Time shortage removed

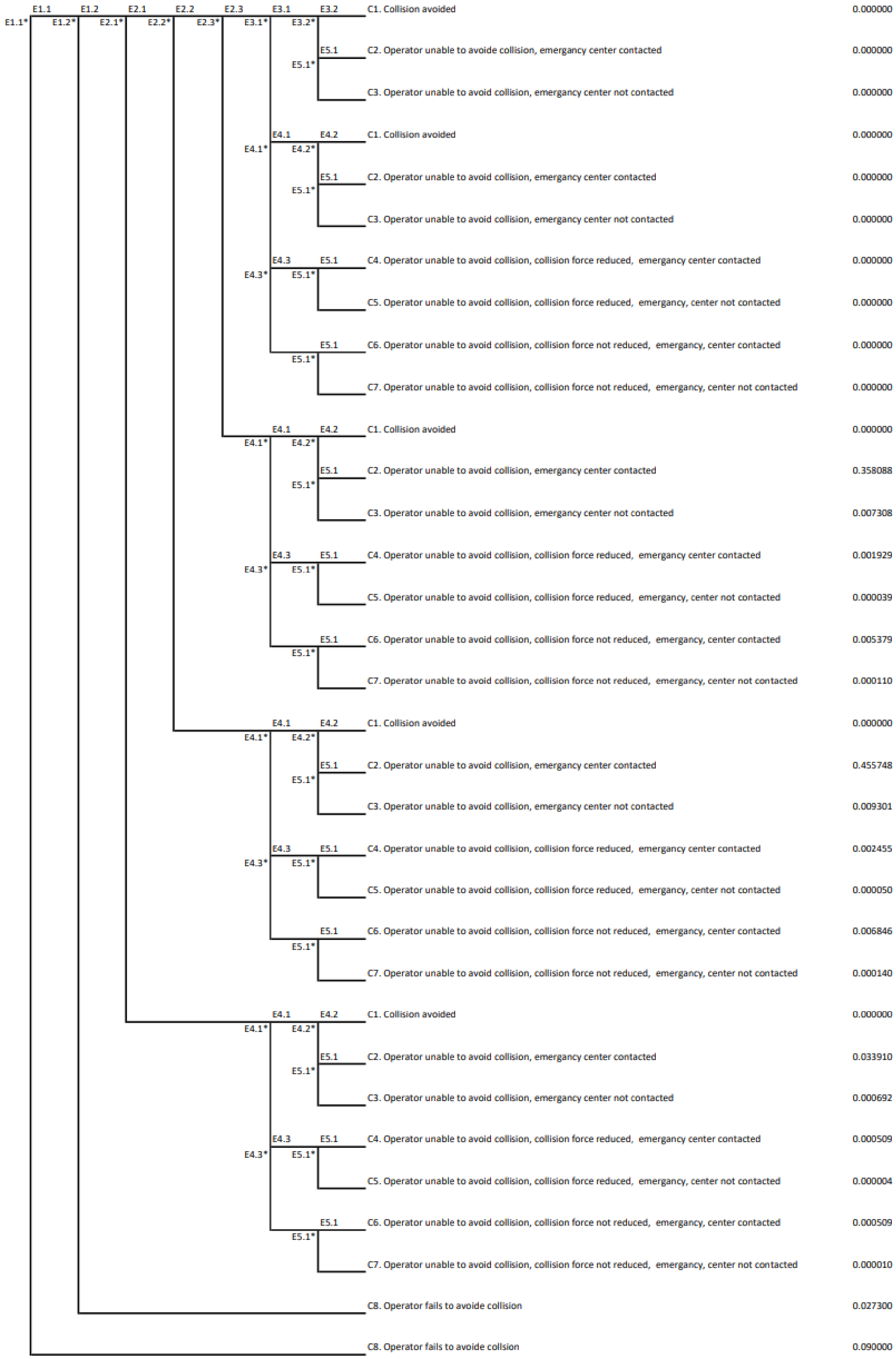

Figure A.1.1: End Event probabilities - shortage of time removed

A.2 Collision avoidance - Task number reduced

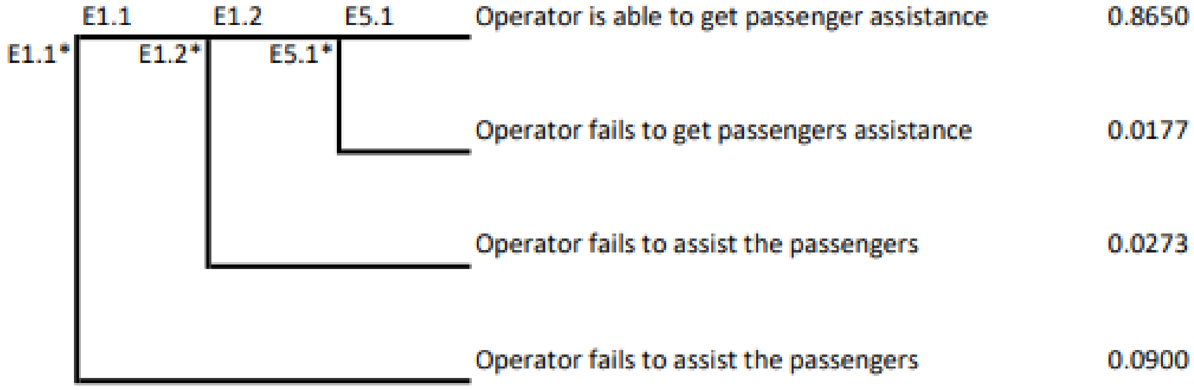

Figure A.2.1: End Event probabilities - tasks reduced

Appendix B

Success and failure calculations - Fire

B.1 Time shortage removed

Figure B.1.1: End Event probabilities - time shortage removed - FIRE

Appendix C

Success and failure calculations - Man overboard

C.1 Time shortage removed

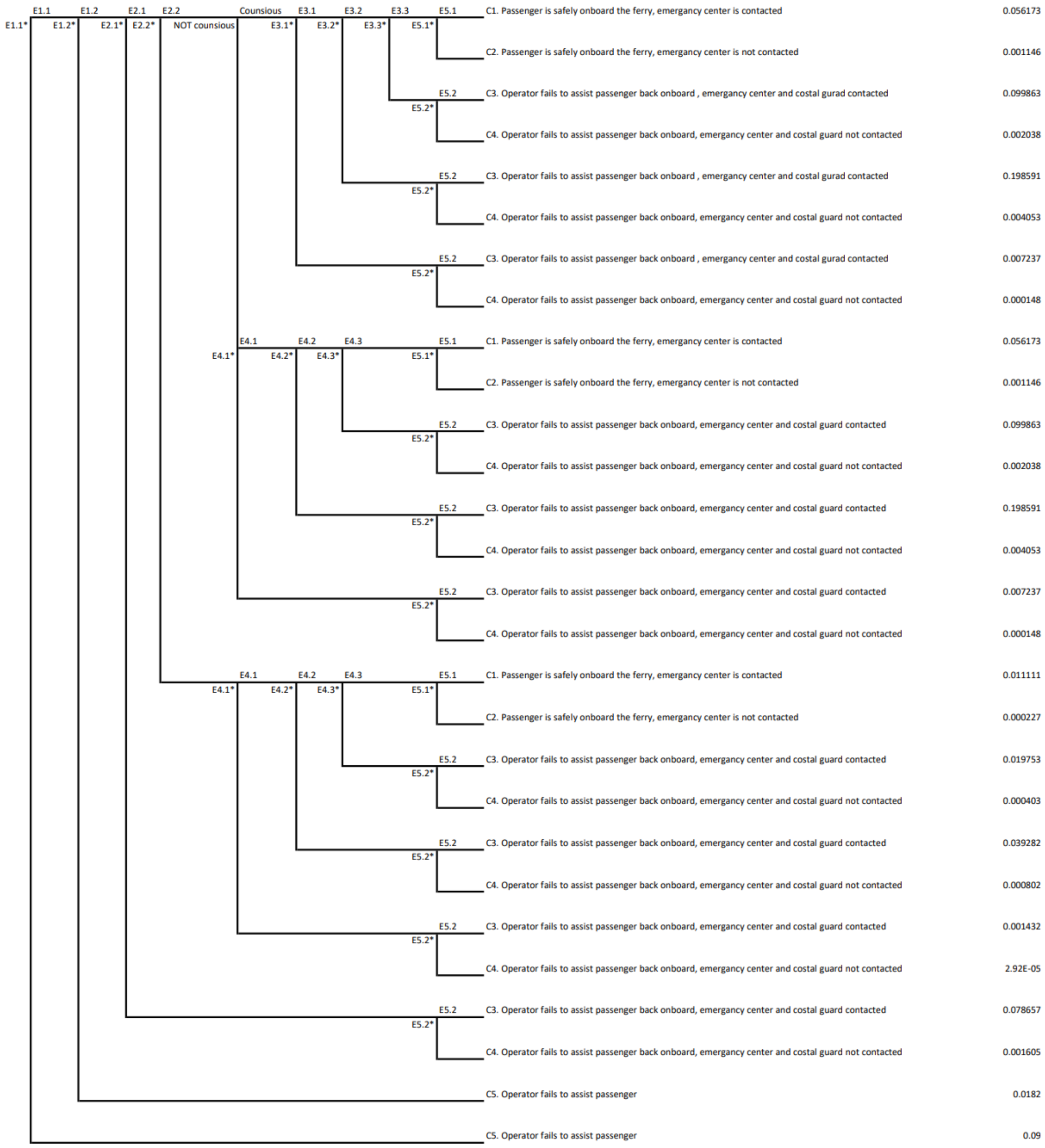

Figure C.1.1: End Event probabilities - time shortage removed - Man overboard