Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Computer Science

Maria Iqbal

Rule-Based Reasoning for Decision Support in Search and Rescue

Master's thesis in Information systems
Supervisor: Pinar Øzturk
May 2021

NTNU
Norwegian University of Science and Technology

Maria Iqbal

Rule-Based Reasoning for Decision Support in Search and Rescue

Master's thesis in Information systems
Supervisor: Pinar Øzturk
May 2021

Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Computer Science

NTNU
Norwegian University of
Science and Technology

ABSTRACT

Implementation of Artificial Intelligence (AI) can revolutionize search and rescue (SAR) missions by generating profound situational awareness and prosecutable information for the first responders. This thesis, as part of the Master program *Information System* of The Department of Computer Science (*IDI)* at Norges Teknisk-Naturvitenskaplige Universitet (*NTNU)* that introduces a model which aims to support the integration of Artificial Intelligence (AI) in Search and Rescue (SAR) operations, thus called AISAR. AISAR's main purpose is to enhance the efficiency and performance of SAR, with a focus on offshore rescue operations. Therefore, we collaborated with *Hovedredningssentralen* (HRS), which is responsible for organizing and managing SAR activities on land, at sea and in the air in Norway.

Awareness is the initial and most important stage of any SAR operation, as it assesses the gravity of the reported emergency and classifies it in terms of uncertainty, alert, and distress. Here, we mainly focused on this most crucial awareness stage as its output tends to differentiate false alerts from an actual distress situation. In this thesis, we performed a thorough analysis of the awareness stage via identifying inputs, outputs and acquiring the knowledge involved for decision making purposes with the help of enterprise modelling.

The knowledge in this project is acquired through knowledge engineering and represented in form of rules, which are usually an implicit and tacit knowledge of domain experts. The knowledge engineering process led to the implementation of a rule-based decision support system model. Furthermore, this model is investigated for the integration of fuzzy logic to enhance the performance of the DSS in terms of accuracy.

Keywords: 4EM, Knowledge based decision support system, Rule-based decision support system, Fuzzy logic rule-based system, Knowledge engineering

ACKNOWLEDGEMENT

I would like to express my deep gratitude to my respected supervisor Pinar Øzturk for her expert guidance, considerate help, and timely feedback throughout my Master thesis. Her support and advice throughout the research not only help me acquire diversified knowledge in the domain of AI, despite of my limited background in the domain but also help me achieve the goal to great extent. I am also thankful for all my academic mentors who have helped me expand the horizon of my knowledge through different courses and research.

I would also like to pay my regards to Per Olaf Torkildsen and Andreas Bull who were our main contact at Hovedredningssentralen (HRS). As domain experts they have provided us with required information and access to logs of past operations that have proved to be valuable source of knowledge for the completion of the thesis.

At the end, I would like to thanks to my family especially to my mother and father for their support and motivation during this whole tenure.

Maria Iqbal
Trondheim, May 11, 2021

CONTENTS

1 Introduction..1
1.1 Problem Description..2
1.2 Research Questions..6
1.3 Research Method..6
1.4 Thesis Structure..7
2 BACKGROUND And LITERATURE REVIEW..9
2.1 Background..9
2.1.1 HRS Processes..9
2.1.2 Awareness Stage..16
2.1.3 Rule Based Decision Support System..17
2.1.4 Fuzzy Logic and Rule Based System...18
2.2 Literature Review...18
3 Knowledge Engineering For Sar..20
3.1 Knowledge Acquisition Process..23
3.2 Knowledge Engineering Methods..23
3.2.1 Interviews / Meetings...25
3.2.2 Procedure Manuals..27
3.2.3 Historical Data...29
4 The Knowledge Base Model...31
4.1 Attributes Based On The Type Of Incidents..31
4.1.1 Assistance Vessels..31
4.1.2 Drifting..32
4.1.3 Diving Incident...32
4.1.4 Medical Evacuation..33
4.1.5 Offshore Incident..33
4.1.6 Missing Vessel...33
4.1.7 Accident at Sea..34
4.2 Identifying The Rules For The Rule-Base...35
5 Implementation Of Rule Based System..36
5.1 Process Of Decision Making..36
5.2 Decision Support System..38
5.2.1 SAR Knowledge Acquisition..40
5.2.2 SAR Knowledge Representation...43

5.2.3 Rule-Based Decision Support System ... 48
6 Evaluation & Results ... 63
6.1 Testing Of Model ... 63
6.2 Results ... 67
6.2.1 Observations ... 67
7 Discussion ... 71
7.1 Modelling Of Standards Sar Processes ... 71
7.2 Knowledge Acquisition And Representation Through KE ... 72
7.3 Rule-Based Model For Assessment Of Emergency ... 73
8 Conclusion ... 76
8.1 Conclusion ... 76
8.2 Future Work ... 77
Bibliography ... 79
9 APPENDIX ... 81

TABLE OF FIGURES

Figure 1: The map shows the Norwegian rescue responsibility area marked in grey color. The area covers the Norwegian sea and parts of the Barents Sea and North Greenland Sea. After JRCC Cooperation Manual [4] 1
Figure 2: Statistics for sea accidents as published in report by General Director JRCC [23] 3
Figure 3: The figure shows the maximum survival time in hours, in water in relation to water temperature. Source: IAMSAR Vol.II. 4
Figure 4: Overall SAR system communication 9
Figure 5: HRS Process Model (The details for symbols and color in model are shown above where processes are represented by orange areas while sub tasks/activities are represented by yellow-colored shapes. Parallelograms represent information from one process to another. [(Iqbal, 2019)]) 11
Figure 6: Awareness stage goals (Showing types of sea emergencies and classification of reported incident) 16
Figure 7: Basic Architecture of a rule-based expert system [21] 17
Figure 8: Awareness Process Model 21
Figure 9: Sample Mapping of Incident for Awareness Stage: Eclipse depicts processes or phase declared, diamond shows decision points. 22
Figure 10: Mind map for Knowledge Base 24
Figure 11: Flow Diagram from Nordavind where process is shown where green color shows the uncertainty stage, blue color shows the alert stage and pink color shown when the emergency is confirmed, and distress stage is declared. 37
Figure 12: Basic input/output for rule-based DSS 39
Figure 13: Workflow for implementation process from knowledge acquisition to decision from rules. 40
Figure 14: KE sources for SAR 41
Figure 15: Decision tree for Attribute and responses: Different colors of the nodes indicate the certainty of the information that is green color exhibits uncertainty, blue is for alert and red is for distress. 42
Figure 16: The four types of rules used in taxonomy. 45
Figure 17: Rule-based DSS framework 49
Figure 18: Search Urgency Assessment form (NATSAR Manual) 52
Figure 19: Assessment of urgency 53
Figure 20: Flow Diagram for implementation 54
Figure 21: Possible combinations for responses of all identified attributes 60
Figure 22: Fuzzy rule attributes for evaluation on emergency state 62
Figure 23: Result depiction 65

LIST OF TABLES

Table 1: Identification of the Attributes for rule based DSS. 27
Table 2: Source Level Trust 47
Table 3: Attributes and weights 56
Table 4:Emergency assessment 57
Table 5: Test Case 64
Table 6: Test Case 2 66
Table 7: Attribute priority assessment survey for different types of incidents 69

ACRONYM USED IN THESIS

SAR	Search and Rescue
AI	Artificial Intelligence
AI-SAR / AISAR	Artificial Intelligence in Search and Rescue
IAMSAR	International Aeronautical and Maritime Search and Rescue Manual
HRS	Hovedredningssentralen
JRCC	Joint Rescue Coordination Centers
RCC	Rescue Center Coordinator
ES	Expert System
CBR	Case Based Reasoning
DSS	Decision Support System
RBS/ FRBS	Rule Based System / Fuzzy rule-based system
KE	Knowledge Engineering
CRS	Coastal Radio Service
IMO	International Marine Organization
AIDSS/ RBDSS	Artificial Intelligence Decision Support System/ Rule Based Decision Support System
PoB	Person on board / People on board
EM	Enterprise Modelling
NLP	Natural Language Processing

CHAPTER ONE

1 INTRODUCTION

The significance of saving lives in emergency situations and providing search and rescue (SAR) services to people in distress is a basic humanitarian necessity. Thus, all around the world, strategies of SAR are acknowledged, and their importance is emphasized in IAMSAR Manual Volume 1 section 1.1.1 [1]. In Norway, search and rescue services are conducted through cooperation between government agencies, voluntary organizations, and private companies who are equipped with right resources for rescue services [3]. The two Joint Rescue Coordination Centers (JRCC) managed by Hovedredningssentralen (HRS) are responsible for conducting search and rescue operations through 28 rescue sub centers in Norway [3]. Figure 1 shows the Norwegian Search and Rescue Region (SRR), for which HRS is responsible [4].

Figure 1: The map shows the Norwegian rescue responsibility area marked in grey color. The area covers the Norwegian sea and parts of the Barents Sea and North Greenland Sea.
After JRCC Cooperation Manual [4]

The rescue operations which are steered by Hovedredningssentralen (HRS) and other stakeholders that are challenging and time sensitive. Therefore, these operations require an accurate information and prompt response for successful completion. HRS together with the software company, InSoft, and NTNU has envisioned a project idea called "Artificial Intelligence for Search and Rescue (AI-SAR)", where a decision support system (DSS) is to be developed for assistance of the SAR operations.

This Master thesis study is conducted in relation to the AI-SAR Project and comprises of an of an elementary analysis for the awareness stage of SAR activities. The target DSS system in AI-SAR project is intended to employ different Artificial Intelligence (AI) methods including Case Based Reasoning (CBR) system [10] and a Rule Based System (RBS). Following master thesis focuses on the use of the Rule-based approach for decision support. During my preliminary studies completed under the specialization project [22] prior to this Master thesis, I have investigated different modeling approaches and devised a unified model for the rule-based component of the project. The model is defined using the enterprise modelling language 4EM. In addition to the portrayal of the processes and procedures of Search and Rescue (SAR) stages it also helps to define the requirements for the AI-SAR decision support system. This study translates the requirements related to the Business rule model of 4EM to the rule-based system component of the DSS. For the building and using of rule base, which can be defined as specific type of knowledge base, the knowledge engineering techniques have been used. The knowledge engineering techniques involved all technical, scientific, and social aspects [5].

1.1 PROBLEM DESCRIPTION

Norwegian sea, Barents Sea and North Greenland Sea in the Arctic region have a great economical value, clustering a wide range of activities and industries. These include fishing, oil and gas exploration, mineral mining, cargo, tourism, recreational usage, scientific research, and military activities. This region offers different challenges for sea activities like extreme weather conditions, communication hazards, different types of ice, long distances, and absence of day light especially from November to February. The conditions also get exacerbated by the relatively long distances between harbors and other infrastructural facilities in wide parts of the Arctic Ocean. These challenges contribute to 5047 maritime SAR incidents recorded by JRCC North Norway from 2011 to 2016 [23]. Figure 2 shows the numbers of different types of incidents that required SAR operations in past few years. In the figure number of different types of SAR operations are depicted, performed by JRCC from year 2015 to year 2017 that include SAR operations on sea, land and air where aeronautical SAR operations are for accidents reported in air and air ambulance shows the SAR operations for medical emergency in air. The given data (Figure 2) indicates that the number of sea incidents are higher than land or air incidents. The Viking sky accident [32] is a well-known example for such a sea incident, in which the lives of 1373 people had to be saved on the sea under worst weather conditions and within a very limited timeframe. Other types of sea accidents include missing small vessels on open sea where prompt response from SAR is of great importance as these vessels usually have limited resources on board.

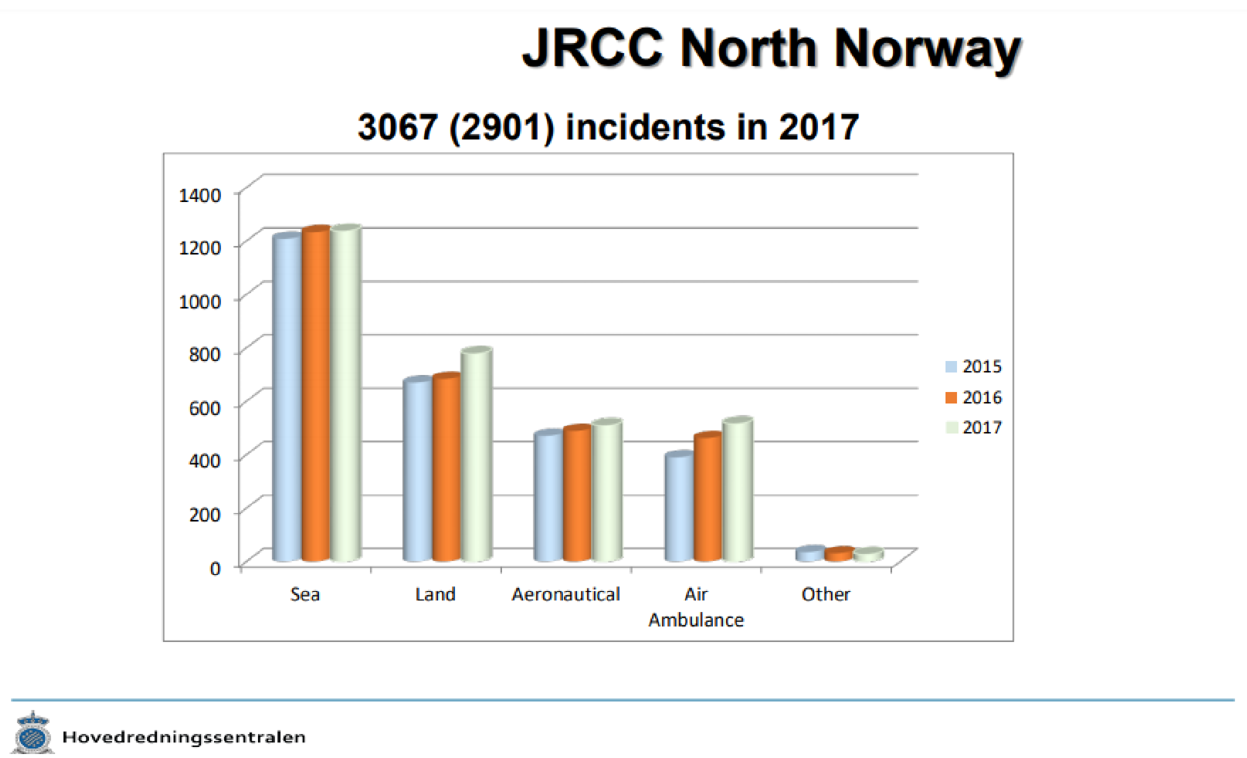

Figure 2: Statistics for sea accidents as published in report by General Director JRCC [23]

These examples show that the success of SAR operations during such incidents depends on the efficiency of their planning and execution. The prompt receipt of all available information by the Rescue Coordination Center (RCC) is necessary for a thorough evaluation of the situation, a quick generation of hypotheses, and ultimately an efficient decision-making leading to correct and successful SAR operations. Experience has shown that the survival chances of uninjured person on board diminish rapidly after the first three days when being missed on sea, whereas for the injured persons it decreases by as much as 80% after the first 24 hours of disappearance under the normal weather conditions and temperature of water (As shown in Figure 3).

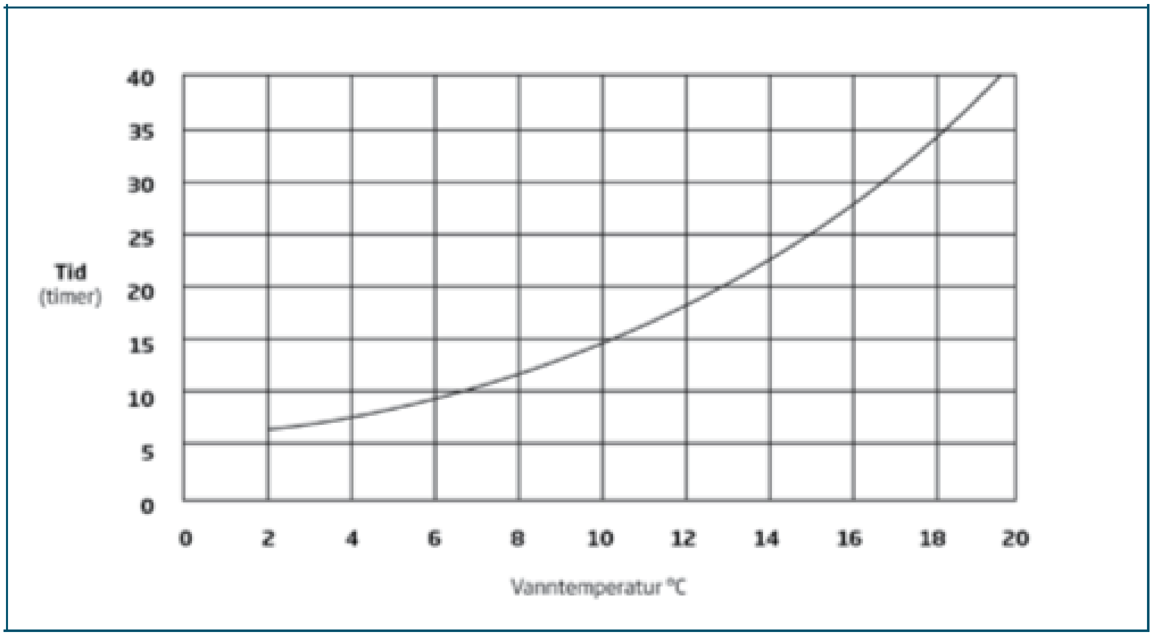

Figure 3: The figure shows the maximum survival time in hours, in water in relation to water temperature. Source: IAMSAR Vol.II.

Awareness: The response to a SAR incident usually proceeds through a specific sequence of stages. T These stages involve mental and physical activities typically performed by the SAR personnel in response to a SAR incident from the time, the system becomes aware of the incident until the response to the incident is concluded [2]. Awareness is the first and vital stage of the process, which is also the focus of this thesis and in which the SAR personnel assess the situation and its requirements for the immediate and emergent action. This stage includes evaluation and classification of information for the subsequent actions. The initial two stages of SAR operations that are awareness and initial action stages can be associated with any or all three of the emergency phases defined by International Maritime Organization of Canada, i.e., Uncertainty, Alert, and Distress [2] to be assessed in the Awareness stage of the process.

“Reactive” behavior is the need of the SAR process that aims to avoid casualties and loss of precious life. However, from the awareness stage the SAR problem solvers move towards a more cognitive approach. The cognitive analysis process is not only deliberative but also involve thorough assessment of situation, generating hypotheses about when-where-how, and planning for further actions.

False Alerts: Alongside assessment and classification of reported emergency, RCC also has to identify and distinguish false alerts from the actual emergency calls to avoid deviation during awareness stage. False alerts as stated in IAMSAR Manual Volume 1 section 4.2.2 [1] are any alerts received by the SAR system which indicate an actual or potential distress situation when no such situation actually exists. Potential cause of false alerts can include equipment malfunctions, interference, testing, and inadvertent human error. Otherwise, if a false alert transmitted deliberately is called a hoax. If alerts are not evaluated for their validity the possible strain on SAR system can increase which can result in increased risk to SAR personnel and also effect the credibility of alerting systems, However, as per SAR mandate it is important that SAR personnel treat every distress alert as genuine until they know differently as agreed in IAMSAR Manual volume 1, section 4.2.2 [1].

AISAR: Integration of Artificial Intelligence for decision making at the main rescue center intends to involve the use of technology and real-time data to achieve safer and faster decision-making in search and rescue operations. AI-SAR can prevent time loss, reduce potential human error, and avoid false alerts, through the implementation and optimization of human-machine interaction. Awareness stage is the base stage in which knowledge and experience of domain experts are the main source of decision-making processes regarding the assessment of reported incidents. The integration of decision support system to the stage aims to enhance the efficiency of these processes with increased accuracy. It also aims to make resources available for the later stages of the operations.

Based on this theoretical background, in this thesis we derived a model for decision support systems, which is facilitated by the knowledge driven through knowledge engineering processes. The process of knowledge engineering involves derivation and representation of knowledge for the rule-base from domain experts and other available resources.

1.2 RESEARCH QUESTIONS

The major goal of this thesis is to integrate the knowledge-based decision support system into the awareness stage of SAR processes. More specific research goals include:

Research Goal A: Modelling the standard SAR processes for awareness stage to acquire understanding of SAR processes and the data flow within them.

Research Goal B: Acquire knowledge to identify inputs and output for awareness stage along with target decisions for the rule-based DSS.

RQ2: Identification of the nature and characteristic of the type of data and information used in awareness stage and different SAR- subtasks, as per the emergency cases.

*RQ2***:** *How to acquire knowledge deploying knowledge engineering methods from domain experts and other available resources?*

RQ4: Identification of the attributes and representing the knowledge as rules for the rule-based DSS.

Research Goal C: Design the reasoning process based on RBS for emergency assessment and hypothesizing the phase of the reported incident based on the rules identified from knowledge engineering.

RQ 5: What value ranges of each attributes can be used as facts to assess the certainty of the incident reported?

RQ6: What approach and methodology can be used for the rule-based system (RBS) to assess the emergency?

RQ7: Can fuzzy-logic enhance the accuracy of emergency assessment of rule-based system?

1.3 RESEARCH METHOD

For our studies, we used the Design Science Research methodology which therefore got integrated with the knowledge engineering methodology. The six steps process of Design Science research as defined by Peffers et al. [25] was followed. The first step of the process is "Problem identification and motivation" in which the specific research problem is defined along with value of a solution as mentioned above in section 1.1. For defining the “Objectives of a solution” the necessary background knowledge was acquired through literature review and background research as defined in section 1.2 and chapter 2. The subsequent step that is “Design and development” was integrated with the Knowledge engineering process [29] through which the model of the solution was achieved and implemented. For the “Demonstration” and ‘Evaluation” the implemented relative model was evaluated with the test case and assessed for the accuracy of results obtained. The last step of the science research methodology that is “Communication” involved the discussion and future work in which the novelty of the solution was focused alongside the approach for achieving the absolute model from relative model of solution.

1.4 THESIS STRUCTURE

This thesis is divided into seven chapters:

1. **Chapter 1: Introduction**

   This chapter includes the introduction and motivation for the thesis project AI-SAR for Awareness stage. The problem description along with research goals and research methodology for the thesis is also defined in this chapter.

2. **Chapter 2: Background and Literature Review**

   The background study is made for the thesis to develop understanding of the SAR processes focusing on the initial stage of SAR that is Awareness stage. This chapter also documents the previous relevant work in the form of literature review and background study of the rule-based systems and its implementation in SAR.

3. **Chapter 3: Knowledge Engineering for SAR**

   This chapter presents the knowledge engineering model used for the acquisition of knowledge for the input and output of the intended process. The knowledge engineering methods for knowledge acquisition are also defined in the chapter that leads the knowledge model for the rule-based system.

4. **Chapter 4: The Knowledge Base Model**

In this chapter the knowledge model is defined that is achieved as the result of knowledge acquisition methods as defined in chapter 3. It documents the identification of relevant knowledge from the sources for design of the knowledge model.

5. **Chapter 5: Implementation of rule-based system**

   The implementation of the rule-based for Awareness stage of SAR is defined in this part. The representation of acquired knowledge in form of rules is also defined. This chapter also includes details regarding the alternative approaches for the implementation of the model and discussed the implemented relative rule based DSS model for the assessment of the emergency reported.

6. **Chapter 6: Evaluation and Results**

   In this chapter the results from the implemented DSS are obtained and discussed. The model is evaluated for accuracy of the results and implementation approach from relative to absolute model.

7. **Chapter 7: Discussion**

   In this chapter we have discussed the research of the thesis in terms of research goals and research questions as defined in chapter 1.

8. **Chapter 7: Conclusion**

   The last chapter concludes with the findings of the thesis and possibilities for the future work. The future work includes the suggestions for the integration of the technologies enhancing the efficiency and accuracy of suggested model.

CHAPTER TWO

2 BACKGROUND AND LITERATURE REVIEW

2.1 BACKGROUND

2.1.1 HRS Processes

Existing SAR operations work in collaboration with individual components that has to work in coordination with each other for successful SAR operations, as defined in IAMSAR Manual Volume 1 section 2.1.1 [1]. The communication among the components is the key requirement as shown in Figure 4. The four main components involved in the system of SAR communication and operation are Search and Rescue facility: Rescue Coordination Center (RCC) or Rescue Sub-center (RSC): Source of Alert, and Alerting post. All the facilities that are involved in receiving and relaying it to RCC or RSC are known alerting posts. RCC and RSC are operational facilities responsible for SAR services and operations. It is important that all components should provide prompt alerting information to Rescue center coordinator (RCC) for the timely dispatch of SRUs (Search Rescue Units) along with other resources and while searching the area and at the same time maintaining two-way communication with people in distress [2].

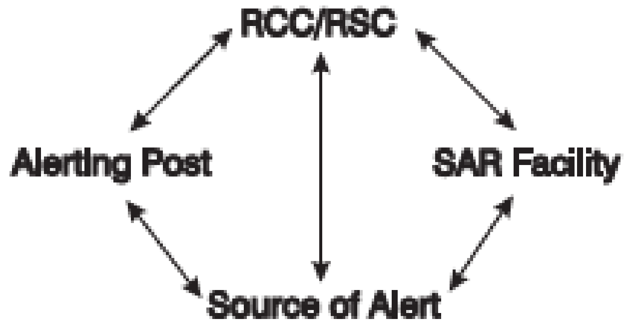

Figure 4: Overall SAR system communication

The communication process among all SAR components continues for the five stages of the SAR operations. The stages involved in SAR operation are modelled during the specialization project [22] as the preliminary studies of the project. The details of the stages are modelled as processes are shown in Figure 5, illustrating the distress call is initiated when emergency call is received at

HRS and they notify JRCC in case if situation may develop to an emergency situation in a shorter or longer term [4]. Activities for SAR operations are divided into 5 different stages that are Awareness, Initial Action, Planning, Operation and Conclusion. These stages are divided into different subprocesses that allow information flow from one stage to another. The details of the operations have been modelled as in Figure 5 where the highlighted area with “red box “in the figure shows the process of Awareness stage which will be explained in detail later.

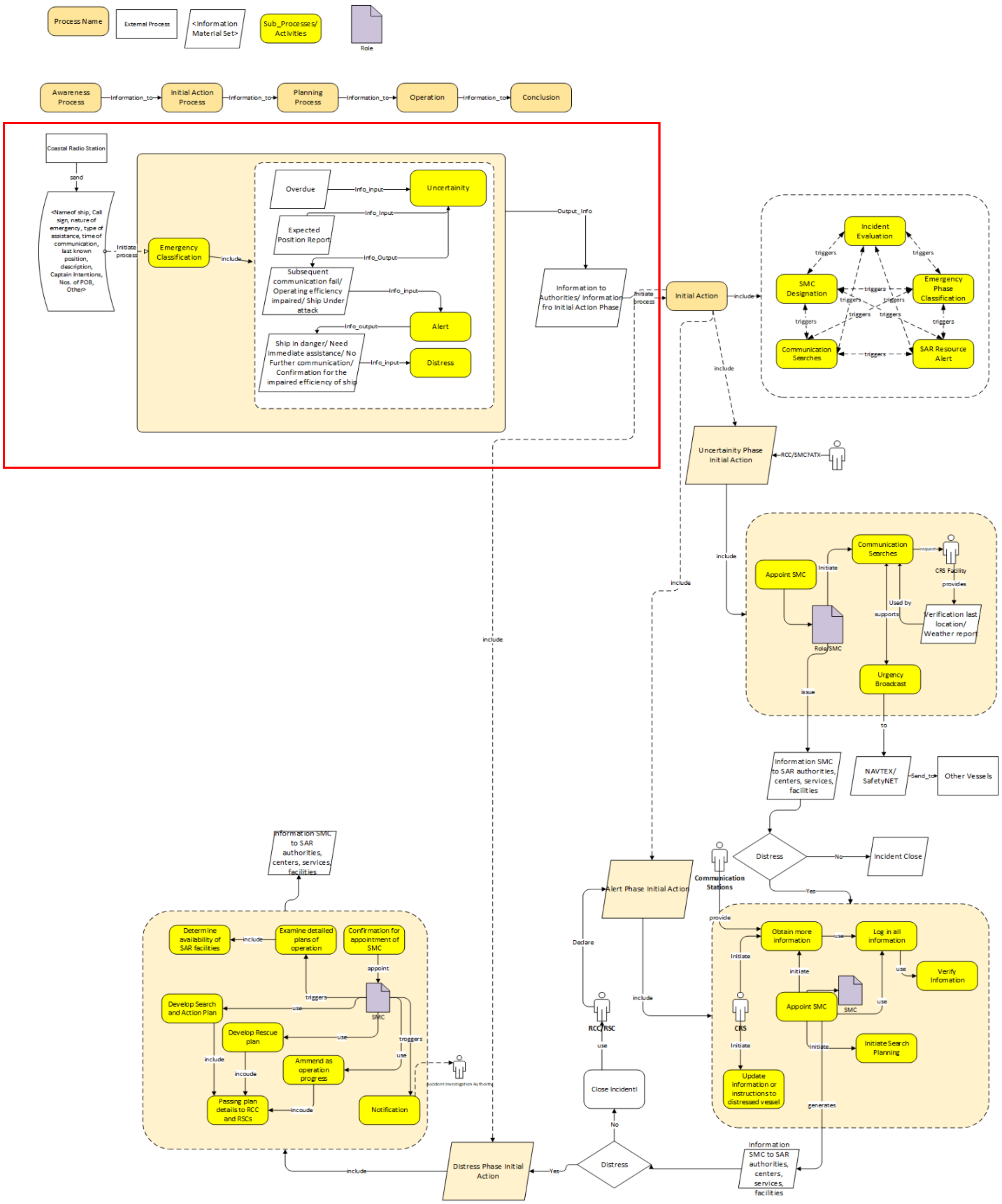

Figure 5: HRS Process Model

(The details for symbols and color in model are shown above where processes are represented by orange areas while sub tasks/activities are represented by yellow-colored shapes. Parallelograms represent information from one process to another. [(Iqbal, 2019)])

For the better visibility and understanding HRS process model as shown in Figure 5 is broken down according to processes involved into parts as shown below. As mentioned above the red box in Figure 5 depicts the Awareness Stage process and is elaborated in chapter 3. However, remaining processes in the Figure are shown below that include Initial action stage process model (Figure 5 A), Uncertainty phase initial action. Model (Figure 5 B), Alert phase initial action model (Figure 5 C) and Distress phase initial action model (Figure 5 D).

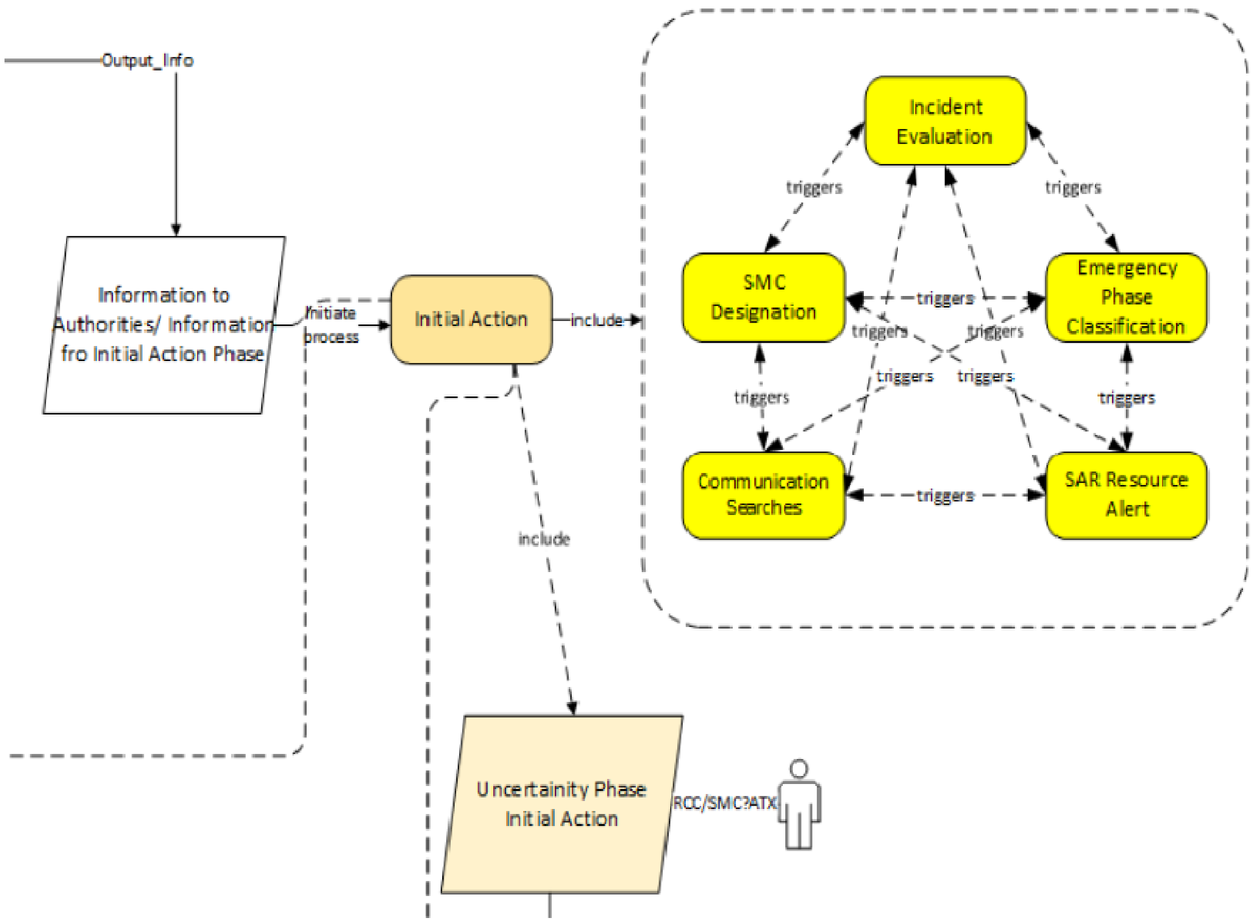

Figure 5 A: Initial action stage process model

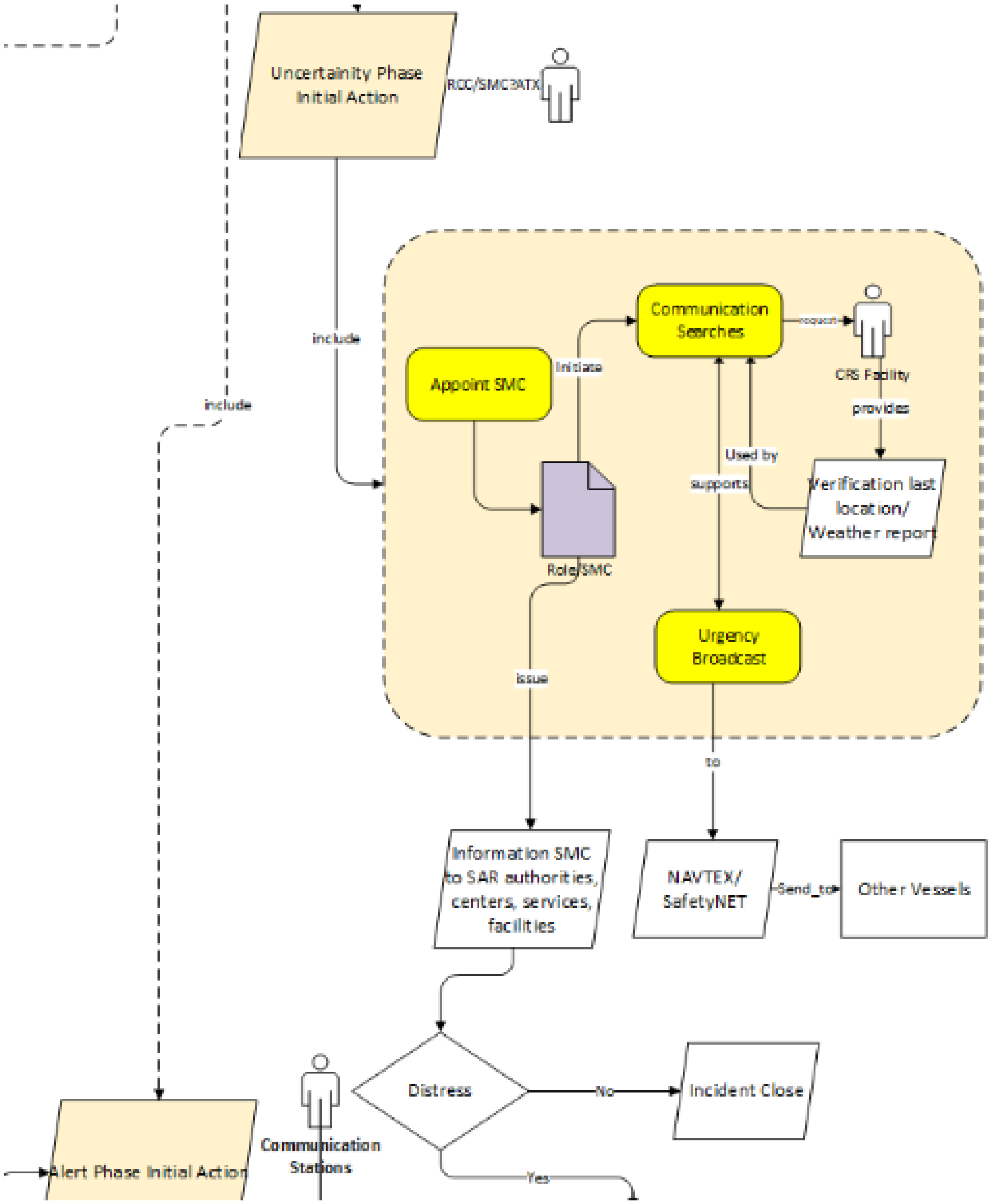

Figure 5 B: Uncertainty phase initial action model from Figure 5

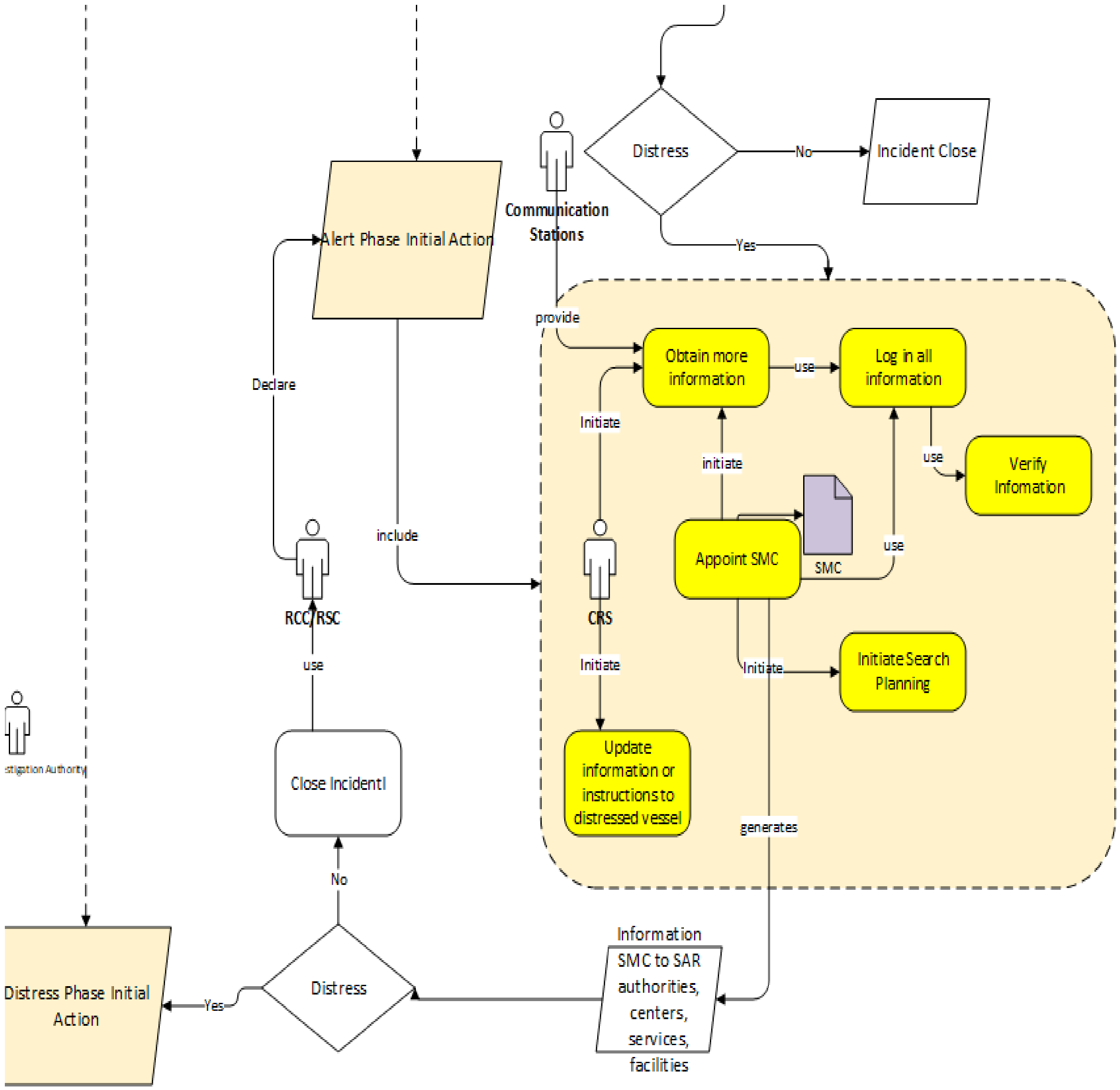

Figure 5 C: Alert Phase Initial action model from Figure 5

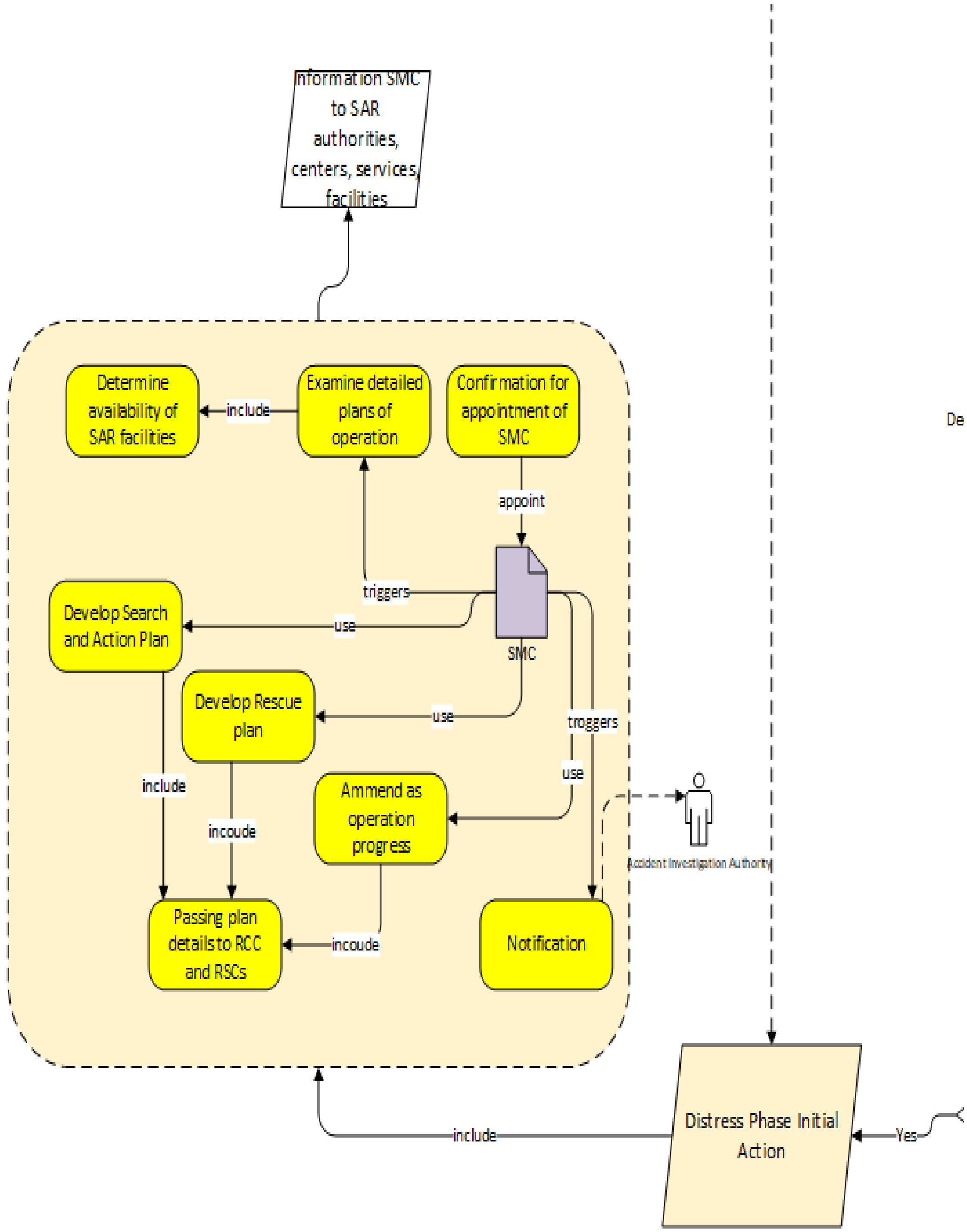

Figure 5 D: Distress phase initial action model from Figure 5

It can be observed in above models (Figure 5- A, B, C & D) that output of one stage becomes input of the other stage. From above models it is also evident how Initial Action stage modifies its process as per the assessment of emergency from Awareness stage.

2.1.2 Awareness Stage

The process of awareness stage is defined in the IAMSAR Manual Volume II [2] as: "*Awareness as knowledge by any person or agency in the SAR system that an emergency situation exists or may exist"*. The awareness stage includes the subprocess "Emergency classification and Assessment" as shown in two boxes labelled IAMSAR Sea incident types and IAMSAR Phases respectively in Figure 6. This stage has two main goals respectively: deciding whether it is a false alert or delay due to deviation from normal plan is present as well as classifying the emergency into **Uncertainty, Alert,** or **Distress** after emergency assessment.

Figure 6 shows the existing process of awareness stage at HRS, where reported sea emergency is assessed and classified by JRCC personals through existing non-AI DSS called SARA and SARA Rapport. It is also shown (Figure 6) that the initial action plan template uses this assessment as input to draw the plan accordingly.

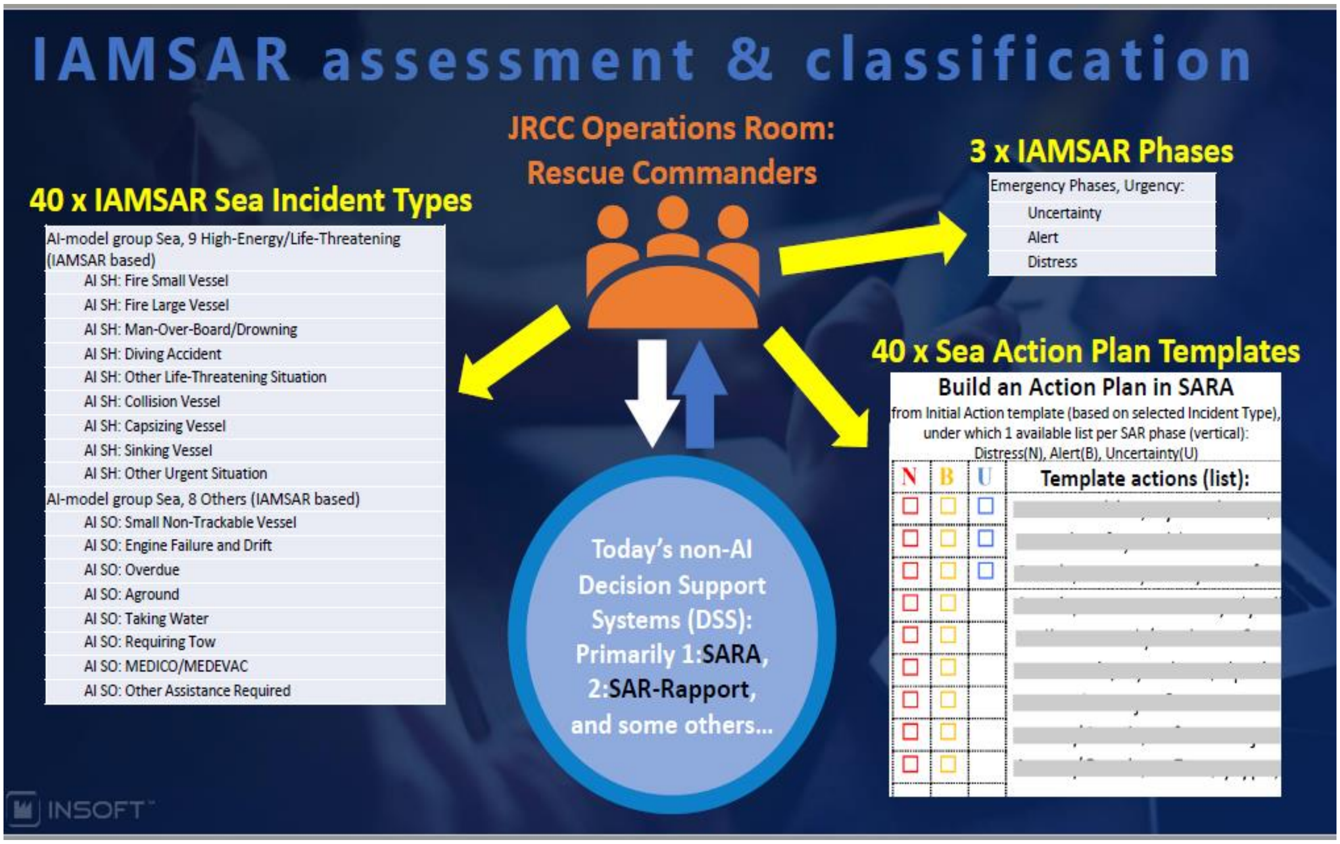

Figure 6: Awareness stage goals

(Showing types of sea emergencies and classification of reported incident)

2.1.3 Rule Based Decision Support System

A rule-based system uses rules as the knowledge representation for knowledge coded into the system [11]. A rule-based system enables to represent domain expert knowledge for a particular domain into an automated system and consists of a set of logical IF-THEN rules, that are a set of facts and some interpreter controlling the application of the rules, given the facts [12]. The working memory of the system is source of facts to the inference engine, where facts represent the information about the current situation of the case. The inference engine determines which rules antecedents are satisfied and those rules are fired [12].

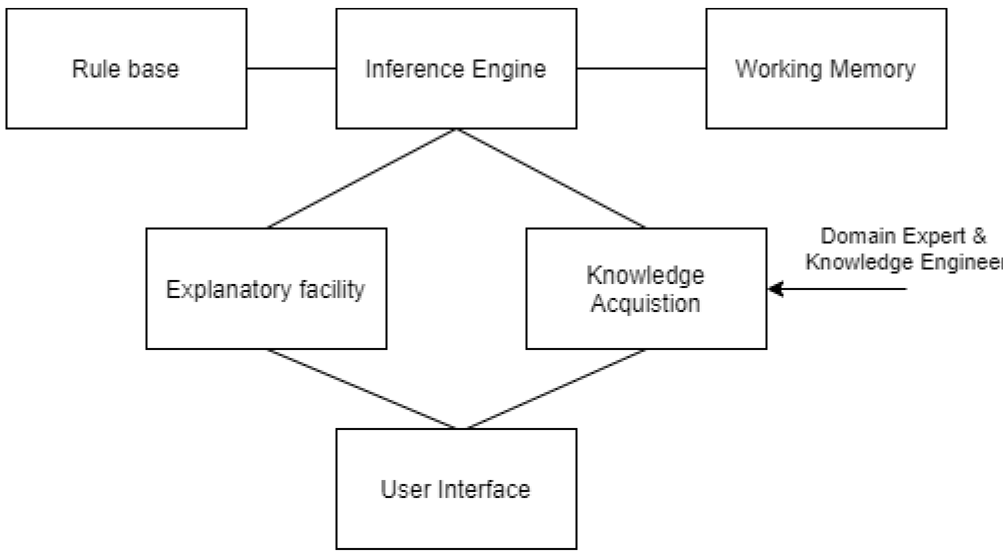

Figure 7: Basic Architecture of a rule-based expert system [21]

The main components of rule-based system as shown in Figure 7 are [15]:

1. Knowledge base / Rule base: This component contains set of rules based on the expert knowledge regarding the problem domain.
2. Facts / Working Memory: that contains set of known facts regarding the problem.
3. Inference engine: responsible for reasoning process by linking the rules to the known facts to find an optimal solution.
4. Explanation facilities: provide information to user for reasoning process.
5. User Interface: way of communication between user and the system.

The inference engine in RB-DSS use two main methods for purpose of inferencing in which one is Forward chaining and second is Basic chaining. The “Forward chaining” is the data driven approach used by inference engine in which decision is concluded from facts however, backward chaining is query driven approach in which is based on hypothesis and conclusion is proved to the facts on which hypothesis is based [12].

2.1.4 Fuzzy Logic and Rule Based System

Fuzzy logic is used where there are more values involved rather than two discrete values of two or false and supports the situation where answer is not clear between yes/no or true/false. This logic uses continuous values that lies between two discrete values of 0 and 1 [27]. Fuzzy rule-based system offers innovative design for problem solving with rules identified with help of domain experts with all possible values.

2.2 LITERATURE REVIEW

Maritime SAR not only ensure the safety of life at sea but also the expression of international humanitarian [1]. Generally, SAR refers to the search and rescue action made by search and rescue force after they acquire distress message, which contains *search* actions and *rescue* actions [2]. *Search* means to determine the location of people in distress with the coordination by SAR coordination center, and *rescue* indicates to save the people in distress, provide preliminary medical service and other necessary service for them, and move them to safe place [6]. The significance of maritime SAR operations has been recently emphasized by the increasing number of migrants through sea [6]. This is also emphasized in a research project called "*Decision support system for maritime environment emergency management*" has been carried out from 2011 to 2015 by two Italian companies (i.e. Selex ES and Codin SpA) and an Italian public university (i.e. Politecnico di Bari), and funded by the Italian National Operational Program for "Research and Competitiveness" 2007-2013 (NOP for R&C) [7]. It has been observed during the research that in the literature many examples of Decision Support System can be found for emergency management in the disaster situations like earthquakes, infectious diseases and nuclear incidents etc. (e.g., by Wallace and De Balogh, 1985, Fredrich and Burghardt, 2007; Ghaderi et al., 2007; Yoon et al., 2008; Amdahl and Hellan 2009; Wang et al., 2013; Wysok et al., 2014; Filippoupolitis and Gelenbe n.a.) However, the systems proposed in the mentioned literature were not developed for managing maritime emergencies [8].

In 2014, Zhang. Y and Yang. X [6] proposed and Expert System (ES) based on the fuzzy rules for maritime SAR activities. In their studies fuzzy inference is used for the SAR Expert System, so the result achieved of inference is a series of membership degree of rescue operation in fuzzy set [6]. The focus of the research is the allocation of the SAR operation as per the assessment of ES.

In 2017, Karatas, M., Razi, N., & Gunal, M. M. [8] composed a hybrid methodology which combined optimization and simulation to allocate SAR helicopters. An integer linear programming (ILP) model was built to provide an effective deployment plan and used as an input to a simulation model which included constraints that the ILP model could not tackle. Integrating a rule-based algorithm, they generated alternative solutions to seek better plans that exist in the vicinity of the ILP model solution [8].

Continuing the work Guo, Y., Ye, Y., Yang, Q., & Yang, K in 2019, developed a method to support decision makers to allocate multiple resources for dealing with Long Range Maritime SAR (LRMSAR) to ensure the sustainable use of resources with the help of integer nonlinear programming (INLP) model [9].

All the previous studies focused on the integration of AI to planning and execution phases of the SAR activities where allocation of resources or devising of action plan are main objectives. However, the situation assessment, being a vital part of the SAR system, is usually neglected to get implemented into AI studies.

CHAPTER THREE

3 KNOWLEDGE ENGINEERING FOR SAR

Background studies lead to the conceptualization of the SAR domain: the process of Awareness stage that is modelled to determine the data flow in/out of the process and within the process, as shown in Figure 8. We have modelled the process of Awareness stage using modelling framework of 4EM [33]. It has been observed from the Figure 8 that the Awareness process is triggered as soon as the information of the potential emergency situation, is received at HRS from the Coastal Radio Station (CRS) or any other resource [2]. The sub-process of emergency classification assesses the certainty of emergency based on the availability and confirmation of information received by the personnel during the awareness stage. The assessed level of certainty regarding the emergency reported along with the other information received initiates the next stage of SAR: The initial action plan.

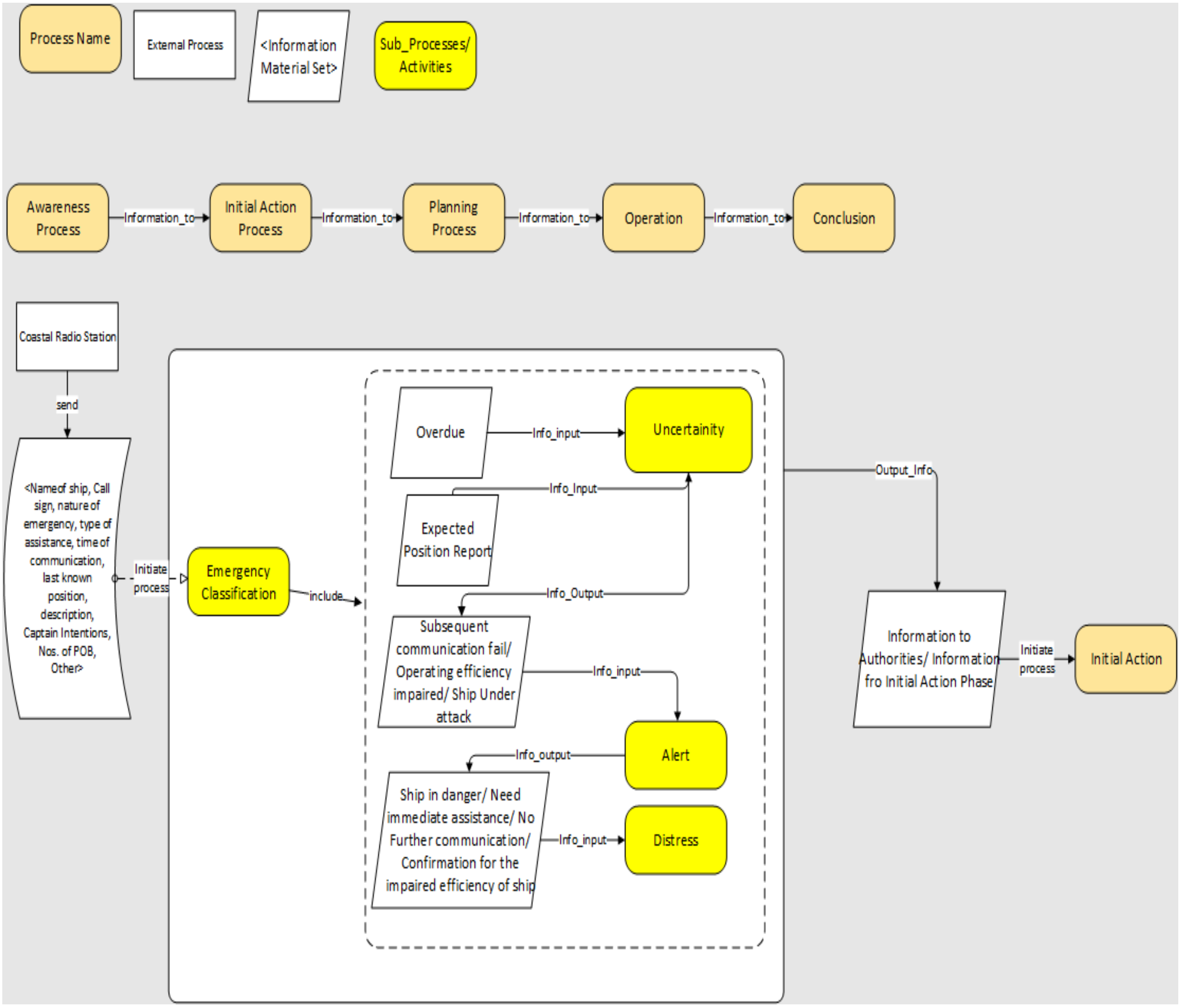

Figure 8: Awareness Process Model

The objective of the integration of DSS for Awareness stage of the SAR operations is to facilitate the evaluation and assessment of the reported alert and the available information for the users. Conventionally the situation assessment for the received alert is based on an interactive Question/Answer processed by the domain expert. The emergency alert prosecution goes through three phases, which can be exemplified as follows : the alert is received at RCC and limited information is available, the operation enters the (i) *uncertainty phase* afterwards additional information is collected, and the operation will progress to (ii) *alert phase* and if the emergency is confirmed taking into account all possible information, the (iii) *distress phase* is declared [2].

Figure 9 shows the simply mapped emergency alert for a missing small leisure vessel during the Awareness stage.

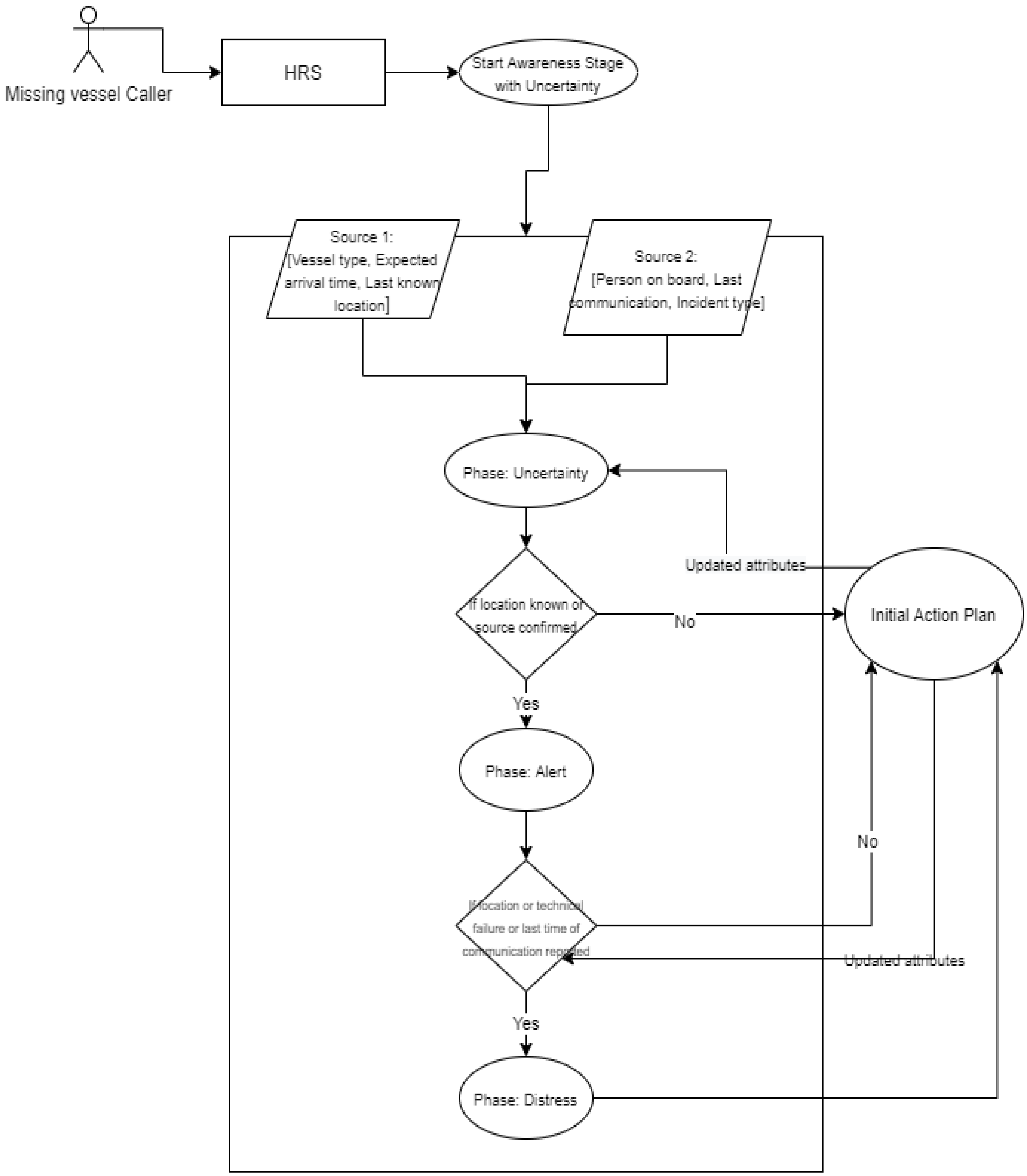

Figure 9: Sample Mapping of Incident for Awareness Stage: Eclipse depicts processes or phase declared, diamond shows decision points.

The sample map of an incident shown in Figure 9 shows how the awareness stage is initiated when the distress call is received by HRS and that every call initially leads to uncertainty until a certain type of information is confirmed or available. It can also be observed that whenever the information is updated at a certain decision point, the state of emergency is assessed along with it. For example, if a small vessel is missing on sea, the state of emergency is declared as uncertainty. The decision regarding the state of emergency will be revised if some new information is obtained like that of location or last time of communication. In such case the decision will be revised from uncertainty to distress for the next stage of SAR operations.

3.1 KNOWLEDGE ACQUISITION PROCESS

The process of knowledge acquisition involves the collection of explicit, implicit, and tacit knowledge. The knowledge that is represented in a formal and systematic way and can be shared and communicated easily is known as explicit knowledge [30]. Typical examples are code, reports, journals, manuals, etc. The implicit form of knowledge is practical form of knowledge where the experiences are recorded on basis of application of theoretical knowledge obtained and is less formal and unstructured [18]. Tacit knowledge is also a form of implicit knowledge which is acquired through experiences and practices and not easily articulated [20] for example, riding a bicycle or driving a car. For the acquisition of all types of knowledge for SAR Awareness Decision Support System, the standard knowledge engineering methods are being used as per availability of resources that will be described shortly.

3.2 KNOWLEDGE ENGINEERING METHODS

For the implementation of the rule-based DSS on Awareness stage, the knowledge engineering methodology has been used to acquire domain knowledge to be translated into rules for knowledge base. Figure 10 shows the mind map for the knowledge base exhibiting resources used for knowledge gathering. The knowledge acquired from the resources enables the identification of attributes for the rules.

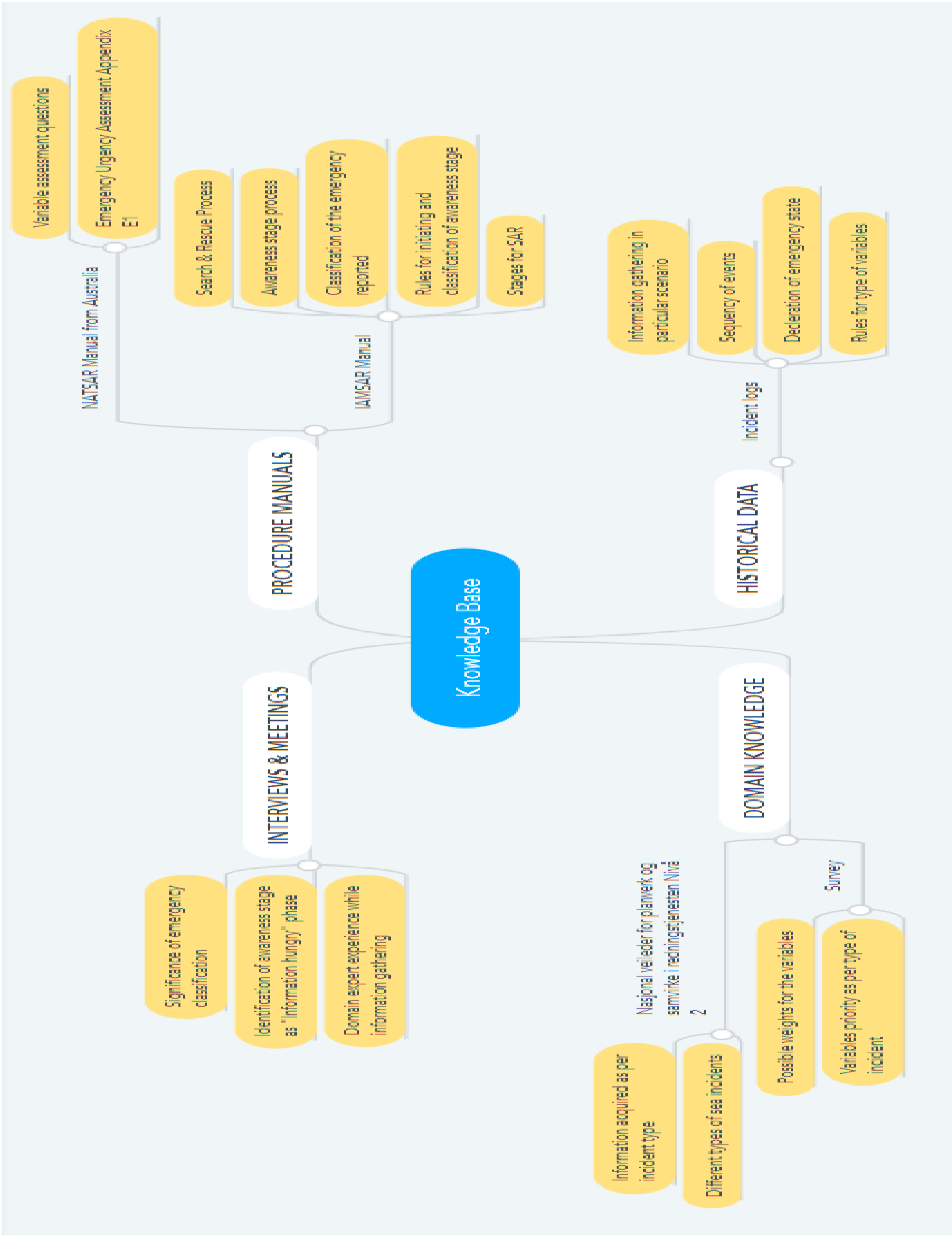

Figure 10: Mind map for Knowledge Base

Traditionally knowledge engineering been viewed as a process of extracting knowledge from human expert and transferring it in a computational form to a machine [17]. For development of decision support system for SAR processes, knowledge acquisition is of great importance that is achieved with the help of different knowledge engineering methods. Methods used to acquire knowledge includes manual extraction of knowledge from search and rescue manual, search and rescue reports, and other literatures, and interviews with SAR expert, as shown in Figure 10.

3.2.1 Interviews / Meetings

The interview technique is based on the assumption that a domain expert can reliably expresses the domain knowledge to a knowledge engineer through unstructured, structured, or prompted interviews [17]. Due to the prevailing COVID-19 situation it was not feasible to organize one-to-one meetings with HRS domain experts. Therefore, we have used user manuals as initial and primary source of information for the project. However, two online meetings could have been organized with HRS personnel during which the Awareness stage is discussed with the domain experts using unstructured and prompted interview. These meetings and email correspondence were the source of gathering implicit and tacit knowledge from domain experts. The outcomes of the meetings are summarized as follow:

- Awareness stage is the “information hungry” stage of the whole process.
- The decision made in the awareness stage is usually based on the implicit and tacit knowledge of the domain experts because of which no formal procedure is documented for the purpose.
- The goal of the stage include acquisition of as much as possible information for the assessment and evaluation purpose.
- The emergency phases “Uncertainty”, “alert” and “distress” are not explicitly used to mention the intensity of the incident, rather the presence or absence of information defines if the reported incident is uncertainty, alert, or a distress call. For example:
    - A big ship reporting technical failure like shutting down of engines in bad weather (Viking Sky) is straight away a distress call. However, all the information is still collected to design a rescue plan.
    - The disappearance of a small recreational vessel like a motorboat which is reported by a third party will initially be classified as uncertainty, until further evidence or confirming information leads to the distress phase of the call.

The meetings enabled us to identify attributes that were later sent to the HRS to confirm their relevancy for the awareness stage. The results obtained are shown in Table 1 below. The attributes listed in the table shows the respective information needed by personals to reach a certain decision. The absence of the information increases the uncertainty of the reported incident and possible values of the incident effects on the severity of the situation. The information gathered during this phase is based on the experience of personals and lacks a formal procedure.

Attributes	**Possible values / Sub-Attributes**	**Relevancy to Awareness Stage**
Category of Incident	Shipwreck, Technical Failure, Missing vessel, Grounding (30 type of incident in SAR)	Yes
Event	Fatality, Drift, Missing vessel grounding, Fire, Technical failure, Forward momentum, Steering, Environmental damage	Yes
Distress Call	Overdue, Mayday, None	Yes
Day Light	TRUE/FALSE	Yes
Time of year	Value	Yes
Weather	Rain, Air temperature, Wind etc.	Yes
Sea Conditions	Wave height / Air knots	Yes
Location	Longitude + Latitude	Yes
Offshore	True /False	Yes
Trafficated (Traffic congestion)	True/False	Yes
Range from shore	Short/Medium/Long	Yes
Last time of communication	Number of Hours	Yes
Radio Contact	True / False	Yes
Vessel Stats	Vessel size, Weight, Loading, AIS, Building year, Speed, Fuel percentage etc.	Yes

Vessel Type	Vessel type, Superstructure, Hull profile, Length, etc.	Yes
People on Board	Single, More than one, Number	Yes
Skills	Experience, No experience	Yes
Medical history	On medication, Healthy, Injured	Yes
Typical behavior	Known, Unknown	Yes

Table 1: Identification of the Attributes for rule based DSS.

3.2.2 Procedure Manuals

Procedure manuals have been important source of explicit knowledge for the whole project due to the lack of availability of sufficient data and physical observations. There are three main procedure manuals used: IAMSAR Manual (Volume I, II & III), National Search and Rescue Manual (NATSAR) and "Nasjonal Veileder for planverk og samvirke i. redningstjenesten Level 2" report.

International Aeronautical and Maritime Search and Rescue (IAMSAR) Manuals are available in three volumes pursues the basic objective to assist member countries in meeting their own Search and Rescue (SAR) needs, and describe the obligations they accepted under the Convention on International Civil Aviation, the International Convention on Maritime Search and Rescue, and the International Convention for the Safety of Life at Sea (SOLAS) (IMO, ICAO, 2010). IAMSAR Manual Volume I, 2010 [1] provides information regarding the organization and management of SAR organizations and operations and provides knowledge regarding the key components of the SAR operations.

IAMSAR Manual Volume II [2] documents the information about mission coordination, SAR services, communication services, five stages of incident response along with theory and practice of SAR planning (IMO, ICAO, 2010). This volume of IAMSAR Manual has been the main source of information for this thesis. The information we acquired from the manual indicated the significance of research that can either confirm or deny if the reported event is to be considered an emergency. The level of emergencies is also defined in detail from the perspective of Awareness stage in the manual. Uncertainty, emergency response (Alert) and Distress are defined in detail especially for the emergencies at sea as mentioned in Chapter 2. The manual defines also how lack of information or certainty leads to the further investigations and provides input for the stage of initial action plan. The output of the awareness stage as defined in IAMSAR Manual Volume II section 2.1.1.1, 2.1.1.2 and 2.1.1.3 are as follow:

Uncertainty

"Uncertainty is used when there is knowledge of an incident that needs to be followed or investigated more closely, but where one does not need to send search and rescue resources" [2].

Emergency response / Alert

"Emergency preparedness is used when people have problem and may need assistance but are not in immediate distress. The urgency of the response to increased vigilance, but there is no known danger requiring immediate rescue efforts" [2].

Distress

"*Distress is also used when the degree of concern for the safety of people who may be in need is so great that it justifies the implementation of a search and rescue action, and otherwise when there is information that indicates that it is reasonably certain that per-zones are at risk and need immediate assistance*" [2].

The IAMSAR manual volume II also provides the basic definition of attributes including situation, location, communication, person on board and weather conditions.

IAMSAR Manual Volume III offers detailed information for the standard mobile facilities used to be carried abroad rescue units, aircrafts, and vessels to help with missions of search, rescue, or on-scene coordinator function. This manual has limited information for the decision making in the awareness stage, which is the scope of this thesis. However, it provides information for the attributes that are significant for the distress situation.

National Search and Rescue Manual Edition 2018 [14] by Australian Maritime Safety Authority documents standard procedures and techniques for cooperation and coordination of SAR authorities in Australia. The manual got analyzed in regard to the use of checklist for the emergency assessment and criteria for defining phases as mentioned in Appendix E-1 of the manual.

The manual "Nasjonal Veileder for planverk og samvirke i redningstjenesten Level 2" finally is used for the purpose of explicit knowledge acquisition purpose that offers domain knowledge of

SAR operations in Norway. This manual is provided by HRS personnel and focus on type of rescue events on sea, land, and air. The type of events included in the manual are based on experience encountered in the Norwegian rescue service since the establishment of Main Rescue center in 1970.

All the manuals provide information for the input to local SAR operations that are adapted based on local topography.

3.2.3 Historical Data

Another source of explicit knowledge available to the project was incident logs provided by HRS. These two logs were used as the historical data source. One log was about the "Viking Sky" incident and other one was about small vessel gone missing, the "Nordavind". The two logs offer an insight into the communication processes that takes place between the reporter and HRS personnel.

Viking Sky Log

The incident which led to the evacuation of "Viking Sky" took place on March 23, 2019. The cruise ship had 1373 people on board, out of which 930 were passengers and 443 were crew members. The first "Mayday" call from the "Viking Sky" was received at SAR Mission Coordination Office (SMC) at 1400 hrs. Within the log it can be observed that the situation was initially characterized "Distress call" as most of the information was available and certainty concerning the extent of the incident was high.

Nordavind log

HRS provided the "Nordavind" log "2018-S-5098 – Action Report 1" for the purpose of this analysis. The analysis of the log showed how the "Beredskap", or Uncertainty phase got initiated as soon as SMC received a call from a friend of missing person. As information regarding the missing person was initially limited and in need of further investigation, the phase was declared as "Uncertainty". The log also shows how the emergency or distress phase got initiated when the evidence was received along with a confirmation of delay.

Other observations made form the log included the attributes that were inquired by the personnel for the verification of the emergency. Few possible values of the attributes also known as response values also have been derived from these logs.

CHAPTER FOUR

4 The Knowledge Base Model

In this chapter the knowledge base model is discussed, as devised on the basis of knowledge acquired. In the previous chapter, it was discussed how knowledge has been collected through knowledge acquisition process using the different resources. This chapter documents what types of information could have been derived from the available resources. The acquired knowledge can be represented in form of rules to build the rule-based system. From the resources the following knowledge elements are identified:

- Attributes determine the type and nature of incident reported.
- Some possible values of the attributes in terms of recorded responses
- Rules that exhibit the urgency of each response
- Priority of attributes for same cases
- Assessment of emergency in terms of certainty and urgency
- Required output of the awareness stage.
- Significance of the emergency assessment for next stages.

4.1 Attributes Based On The Type Of Incidents

It has been mentioned that "Nasjonal Veileder for planverk og samvirke i redningstjenesten Level 2" is the manual by HRS that provides information of different type of events at sea and their associated attributes. Some important types of the incidents at sea include:

4.1.1 Assistance Vessels

This event is reported when a vessel on sea requires assistance to avoid possible danger especially to the lives of people on the board. This can include engine failure, structural damage or any such problem that can compromise safety of people on the vessel.

Attributes for the event include:

- Situation of event occurred.
- Location of the vessel

- Type of vessel
- People on board
- Equipment on board
- Communication source
- Weather profile

4.1.2 Drifting

This event occurs when the vessel is *drifting* and can result in danger to human life.

Attributes for the event included:

- Situation
- Location
- Vessel Information
- Suspected injury / health
- Veins, mooring (worn off, part of the vessel)
- Damage
- Weather conditions
- Motor status

4.1.3 Diving Incident

This event is reported in case of a missing diver or as a result of accident to the divers. The diving in question can be professional, sport, or freediving.

Attributes for the event included:

- Situation
- Location
- Number of people involved.
- Suspected injury
- Profile of the diver
- Communication source
- Resources on site
- Equipment available

- Time
- Weather conditions

4.1.4 Medical Evacuation

This event involves *medical evacuation* of a vessel on sea. In Norway, the authorities are responsible for providing medical assistance service for seafarers. Medical assistance is also provided through radio or phone to vessel on sea and called as “Radio MEDICO”.

For medical evacuation, the inspected attributes are as follow:

- Situation
- Location
- Communication source
- Status of patient on sea
- Presence of medical facility on vessel
- Weather

4.1.5 Offshore Incident

This event is reported in case of an accident at an offshore installation site. SAR service for such event is also provided in compliance with Petroleum act according to which the service is provided in event of danger or accident at site until the public authorities take over.

Required attributes for this event include:

- Situation details
- Location / position
- People on site
- Personal injury
- Safety measures available
- Communication
- Weather

4.1.6 Missing Vessel

Incident of vessel gone missing are reported in case a vessel disappears on sea without further information on the incident and its background (accident, communication breakdown etc.). The types of vessels that can be reported missing include all seaborne craft of any type from leisure vessels to cargo and passenger ships.

For *missing vessel* following attributes are inquired initially:

- Event description
- Last known location
- Vessel description
- People on board
- Weather condition
- Communication

4.1.7 Accident at Sea

In case of *accident at sea* that may involve vessels of different type, the incident is reported at HRS.

Some basic attributes required to evaluate situation include:

- Situation
- Location
- Vessel type involved.
- People on board
- Suspected injury or health condition
- Communication source

Along with these incidents other sea incidents specified in the manual include accidents of *drowning person* with the same basic attributes required for the report of other incidents. However, the types of sea incidents are not limited to those mentioned here, as HRS has approximately 30 types of sea incidents recorded that also include *fire on vessel* and different events for small and large vessels.

4.2 IDENTIFYING THE RULES FOR THE RULE-BASE

As mentioned in the third chapter of the thesis, IAMSAR Manuals provide the basic information to formulate rules. In IAMSAR Manual Volume II chapter 3, the conditions are described for the declaration of Uncertainty, Alert or Distress phase that is also the output of the awareness stage.

The basic rules identified from the IAMSAR Manuals can be categorized as following:

1. Definition of “Uncertainty” phase with respect to information available as in section 3.3.2 of the IAMSAR Manual Volume II.
2. Declaration of “Alert” phase in terms of gravity of situation and information required is defined in the section 3.3.3 of IAMSAR Manual Volume II.
3. The confirmation of emergency is defined as declaration of “Distress” phase as mentioned in section 3.3.5 of IAMSAR Manual Volume II.
4. Criteria for the positive information that is confirmation of emergency,
5. Declaration of distress call in case of delayed communication.
6. Declaration of distress call in case of problem with the operating efficiency of vessel.
7. Use of checklist for emergency assessment from NATSAR Manual as mentioned in Appendix E-1.

CHAPTER FIVE

5 IMPLEMENTATION OF RULE BASED SYSTEM

This chapter documents the details for the implementation of knowledge-base model for the rule-based DSS for awareness stage. For this purpose, the first step was to analyze the current decision-making process at HRS for assessment of emergency as discussed in section 5.1. In later section 5.2.3.2 the alternative approaches have been discussed for the implementation of RBDSS. For the implementation of the model, MATLAB has been used. MATLAB is a popular tool for implementation of rule-based models because of its utility of Fuzzy logic toolbox. However, for this thesis MATLAB is used for the implementation of the basic rule-based model as discussed in section 5.2.2.

5.1 PROCESS OF DECISION MAKING

Awareness stage is an information hungry phase of the SAR operations as confirmed during knowledge acquisition part of the project. This stage leads to the decision after the emergency assessment. From the information gathered through meetings and IAMSAR Manual, it has been observed that there is no formal procedure followed for the assessment of incident reported.

For the assessment of emergency, information is acquired through different resources and by asking questions from the correspondents. The information is collected depending upon the type of incident reported. Some of the basic required information for various incident types is stated in the official document "Nasjonal veileder for planverk og samvirke i redningstjenesten – Nivå 2". Most information is collected during run time based on the type of incident and the prevailing scenarios. From the Nordavind case report, we extracted and visualized the thought process of domain experts involved in the decision-making process in form of flow chart as shown in Figure 11. The flow chart in Figure 12 shows how state of emergency changes with the availability of information from uncertainty to distress. It was observed that awareness stage of the process begins when the call is received at the center from an unidentified resource. The caller is investigated for the possible information and the questions were asked based on the response of the caller. As the location of the vessel was unknown but the identification of the vessel was known, the uncertainty phase was declared. With the availability of information like identification of the person on board, origin of the vessel, and time of last communication the stage progress from alert to distress.

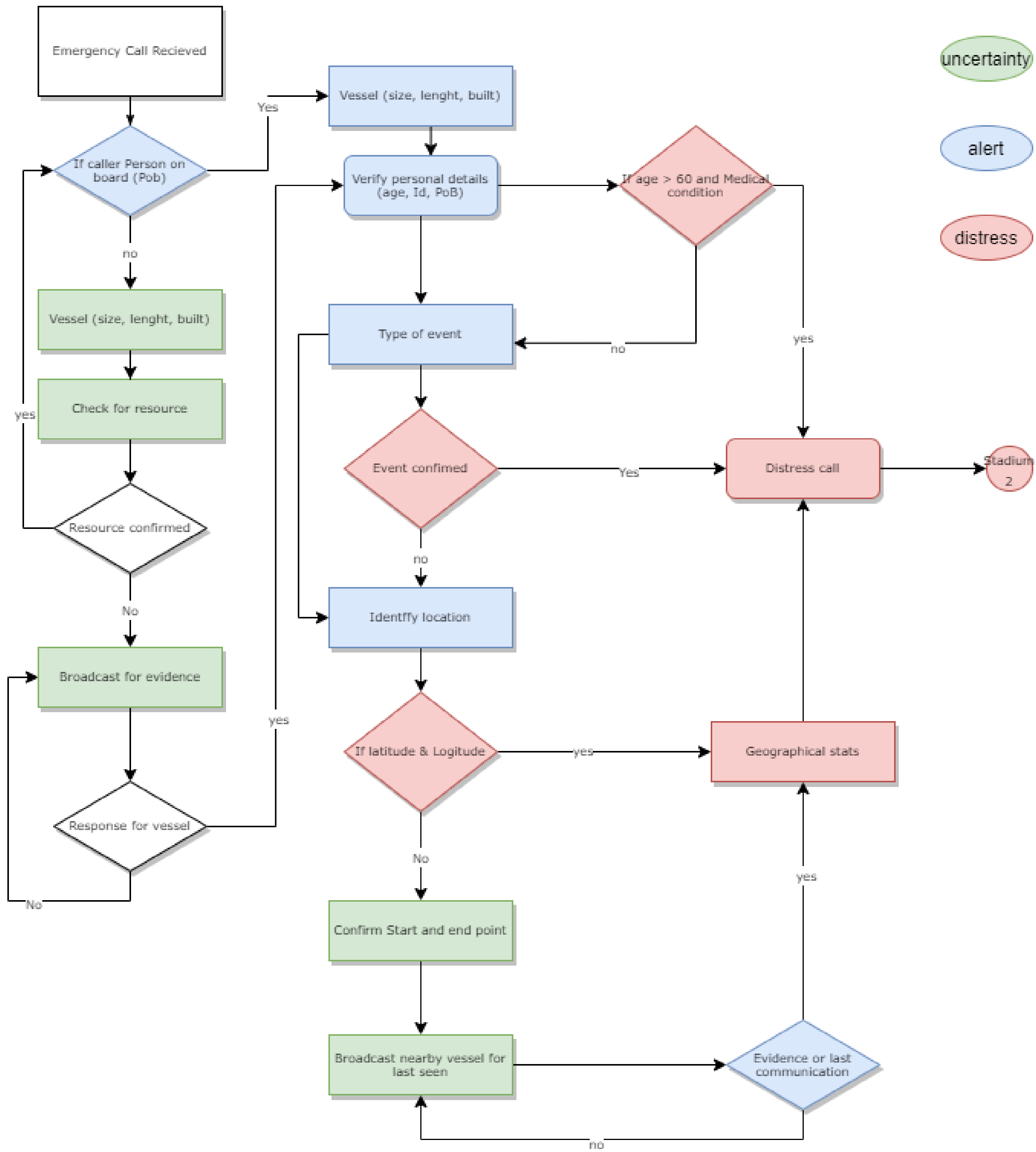

Figure 11: Flow Diagram from Nordavind where process is shown where green color shows the uncertainty stage, blue color shows the alert stage and pink color shown when the emergency is confirmed, and distress stage is declared.

The process of assessing the emergency is intended to be supported by Decision Support System (DSS) for enhanced efficiency and integration of AI for SAR process.

5.2 DECISION SUPPORT SYSTEM

Charles Stabell has defined in the paper "A Decision-Oriented Approach to Building DSS" following activities involved for decision making process in diagnosis of problems [16]:

- Collection of data on current decision making which has been achieved through knowledge engineering techniques.
- How decisions are made currently
- Identification of process for how decision should be made.

The input for decision support system is acquired through these activities. Like many other domains, it is not feasible to attain full-scale conclusion of decision making for Search and Rescue process. However, a proposed relative model can offer a limited analysis for prevailing situation for decision making. The output of the decision support system for the awareness stage is the assessment for the state of emergency reported at HRS that is to determine if the emergency reported is Distress, Alert or Uncertainty. The input for problem solving is a set of attributes that are obtained from the incident reported. These attributes will correspond to "facts" in a rule-based system that goes into the working memory and will be mapped with the IF parts of the rule-base to determine which rule will be executed as per the value of the attributes, For the decision-making process, inputs and output of the DSS are shown in Figure 12.

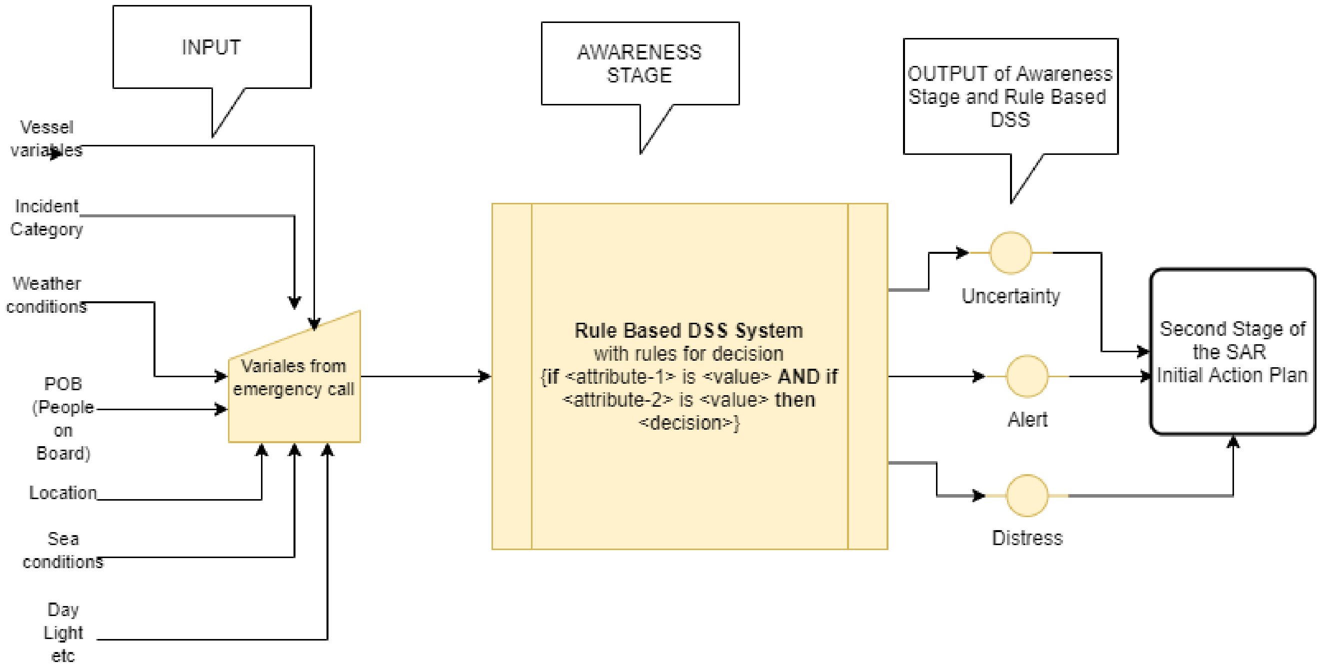

Figure 12: Basic input/output for rule-based DSS

To achieve decision from the rule-based DSS we need to define the logical rules by representation and application of the decision knowledge [31]. The workflow for the implementation of the rule-based DSS has been depicted in the Figure 13 below:

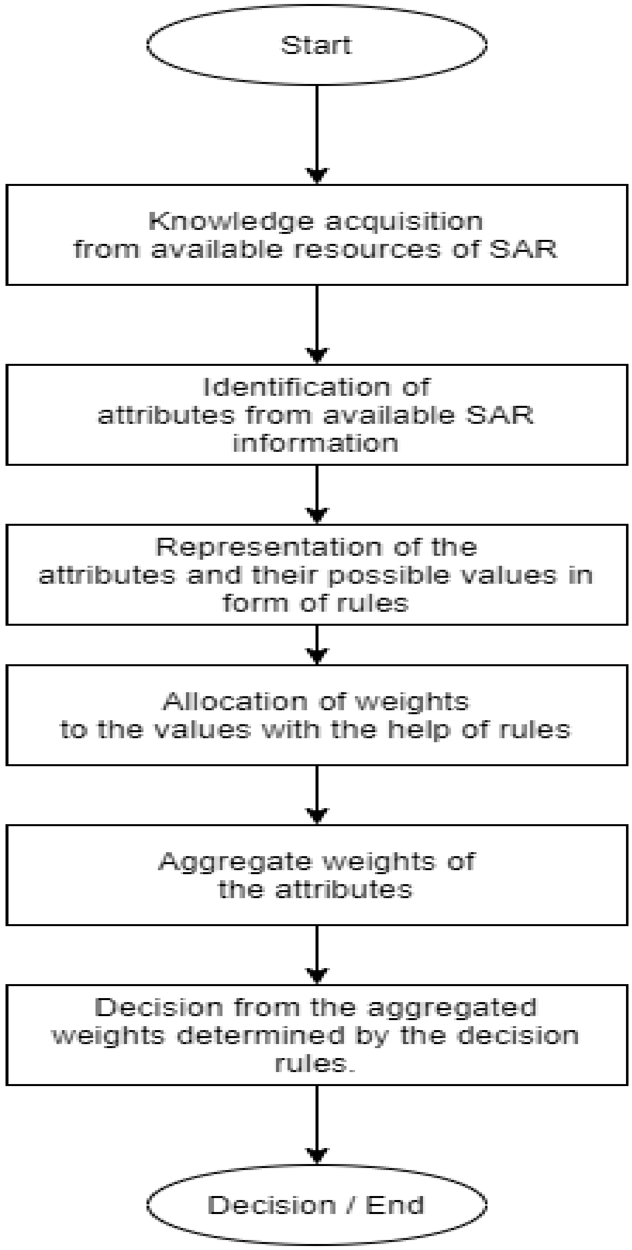

Figure 13: Workflow for implementation process from knowledge acquisition to decision from rules.

5.2.1 SAR Knowledge Acquisition

We have adopted the process of knowledge acquisition for the development of rule base as per the theory, that rule-based system is established on the fundamental belief that people are able to express their opinion and experiences on preferences using rules [31]. The output of the process was information and expert knowledge that are the building block of rules. The process of knowledge acquisition for implementation of SAR decision support system has been discussed in chapter “Knowledge Acquisition” in detail.

Methods used to acquire knowledge includes search and rescue manual, interviews with SAR expert, search and rescue reports, and other literatures as shown in Figure 14.

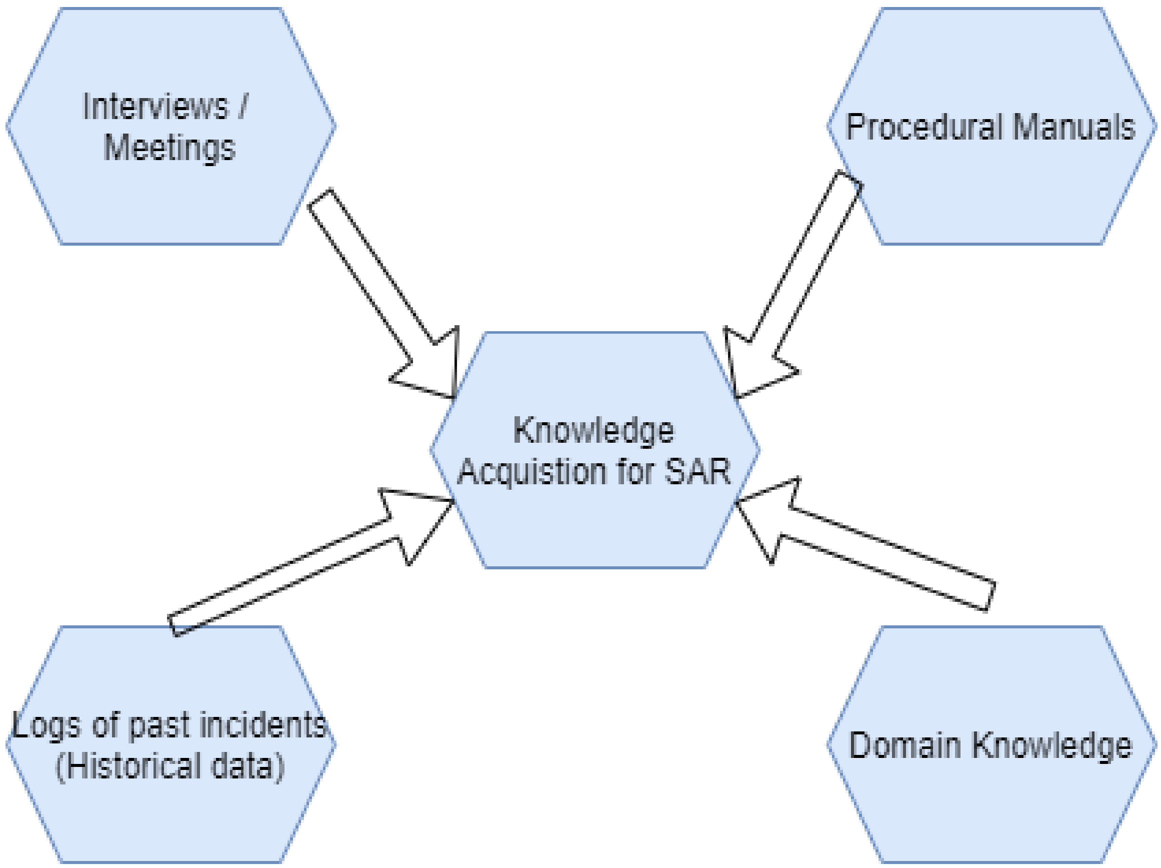

Figure 14: KE sources for SAR

5.2.1.1 Response Decision Tree

From the knowledge acquisition process, we recorded the response for identified attributes that enables HRS personal to assess the state of emergency. We mapped the decision tree as shown in Figure 15 for the possible responses of the attributes that can lead to further action.

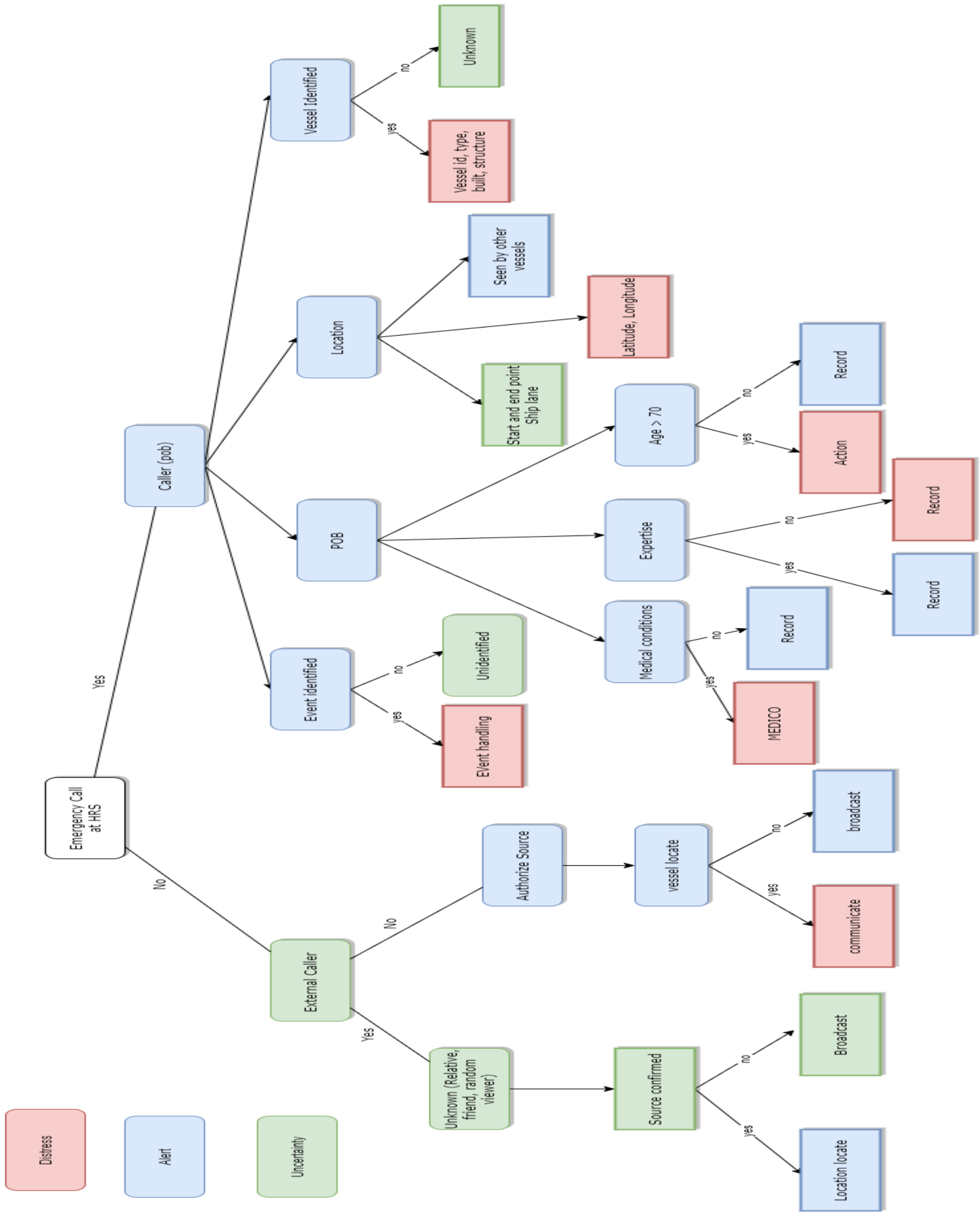

Figure 15: Decision tree for Attribute and responses: Different colors of the nodes indicate the certainty of the information that is green color exhibits uncertainty, blue is for alert and red is for distress.

The decision tree is mapped on the basis of generalized process of awareness stage and is not case specific. A node in the map leads to different types of action nodes. Some nodes are for gathering further information while some sub-nodes may lead to direct action plan stage. The nodes showing record indicates the information obtained is saved. The saved information is analyzed collectively with other information available for further decision. For example, if vessel is reported missing and medical condition of person is not known then other obtained information is collectively analyzed for the assessment of emergency.

5.2.2 SAR Knowledge Representation

Knowledge representation is the second step in the implementation phase of rule-based system where human knowledge acquired through knowledge acquisition is to be encoded into a form that can be processed by computer algorithms and heuristics [19]. For the SAR - DSS, rules are used for the formalism of the acquired knowledge. A rule is a two-part structure consists of IF-THEN part, and the basic building block of Rule-based decision support system. An IF-THEN rule represents the implication where the IF part contains the antecedent clause, a Boolean expression that may contains AND, OR, or NOT connectives, which when true implies the truth of the THEN part which consists of a consequent i.e., an inferred action or information.

IF(A) **AND** (B) **THEN** S1.

For example, for the case of missing vessel with person on board experiencing injury the rules will be:

IF vessel is missing and medical condition is injury then emergency is distress

In this rule IF part of rule is antecedent clause and Then is consequent clause where AND is the Boolean expression. When the Boolean condition will stand true for antecedent clause then consequent clause will also inferred true.

For the rules, attributes have been identified through different resources during knowledge acquisition process. These attributes are identified as information required by HRS personal to identify and investigate the incident reported. The responses to these attributes are the values that enables the personals to assess the emergency reported in terms of distress, alert, or uncertainty.

For example: In the case of Nordavind, the incident of missing vessel is reported on 23.11.18 at Kl 10:33 and following attributes were recorded for the reported incident.

1. Person on board
2. Age
3. Vessel Identification
4. Start point.
5. Last time contact
6. Equipment on board

For the knowledge representation the rules were formulated using these attributes and their responses. Two models were used to formulate rules. In first model, four different types of rules are identified based on the type of the actions or decisions they result in. However, in second model fixed number of attributes are identified with limited number of response values. These response values are assigned with weights and aggregate weights of the values determine the emergency type for reported incident. Both methods can complement each other if all the possible response values of attributes can be identified. In this way weights can be assigned to the response values of the attributes considering the type of the rule and prioritizing it accordingly. For example, in case of uncertain emergency the priority of information gathering rules increases to identify missing attributes.

5.2.2.1 Taxonomy Based Rule Model

In the following method we created a taxonomy that defines 4 types of rules that are identified on the basis of possible responses received or investigated for the attributes on the basis of which the incident is assessed when reported.

These four types of rules as shown in Figure 16 are:

1. Decision rules
2. Attribute identification rules (how to)
3. Information gathering rules (What is to be asked)
4. State identification rules

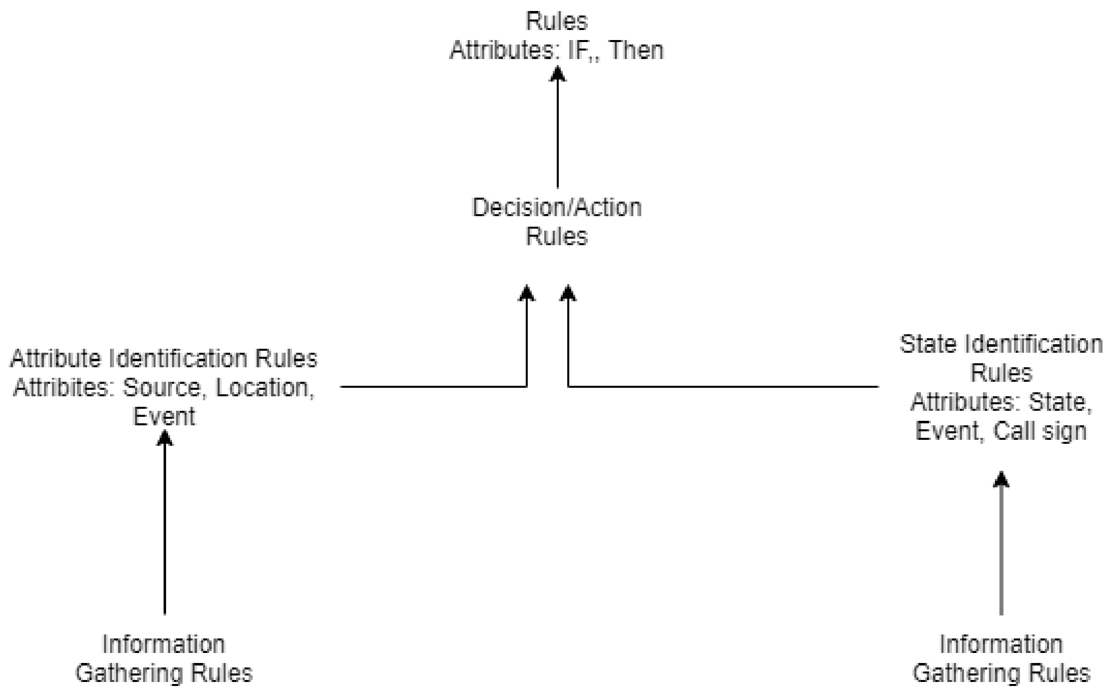

Figure 16: The four types of rules used in taxonomy.

Decision / Action rules

These types of rules enable in decision for some action on basis of attributes identified.

For example:

1. If call_sign is distress and emergency_call is true, then initiate action_plan.
2. If vessel location is unknown and emergency_call is true check for communication delay.
3. If emergency_call is true and source is CRS then check vessel_identity.

In the rules mentioned above when the value of attribute is true, it indicates the presence of the value of attribute or if the attribute is known.

Attribute identification rules (how to) Rules.

The attributes identification rules are triggered as soon as emergency is reported. These rules enable the identification of the attributes on the basis of values.

For example:

1. If vessel location is on sea and people on board need assistance, then emergency_call is true. [IAMSAR Manual Volume 2 section 1.6.2]

2. If emergency_call is true and caller is via GMDSS (Global Maritime Distress and Safety System) then source is known.
3. If latitude is true and longitude is true then location is known.

In the above-mentioned examples when the value of the attribute is true it indicates the value is known or present however, if the value of attribute is false, it exhibits the value of the attribute is not known.

Information gathering rules (What is to be asked)

These rules are subset of *attribute identification rules and state identification rules* where rules identifies if the certain attributes are missing on the basis of values.

For example:

1. If emergency_call is true and event_type is unknown, then inquire event_type.
2. If emergency_call is true and vessel is overdue then inquire last_time_contacted.
3. If vessel location is unknown and emergency_call is true check for weather conditions.

In these examples the true value of attribute indicates the presence or known value of attribute and false indicates the unknown value of the attributes. In "THEN" part of rule the inquire indicates what is to be asked or investigated.

State Identification rules

These set of rules are used to identify the state of the emergency with the help of information available. The identification of the attributes defines the state of emergency. The more attributes identified the certainty of emergency enhances and declared as distress state. The distress state can lead to decision rules instantly.

For Example:

1. If emergency_call is true and SLT is 2 or SLT is 3 the call sign is alert.
2. If emergency_call is true and SLT is 4 or SLT is 5 the call sign is distress.
3. If signal is Mayday and vessel has People_on_board then call_sign is Distress.

In these types of rules, the state of the emergency is identified on the basis of values of the attributes. The SLT in above examples is Source Level Trust which we have defined on the basis of source of the information received as shown in Table 2.

SOURCE: Source Level Trust = [SLT] = 1 – 5

Caller		**SLT Level**
Third person/ Person not on-board / Person on land	Unidentified	4-5
Observer on sea / person on another vessel	Mobile – GMDSS	2-3
Person on-board	GMDSS / Mobile / MEDICOS	1
	Coastal Radio Station	1

Table 2: Source Level Trust

5.2.2.2 Aggregate Weights Model

In the following model we have identified limited number of response values for the identified attributes as their values. Each attribute has a number of possible values and number of response values may vary across attributes. Some may have a binary value while other may have a finite set of positive values. For example: For the attribute of vessel identification there can be two possible values for assessment of emergency that is either the identity of the vessel is known, or the identity of vessel is unknown. However, for the attribute of source of call there can be different possible values categorized based on their trust level.

Then we allocated the values which are acquired as per the response of investigation, with weights as per the severity of situation or confirmation of information. The weights for the response values for individual attributes are to be evaluated by domain experts however, a general framework has been used for the implementation of the model for this thesis, that is proposed in NATSAR Manual as explained in section 5.2.3.2. For example, the attribute of source or caller can have different values or known as responses like if caller is Person on board (Pob), costal radio service (CRS), MEDICOS service, random observer on sea, random person on land or unknown source. These responses for the attribute of source are allocated with weights depending upon the trust level or how confirm the source is. As the SLT is highest in case the caller is person on board on the vessel facing emergency, the weight allocated to the source is 1 however, if the source is ambiguous the SLT is lowest and allocated weight is highest that is 3.

IF (Attribute_1) **AND** (Value) **THEN** Weight

For the overall assessment of the situation the weights of the values are aggregated that leads to the decision for the state of emergency that is uncertainty, alert, or distress.

Each attribute has an identification $attrib_n$. We assume there are n attributes in RBS and for the decision we have:

$$\text{IF } (attrib_i = value_j) \text{ AND } (attrib_m = value_k) \text{ AND } \ldots \text{ AND } (attrib_n = value_i)$$

5.2.3 Rule-Based Decision Support System

The proposed framework for the implementation of rule based DSS is a structure composed of two parts that is working memory storing facts and other part is rules with if-then condition as shown in Figure 17:

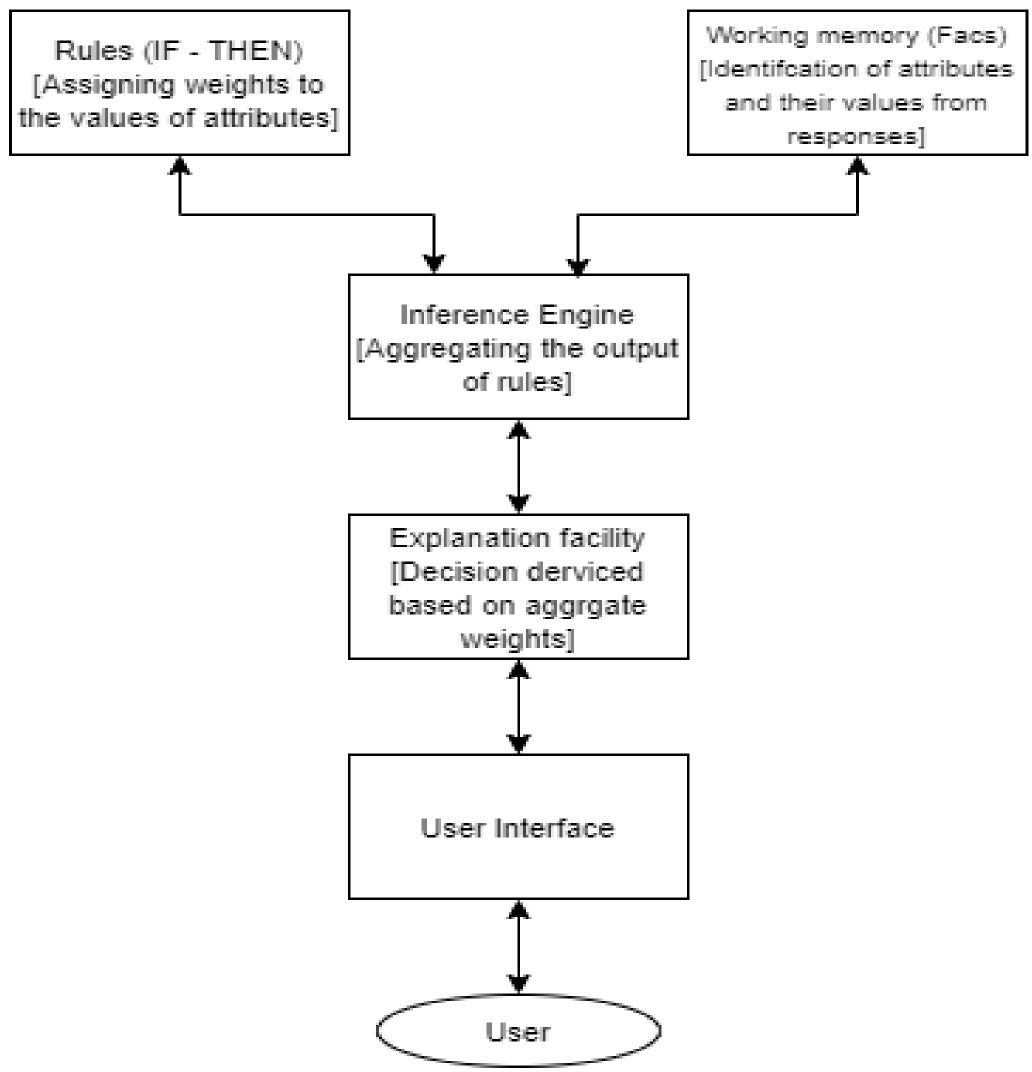

Figure 17: Rule-based DSS framework

The facts are contained in the working memory of the DSS and represents the attributes and their values as per current situation. The values are gathered for the attributes from the response of callers or investigation made by HRS personals. Weights are allocated to the values through rules stores in rules part of DSS. The facts stored in the working memory of the framework contains the declarative knowledge while the actions stored as procedural knowledge.

As mentioned in the knowledge representation part there could be two possible models for the implementation of rule based. We have used two approaches to implement the devised model. The first approach is based on taxonomy-based rule model in which the type of rules is triggered based on type of event. However, the priority of attribute can vary depending upon type of event reported.

The approach is based in our devised model of aggregate weights where the response value of each attribute is assigned with weights. Both approaches are discussed below:

5.2.3.1 APPROACH-1: Taxonomy Based Rule Model.

In this approach the goal is to assess the emergency with all the possible response value for the attributes according to the type of incident as discussed in section 4.1. In different type of events like "Fire in vessel" or "Missing vessel", same attributes can have different degree of importance and priorities. The rule base can be developed for individual type of incidents. The attributes can be prioritized according to the type of incident with all possible response values. In this approach the type of rules as defined in section 5.2.2.1, are triggered based on type of action or type of information required.

For example:

For the attribute of age of person on board (PoB):

Incident type: Small size missing vessel

For the type of incident where small size vessel is missing and person on board (PoB) is single the priority of attribute: age of the person will be higher. In such scenario the rules can be defined as follow:

IF event is small size vessel missing and PoB is single THEN inquire age. (Information gathering rule)

IF PoB is single and age > 50 THEN emergency is Distress (State identification rule)

Incident type: Technical failure in medium size vessel

However, if the incident type is of Technical failure in vessel of medium size with many numbers of people on board the significance of the attribute of age of people on board will be minimum, for evaluation of emergency state.

IF event is technical failure and PoB is not single THEN inquire location. (Information gathering rule)

Limitations:

For this approach, the biggest limitation is availability of data. In the knowledge acquisition phase, the acquired information regarding different scenarios was with generalized attributes. However, all possible values for the attributes are not known as most of the knowledge required for this approach is either implicit or tacit.

For the case analysis, the log available was depicting single scenario and that was of missing vessel. Though the attributed have been identified from the log but the knowledge regarding the possible values remain limited.

Due to these constraints the absolute model for rule based DSS for awareness stage could not be achieved. Therefore, a second approach is opted for the implementation that enable us to visualize relative model of the rule based DSS.

5.2.3.2 APPROACH -2: Aggregate Weight-Based Assessment.

After attributes are identified, we use them to assess the state of the emergency reported. For this purpose, Andreas Bull from JRCC has referred (sent on: 29/9/2020), the NATSAR Manual Australia in his email, for Search Urgency Assessment as shown in Figure 18 form that is used to rate the information regarding missing persons. In this form the response value for each attribute is assigned with the weight that shows the urgency state of each attribute.

Appendix E-1 Search Urgency Assessment Form

Search Urgency Assessment

Name of Incident:			No:
Date Completed:	Time completed:	Initials:	Incident date:

Number of subjects		
1 person	1	
2 people or 3 or more –separated	2	
3 people or more – together	3	
Age		
Very young	1	
Other	2-4	
Very Old	1	
Medical Condition		
Known illness or requires medication	1	
Suspected illness or injury	2	
Healthy	3	
Known fatality	4	
Potential vision impairment	1	
Intent		
Suicidal	1	
No known intent	3	
Absconder from facility	4	
Cognitive Capacity		
Dementia / Alzheimer's /Parkinson's	1	
Capacity of 16 year old or less	1	
Diagnosed mental illness, depression or anxiety	2	
No known capacity issues	3	
Experience profile		

Figure 18: Search Urgency Assessment form (NATSAR Manual)

In Figure 19 it can be seen how the accumulative weight of attributes is used to assess the urgency state of the emergency for the incident of lost person on land. The abstract rule stated is “the lower the number the more urgent the response”. In the form it is declared that, if the accumulative score of weight is between 9 – 17 the urgency is assessed as “Emergency Response” which is “Distress” in our case. If the score is between 18 – 27 the urgency is assessed for “Measured Response” which refers to “Alert state” in our case. For the accumulative score between 28 – 40 the urgency is assessed for “Evaluate & Investigate” which mirror “Uncertainty state” for our case.

Very good	3	
Equipment Profile		
Inadequate for activity/environment	1	
Questionable	2	
Adequate	3	
Very Well equipped	4	
Weather profile		
Existing Hazardous weather	1	
Hazardous forecast (8 hours or less)	2	
Hazardous forecast (more than 8 hours)	3	
No hazardous weather forecast	4	
Terrain and Hazards profile		
Known hazards	1	
Difficult terrain	2	
Few hazards	3	
Easy terrain, no known hazards	4	

9-17 Emergency Response 18-27 Measured response 28-40 Evaluate & Investigate
Note: If **any individual category** above is rated as **ONE (1)**, regardless of its total – the search could require an emergency response
Remember: the lower the number the more urgent the response!!!

Figure 19: Assessment of urgency

Following this second approach from the assessment form, limited value responses were identified for the attributes through knowledge engineering and the responses are assigned with weights. The flow diagram for the alternative implementation approach has been depicted in the Figure 20 where the process is initiated by reading the response for the attributes relevant to the situation. Next step is to read the weights assigned to individual responses and later sum all these weights to assess the emergency reported. The output of the process is affirmation for the state of emergency that also depicts the certainty level of the reported incident.

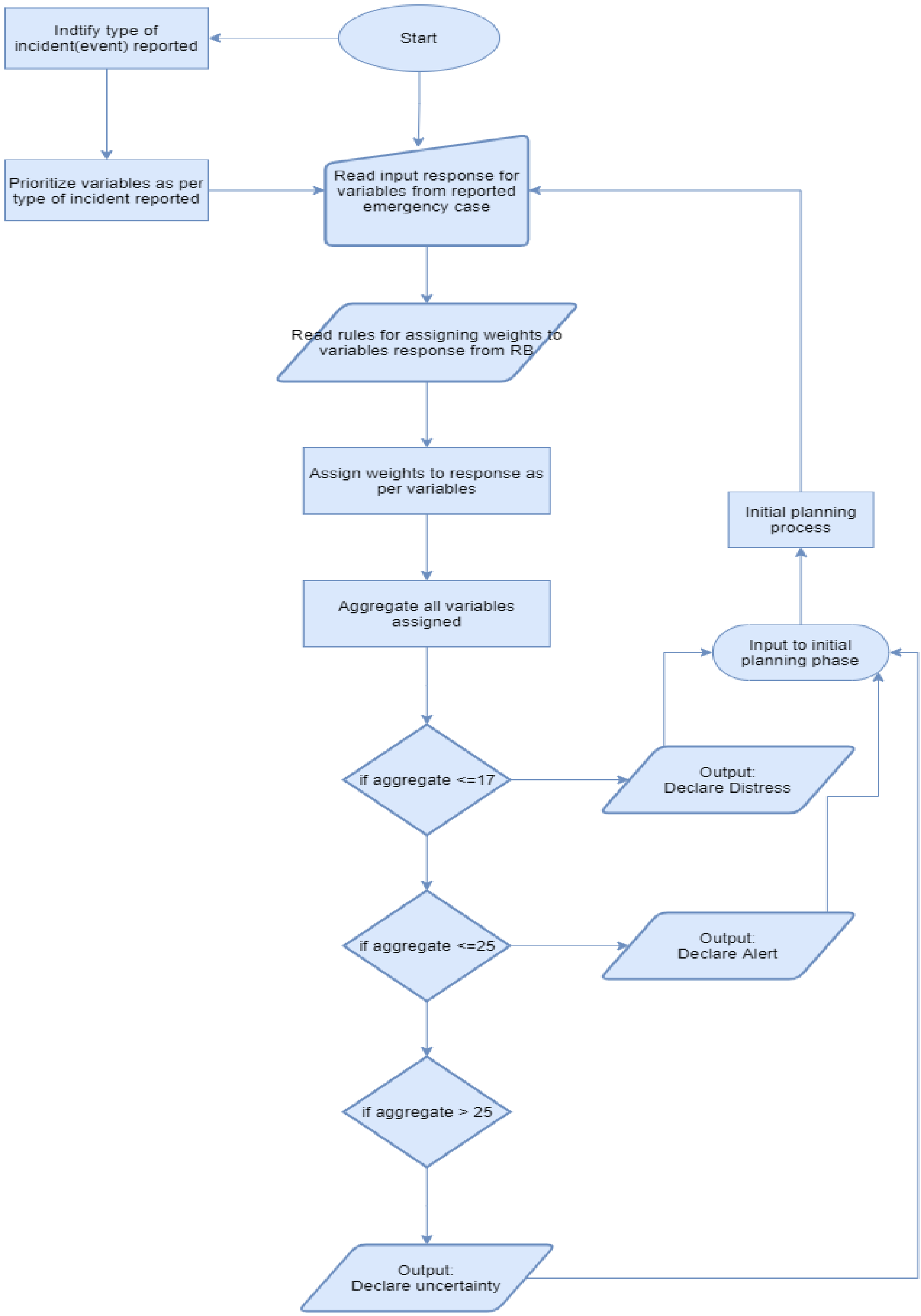

Figure 20: Flow Diagram for implementation

For assigning the weights to response value of attributes, the same principle has been followed as defined for urgency assessment that is lower weights are assigned to the response with higher urgency level as shown in Table 3.

	Attribute	**is**	**Condition/ Response value**	**THEN**	**metric**	**is**	**Weight**
IF	**Caller/Source**	is	Person on board (PoB), CRS, MEDICOS	THEN	metric	is	1
			Observer, GMDSS				2
			Person on land, Third person, unknown				3
IF	**Vessel Identification**	is	Known	THEN	metric	is	1
			Unknown				2
IF	**Number of subjects**	is	1 person	THEN	metric	is	2
			< 1 person				1
IF	**Age**	is	<18 years	THEN	metric	is	1
			18-55 years				2
			>55 years				1
IF	**Medical conditions**	is	Healthy	THEN	metric	is	3
			Known illness or required medication				2
			Suspected injury				1
IF	**Experience profile**	is	Not experienced/Not familiar from the area	THEN	metric	is	1
			Not experienced-familiar with area				2
			Experienced - not familiar with area				3
			Experienced - familiar with area				4
IF	**Equipment profile**	is	Inadequate equipment for survival for more than 4 hours	THEN	metric	is	1

			Adequate equipment for survival for more than 4 hours				2
			Well equipped				3
			Hazardous weather on sea				1
			Hazardous forecast (8hours or less)				2
			Hazardous forecast (more than 8 hours)				3
IF	**Weather profile**	is	No hazardous weather forecast	THEN	metric	is	4
			Known hazards				1
			Unknown hazard				2
IF	**Geographical Hazards profile**	is	No hazards	THEN	metric	is	3
			Longitude & latitude known				1
			Start point and End point known				2
IF	**Location**	Is	Location unknown	THEN	metric	is	3
			Mayday				1
			Technical error / fire				2
			Medical emergency				3
IF	**Event**	Is	Delayed	THEN	metric	is	4

Table 3: Attributes and weights

The urgency of the emergency is assessed by combining weights of response value of all attributes as shown in Table 4. The reported emergency is assessed with the help of rules that we have concluded based on the emergency assessment form as shown in Figure 19.

	Sum of					
	Caller/Source		< = 9 && < = 17		emergency is	**DISTRESS**
			> = 18 && < = 25		emergency is	**ALERT**
	AND		> 25		emergency is	**UNCERTAINTY**
	Vessel Identification					
	AND					
	Number of subjects					
	AND					
	Age					
	AND					
	Medical conditions					
	AND					
	Experience profile					
	AND					
	Equipment profile					
	AND					
IF	**Weather profile**	is				
	AND			THEN		
	Geographical Hazards profile					
	AND					
	Location					
	AND					
	Event					

Table 4:Emergency assessment

The DSS that is implements this model is developed using the MATLAB. For this purpose, the attributes are stored in form of questions through an array. At this point the attributes and their responses are hard coded to evaluate the emergency.

//Array for storing questions.

quest = ["Define the source of call? ","Is vessel id known or unknown? ","Number of subjects on board? ","What is age of the subject? ","Medical condition of the subject? ","The experience profile of the subject(s) on board? ","What is the equipment profile on board? ","Define the weather profile? ","Is geographical hazard profile of the area is known or unknown? ","Is location of the vessel known? ","Event is defined as: "];

Possible response values of all questions are stored using a structure array. The answers and their value (weights) against each answer is stored in *fields*. Structure array is also used as it would enable storing of different types of data in *fields*.

```
answers = struct('answ','value');
j=1;
while (j <= length(userInput))

    result = result + answers(j).value(userInput(1, j));

        j = j+1;
```

The combination of all weights is stored in *result* which is then used to assess reported emergency with if-else statements to classify emergency as “Distress”, “Alert” or “Uncertainty”.

```
disp(result);
   if (result>=1)&&(result<=17)
      disp("The state of emergency is Distress")
   elseif(result>=18)&&(result<=25)
      disp("The state of emergency is Alert")
   elseif (result>=25)&&(result<=33)
         disp("The state of emergency is uncertainty")
   end
```

The model we have acquired through the process is relative but not absolute. The model is defined relative, as evaluation made is relative to the case provided for assessment. With the help of relative model of DSS stated above, for the assessment of emergency reported, we are able to evaluate the certainty level of reported incident in terms of uncertainty, alert, or distress. The results acquired through the model are based on the response value defined for the attributes by the personals. For this relative model, the values for the attributes are defined manually as the number of responses known for the attributes are limited and hard coded.

5.2.3.3 Integration of RBS With Fuzzy Logic

To achieve absolute model that can enable the evaluation based on type of situation, we have recommended integration of fuzzy logic with RBS for accuracy of results. For this purpose, we estimated the minimum and maximum number of possible values for combination of response values of attributes as shown in Figure 21.

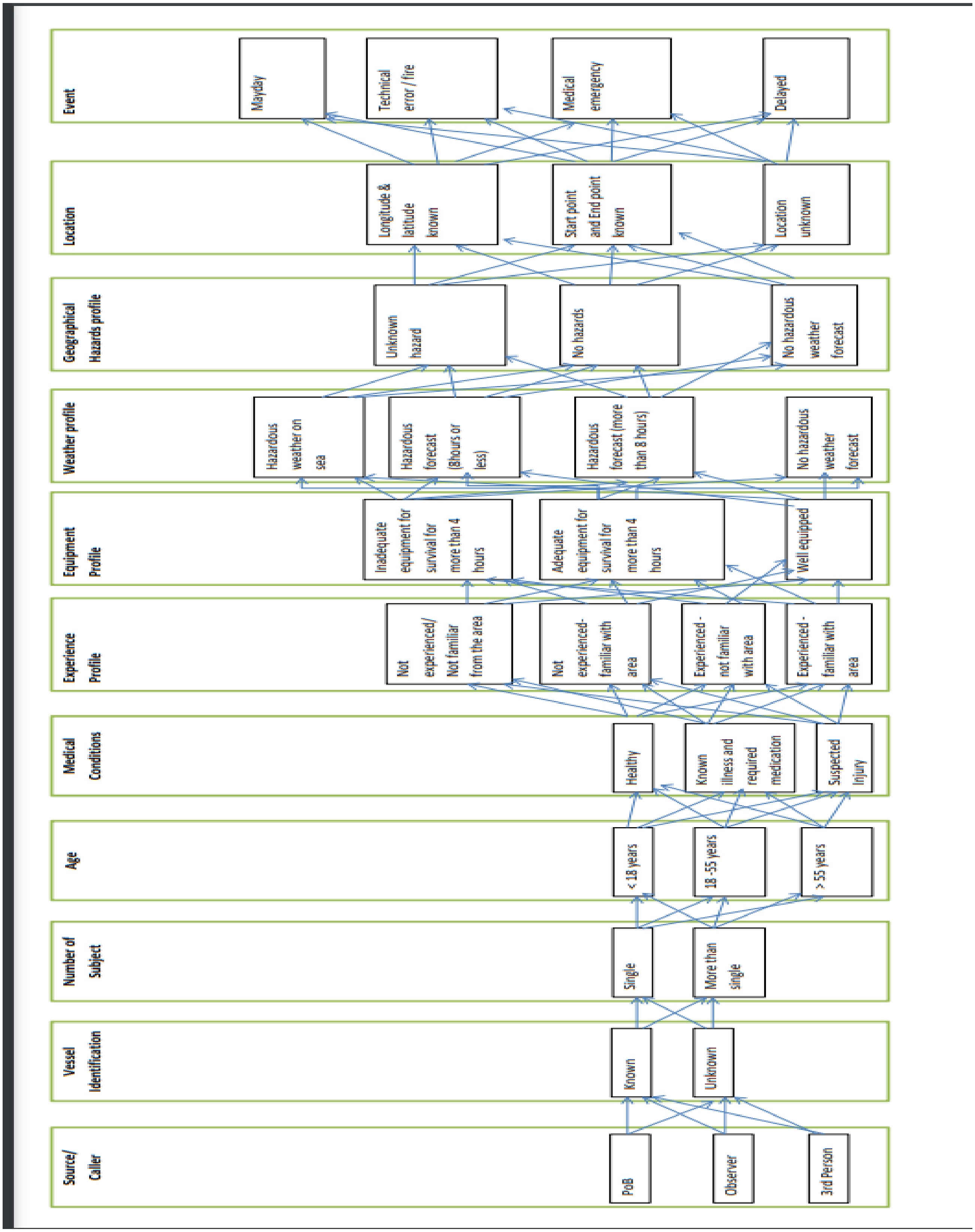

Figure 21: Possible combinations for responses of all identified attributes

The possible combinations identified for the attributes and their response values are calculated as:

$$C(n,r)=?$$

$$C(n,r)=C(36,11)$$

$$=36!(11!(36-11)!)$$

$$=36!11!\times25!$$

$$=6.00805296E+8$$

$$= 600805296$$

We have observed that there are more than 6 x 10^8 combinations possible for all response values of all attributes. However, many response values may not have any value for the assessment for certain types of emergencies.

In such case we propose that the fuzzy logic RBS can offer precise results for the evaluation of emergency reported. Fuzzy logic offers more than just true or false values [27] thus, from discrete values for the assessment of the emergency we can evaluate the emergency in terms of continuous values.

For implementation of fuzzy logic from the attributes of Awareness stage we require to identify fuzzy rules that can evaluate uncertainty of the emergency reported. In the alternative approach we have used earlier, we have identified 11 attributes for the assessment of emergency. For the fuzzy set of rules, we have identified the input attributes for the RB as: person on board profile, vessel profile, geographical profile and type of event reported as shown in Figure 22. For these attributes, the membership functions can be defined as “Low”, “Medium”, and “High” with the degree of relevance as 3, 2, 1. The degree of relevance also shows the state of urgency of attribute or confirmation of the information for the attribute.

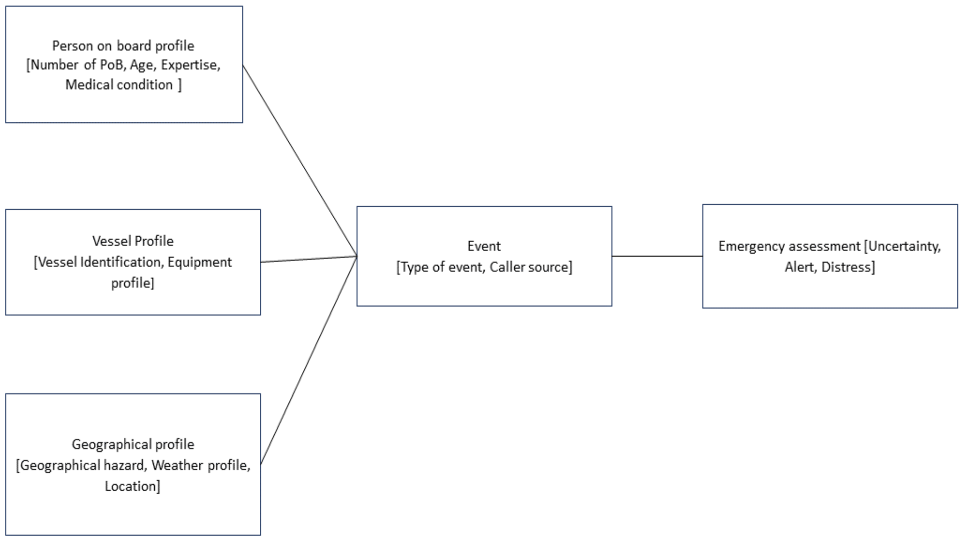

Figure 22: Fuzzy rule attributes for evaluation on emergency state

For the application of the mathematical model, we need to identify relation between all values of inputs and output that require more information regarding the possible values of the attributes and their weight according to the type of reported incident.

CHAPTER SIX

6 EVALUATION & RESULTS

In this chapter the relative model defined in the Implementation chapter is tested with the sample case for the evaluation of accuracy.

Various methods are used for the testing of decision support system (DSS) with an aim to detect errors without subjecting system to real life conditions. Most of the methods are developed in the field of Software testing or expert systems [28]. We have used manual approach for evaluation of the model of DSS with limited data. Despite of restricted resources and contacts with domain experts, we completed the static manual inspection of the expert system using “gold standard” test.

6.1 TESTING OF MODEL

For the “gold standard” test, the knowledge base is compared to either knowledge of expert or to the knowledge source that is used to build the DSS [24]. We have used the Nordavind case log 2018-S-5098 – Action Report 1, as the base case for the construction of the RBS therefore, the RBS model implemented is tested against this case for evaluation.

Test 1:

In Table 5, a test case has been run for Nordavind case using the information stored in log 2018-S-5098 - Action Report 1. The code of the model mentioned in section 5.2.3.2 is tested with the response values derived from the information stated in the log. The first test was conducted for the initial call received at the emergency center and information was provided by the caller for the missing vessel on sea. The information provided was regarding the identity of the person and origin of the vessel. The information was tested with the proposed model as shown in Table 5 In the table first column indicates the attributes and second column shows the response values derived from the information stated in the log. The third column of the table exhibit the weights as per the response value from the log. The last row showed the aggregated weight obtained after the sum of weight of all attributes. The aggregated weight achieved is 26 which indicates the range of “Uncertainty” phase.

Sample result	As reported in log (Response values)	case 1 (Weights)
Caller/Source	Notifier: XXXXX	3
Vessel Identification	Paragon 31'Ocean.Superstructure. Egg color with black stripe. 31fot. Call Sign LH2273 Name: NORDAVIND	1
Number of subjects	"Is alone on board"	2
Age	"Have a friend, XXXX 56-57yrs"	2
Medical conditions	"Sounded like he was hit on something and lost mobile, Sounded like one a little scream".	1
Experience profile		3
Equipment profile	"Have VHF on board"	2
Weather profile	No hazardous weather forecast	4
Geographical Hazards profile	Sounded like he was hit on something	2
Location	Was in Bergen soon. Run boat from the Helgeland Coast / Sandnessjøen	2
Event	Sounded like he was hit on something	4
Phase reported in log	Fase: Beredskap	
Phase as	>25 Uncertainty/Alert	26

Table 5: Test Case

The response value for each attribute is exhibited in Figure 23 where each response value is visible using colors depicting the state of urgency for individual attribute. The green color is for the least urgency response, yellow for medium urgency and red for response with highest urgency.

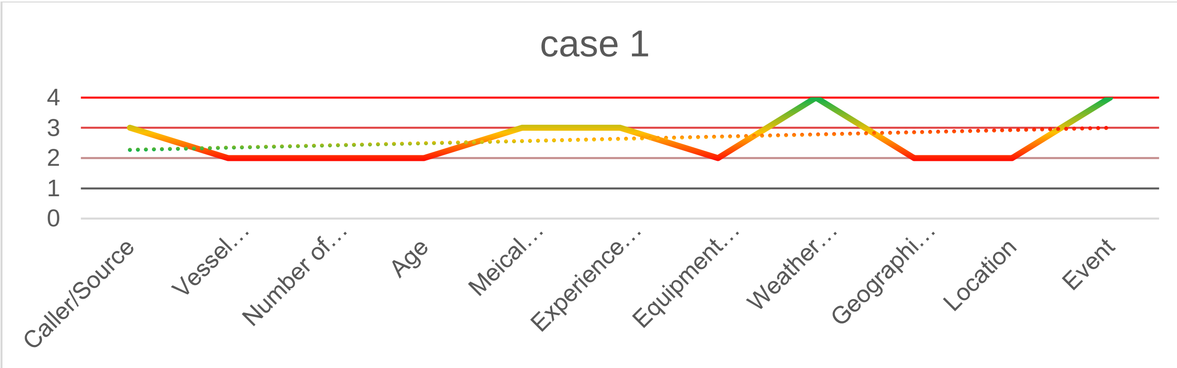

Figure 23: Result depiction

The x-axis of the graph shows the list of attributes used for assessment of emergency while the y-axis shows the weights assigned. Lower the number of weights is higher the level of urgency or level of confirmation for response value and higher the value of weight is, lower the level of urgency for the response value is. From the graph in Figure 21 above, it can be observed that most of the weights for the attributes are in the range between 2 and 4, showing low level of uncertainty because of the lack of confirmation for the information provided.

Test 2:

The second test case was conducted for the same incident of Nordavind, for the phase when more information was received by HRS from different sources as shown in Table 6. The second column of the table shows the information stated in the log from which the response values of attributes are assessed with respective weights.

Sample result (Attributes)	As reported in log (Response values)	case 1 (Weights)
Caller/Source	*Til: HRS Fra: FS SOLA* Provides short info sends mobile base coverage and picture boat by mail, 1h15min *Til: KV TOR Fra: LGQ* *Kategori: Publisering* *Flagg: HRS mottatt* Given phone number to Los 123: XXXX HPB heading north over Hjeltefjord. Soon by Fedje. Must info they about SAR group 21. KV Tor believes that if the missing is observed at full speed south	1

	by Fedje then there is little natural in this fine weather and does not continue south over the Hjeltefjord. Checked out by ops05, time: 23.11.2018 13:39 (UTC + 1)	
Vessel Identification	Paragon 31'Ocean.Superstructure. Egg color with black stripe. 31fot. Call sSign LH2273 Name: NORDAVIND	1
Number of subjects	"Is alone on board"	2
Age	"Have a friend, XXXX 56-57yrs"	2
Medical conditions	"Sounded like he was hit on something and lost mobile, Sounded like one a little scream".	1
Experience profile		
Equipment profile	"Have VHF on board"	2
Weather profile	No hazardous weather forecast	4
Geographical Hazards profile	Sounded like he was hit on something	2
Location	*Til: HRS Fra: RONJA STRAND* About 1030 they were at Toska just before the Terminal. Thinking it was a similar boat came by furiously. Meaning it may be this boat that went south. Til: HRS Fra: SLA BERGEN Note slightly north of oil spill in subheading 6050.63N 004 51.94E Til: HRS Fra: SAR21/S50 ETA 1358LT. Requests search area Will apply from Hjellestad and up the Hjeltefjord.	1
Event	*Til: KRS SØR Fra: HRS* Ask them to upgrade to the Mayday relay	1
Phase reported in log	Fase:Nød	
Phase as	>=17 Distress	17

Table 6: Test Case 2

When the response value of the attributes changes the phase of the emergency changes from uncertainty to distress as per the calculation of collective weights in the defined model.

6.2 RESULTS

For the first test, the response values for the attributes are translated from the initial information received at HRS by caller and as recorded in log. The attributes identified in the knowledge engineering phase of the project are located in the log first. The response recorded for these attributes in the log are assigned with weights as per the rules defined in the RBS. When the sum of all the weights is calculated, that is 26, the state of the emergency reported is defined with the help of *state identification rule* that is:

IF result (AND weights of all attributes) is greater than 25 THEN the state of emergency is uncertainty.

The result achieved in the first test is “Uncertainty” for emergency phase. The result achieved is same as that of phase identified in the log of the case and stated as Fase: Beredskap.

For the second test, the information recorded in the log showed how the phase of emergency changed from uncertainty to distress with the availability of more information and confirmation of source of information. When more information is received at HRS from different sources there is change in the response value of attributes like source, location, and the nature of event. With the confirmation of the information increases result in decrease of e weight of the response values. The weights are assigned with rules defined in RBS and they are summed for the decision. As the sum of combined weights is calculated to 17 then state identification rule enabled to identify state of the emergency reported that is:

IF result (AND weights of all attributes) is less than equal to 17 and great than equal to 9 THEN the state of emergency is distress.

The state identified through the model in Test 2 is “Distress” that is same as that of state defined in the log of Nordavind case that is Nød.

6.2.1 Observations

As per the results of the two tests for the Nordavind case the relative model can be evaluated in terms of accuracy. However, as the result can be verified only for one case available therefore, the accuracy of the relative model may require more cases for authorization purpose.

It is also observed from the tests that how weights of the responses can change the state of emergency by difference of one number only. It is also because we have used discrete threshold values for defining the state of the emergency in the rule based following the search urgency assessment form as shown in Figure 18.

As the evaluated accuracy of the model is limited as per availability of cases, however the accuracy can be enhanced further for the emergency assessment after assessing individual type of incidents, with complete logs. Therefore, we proposed a survey, which can be assessed if the priority (weight) of the attributes varies with the type of incident and weights of different attributes can vary with the incident type. The survey is created from the information for the different emergencies that has been extracted from the Nasjonal-veileder-for-planverk-og-samvirke-Vedlegg-planmaler sent by the personals from HRS (Table 7).

1: Distress / High risk/Confirmed emergency; 2: Alert / Low confirmation; 3: Low Confirmation; 4: Uncertain; 5: Ambiguous		Prioritize variables as per the incident: 1 for highest priority variable and 2 for less and so on										
Attributes	**Metrics**	**May day**	**Technical error / fire**	**Medical emergency**	**Delayed**	**Drifting vessel**	**Assistance vessel**	**Diving incident**	**Offshore incident**	**Sea Accident**	**Person in water**	
How would you rate if source of alert call is:												
Person on Board (PoB)												
Coastal Radio Service (CRS)												
MEDICOS												
Observer												
GMDSS												
Person on land, Third person, unknown												
How would you rate if identification of vessel is:												
Known												
Unknown												
Not required												
How would you rate emergency if person on board is												
1 person												
2 persons												
3-10 persons												
More than 10 persons												
Unknown												
How would you rate if age of person is:												
Unknown												
<18 years												
18-55 years												
>55 years : :												

Table 7: Attribute priority assessment survey for different types of incidents

For the data collection through the survey suggested in Table 7, we needed response from domain experts which could not have been achieved due to accessibility constraint. The response from the survey can enable to identify the ranges for the fuzzy rules set as per the type of incident as discussed in Chapter 5 defining the response values in terms of low, medium, or high.

CHAPTER SEVEN

7 DISCUSSION

In this chapter, we address the research questions mentioned in chapter 1 section 1.4. The discussion includes details about the identification, investigation, and results of these queries.

7.1 MODELLING OF STANDARDS SAR PROCESSES

Research goal A: *Form an understanding of the mental process underlying a SAR problem solving process. That include the mental actions of RCC people to generate a hypothesis for the type of emergency while evaluating the severity.*

To develop an understanding of the psychological process used for the SAR problem solving, we made a detailed analysis of the SAR processes using IAMSAR Manuals [1, 2] and experience of SAR personnel at HRS. IAMSAR Manuals [1, 2] provided the standard SAR processes for identification and modelling of the Awareness stage using 4EM (Enterprise Modelling). In Chapter 2 section 2.1 the overall processes of SAR are modelled using 4EM architecture which enabled us to identify the flow of information from one process to other. The gained insight into SAR processes highlighted the fact that the output of Awareness stage has a great importance as an input to other stages of SAR operations. Subsequently, 4EM was used to model Awareness stage (see Chapter 3) for identifying tasks and sub-tasks. Along with inputs and outputs, the resulting model of Awareness process also showed the information flow within the process.

Furthermore, we mapped sample incidents which familiarized us with potential decision points and details for workflow from the perspective of HRS personnel in the awareness process. Mapping and modeling of the processes provided accurate definitions for the state of emergencies i.e., uncertainty, alert, and distress. HRS personnel interviews were used to extract the reasoning for the decisions in certain states of emergency. The interviews were also used to contemplate the relevance of the confirmation of the reported incident and availability of information for the state of emergency, rather than the content of information.

For the understanding of role of AI for SAR, we have also made literature review as mentioned in chapter 2. Previous studies showed the novelty of the idea of using DSS for analyzing the incident reported in terms of state of emergency. It has been observed, those studies are limited to the integration of the AI into SAR operations for the action plan stage. or for planning of search and rescue operations.

7.2 KNOWLEDGE ACQUISITION AND REPRESENTATION THROUGH KE

RQ2: *Identification of the nature and characteristic of the type of data and information used in awareness stage and different SAR- subtasks, as per the emergency cases.*

The second research question required the identification of the type of the data and information that are generally recognized by personnel in different SAR sub tasks, based on their experience related to the different types of incidents. Our models are created using the Enterprise Modelling approach, which allowed the identification of flow of information between the sub-tasks and also from one stage to another. The information flow of Awareness stage is represented in Figure 8 (see Chapter 3). The process model shows the nature and type of data required for decision making, the impact of availability of the distinct data on the next sub-task within the same process or next stage. For example, in the case of a missing vessel, the availability of information regarding the last known location at sea can change the state of emergency from Uncertainty to Alert.

RQ3: *How to acquire knowledge deploying knowledge engineering methods from domain experts and other available resources.*

DSS modelling requires the processing of the human knowledge into the requirements and expectations of the domain expertise. Later, the model was integrated into the knowledge base to gain robust, useful, and intelligent system [26]. To attain and process the knowledge, we used knowledge engineering methods as discussed in chapter 3. Building of DSS required various types of knowledge, which was acquired through different methods. However, most explicit knowledge was gained via the procedural manuals and historical data. These resources provided us with the standard procedural knowledge for the SAR operations and expected input and outputs of these processes. These documents defined SAR terminologies, roles of different domain experts, input and output of Awareness stage, criteria for emergency assessment, and classification of the emergency terms (Uncertainty, Alert, and Distress). Definitive information related to types of sea emergencies and their assessment was acquired from manual of “Nasjonal Veileder for planverk og samvirke i redningstjenesten Level 2” provided by HRS.

The data acquisition of the implicit and tacit knowledge was gained via interviews & meetings with domain experts, and investigation of the past incidents. Although the unforeseeable circumstances (due to COVID-19 pandemic) restricted our interaction with domain experts, teleconferences and email communication was maintained. Despite of the restrictions and hurdles, we managed to identify the required input of the awareness stage. The input resulted in the model of the DSS with relative values. We used logs of the “Nordavind” and “Viking Sky” incidents for the analysis, which enable us to draw the decision tree for the incidents and map the flow chart for the incident assessment process. The information acquired from these sources depicted the tactics and experience of domain experts, as well as the application of the explicit knowledge in practical environment.

RQ4: *Identification of the attributes and representing the knowledge to rules for the rule based DSS.*

Through the knowledge acquisition process, we were able to identify the attributes required for the assessment of the emergency in the awareness stage. In Chapter 4, we have defined the knowledge base model where identification of the different attributes varies with the types of incident on the sea. Thus, the priorities of these attributes also vary with differing conditions of the incidents, e.g., In the case of small missing vessel the information about the number of people on board is more important than in the case of large vessel with hundreds of persons on board. Accordingly, the priority number will determine the next stage that is action plan of the SAR operations. The identified attributes (Table 1) were also consulted with HRS domain expert to verify the relevancy of the attributes for the awareness stage.

7.3 Rule-Based Model For Assessment Of Emergency

RQ 5: *What value ranges of each attributes can be used as facts to assess the certainty of the incident reported?*

We used the knowledge acquisition process output to define attributes that are used to assess the reported emergency. Along with these attributes the potential response values are also identified. The defined attributes and their possible response values or actions are mapped as a decision tree in Figure 15, which leads to knowledge representation process of knowledge engineering. We have used rules for knowledge representation, where attributes and their responses are represented in form of rules.

For the knowledge representation two approaches have been adopted. In first approach different types of rules have been identified according to the attributes and their response values as discussed in chapter 5, section 5.2.2.1. We defined four different types of rules which aids to *identify attributes from information*, *information gathering*, *identify state of emergency*, or can lead to some decision in form of action through *decision rules*.

In the second approach, attributes are assigned with a finite number of response values and the response values are allocated with weights with the help of rules. The weights of the response values indicate the gravity of the value in terms of urgency or indicates the conformation of the value present. The knowledge represented in form of rules is stored in rule-base component of the RBS.

RQ6: *What approach and methodology can be used for the rule- based system (RBS) to assess the emergency?*

We implemented the rule-based system for emergency assessment after the knowledge representation process. Similar to knowledge representation for RBS, we have also proposed two alternative approaches for implementation of RBS for awareness stage of SAR operations (see Chapter 5, section 5.2). In the first approach we defined the implementation of RBS with attributes and their all-possible response values as per type of incident. In this approach it has been hypothesized the response value of attributes should be treated as per type of incident in terms of gravity. For this approach forward chaining can be implemented that can enable the system to assess the emergency reported. However, maturity of this stage depends on the availability of the data, which was limited at the time of this project.

Therefore, we have used second approach for implementation of the RBS, and we are able to achieve relative model for the assessment of the emergency in awareness stage. For this model we have used the second approach of knowledge representation, where finite number of response values are identified for each attribute. These response values are assigned with discrete weights with the help of rules. The sum of the weights of all attributes enabled the assessment of emergency reported in terms of uncertainty, alert, or distress. The major rule for the implementation of this approach used was the lower the number, higher will be the gravity of situation in terms of urgency. Thus, lower the sum of all response values, higher will be the state of emergency. Though, we have achieved a relative model of RBS. However, the additional data can help us to develop this model into absolute model of RBS for emergency assessment in awareness stage. Possible data that can be used to implement an absolute model is shown in Table-7. Similar queries can accumulate more data and can help to identify response values of attributes for a particular type of incident reported. Appropriately, the priority of the attributes can be assigned for the individual incident, which can calibrate our existing model.

RQ7: *Can fuzzy-logic enhance the accuracy of assessment on rule-based system?*

We achieved more accurate results after using "Gold standard" where same case is used for the development of the system and the testing of the system (see Chapter 6). The results acquired through this approach are discrete and can vary with a minor change in the response value of attribute. Using discrete values for the emergency assessment can also lead to errors when the situation is complex, or information is missing, which can lead to varying decision with difference of one digit.

Considering this as we have explained in Chapter 5, section 5.2.3.3, integrating the fuzzy logic with identified membership functions and defined degree of relevance can enable us to acquire accurate decisions for various types of incidents with diversified response values for attributes. The survey analysis can enable identification of mathematical model that can lead to absolute model for the assessment of the SAR emergency reported at HRS with fuzzy rule-based system. However, for this thesis we are not able to do sufficient for the implementation of the proposed fuzzy rule based DSS and proposed for the future work.

CHAPTER EIGHT

8 CONCLUSION

In this chapter we present the conclusion of our investigation and research made for the AISAR project focusing on the awareness stage of the SAR operations. In section 8.2 we propose a future work that can reinforce the achieved model and allows to further enhance the performance and accuracy of the system.

8.1 CONCLUSION

Previous studies showed that most of the work done for the integration of AI for SAR process was concerned to the planning stage where objective was to plan the SAR mission using Artificial intelligence after the confirmation of emergency. However, not much work could have been found where AI has been used for the assessment of emergency in the initial stage of SAR operations, although studies have highlighted the significance of awareness stage in the operations of search and rescue. This also implies that output of Awareness stage is of substantial importance for the decisions in later stages of SAR operations. Thus, in the present study we came to the conclusion that rule-based methodology is suitable for the integration of artificial intelligence in the Awareness stage of AISAR. Rule-based models can accomplish the reduction of the decision-making time for rescuers (domain experts) and they can promptly evaluate uncertain situations from distress calls, while assessing the multiple calls simultaneously.

However, the background research also revealed that decisions made in Awareness stage are mostly based on the implicit and tacit knowledge of domain experts rather than that of explicit knowledge. Due to this shortfall of explicit information, the SAR operations lack formal procedures and rules in Awareness stage. This is one of the main reasons we have focused on the knowledge engineering of Awareness stage, that enabled us to conclude rules for the implementation of rule-based model. For the knowledge engineering we have followed the three steps of the process that are knowledge acquisition, knowledge representation and implementation.

To acquire explicit, implicit, and tacit knowledge of the awareness stage we have used different knowledge acquisition methods that include domain expert meetings, historical data, procedural manuals, etc. The knowledge acquired defined the knowledge base model where attributes are identified. The attributes are identified on the basis of their impact on the output of the awareness stage.

After the acquisition of the knowledge the step was the representation of acquired knowledge in terms of rules. We investigated different approaches to define rules with possible response values for the gained attributes. Initially, different types of rules were identified on the basis of their goals. However, for this approach all possible response values for attributes should be known. Due to the limited availability of data an alternate approach has been adopted. In this approach we identified limited response values for each attribute and allocated all values with weights as per level of emergency exhibited by each response value, or as per confirmation of the information represented by each response value.

Subsequently, we investigated different approaches for the implementation of the RBS for Awareness stage with defined rules. We opted for the approach in which an emergency was assessed based on the limited response value of the attributes and their weights. We defined a relative model for this approach, in which we established rules that assess the sum of weights of all attributes and define the state of emergency in terms of Uncertainty, Alert and Distress. The test results have shown that decisions achieved through this model were the same as the ones achieved in cases which followed the well-established "gold standard". However, further testing of the model by applying it to additional cases can help validating the relative model, especially if checked for different types of sea incidents.

8.2 FUTURE WORK

Heretofore, we developed a relative model through RBS for awareness stage, which can provide relative values for the state of emergency. In future, we would like to design an absolute model, in which all attributes and their response values will be checked for different types of sea incidents. Furthermore, defining the priority of attributes as per the type of sea incident can help achieve accuracy and ultimately lead to absolute values for all types of incidents. Additionally, with the help of this data and known relation between all attributes, fuzzy logic can be integrated to RBS that can help to translate domain expert knowledge to computer knowledge in a more effective way.

To achieve the absolute model, it is recommended that due deliberation of historical data is required to express all attributes and to estimate their response values according in reference to different types of sea incidents/accidents. Defining priority of the attributes as per the type of sea incident can help achieve accuracy in results for all types of incidents. After screening this historical data can be further defined in known relations between all attributes.

Fuzzy logic is one of the best tools using AI to integrate RBS that can provide best help in translating domain expert knowledge to computer knowledge in most effective way. This method of reasoning will resemble to human reasoning and hence will be easy for paramedics and health related personal to understand an engineering approach of reasoning. Further fuzzy logic will reduce the risks using intermediate possibilities between “0” and any absolute value.

Along with this integration of Natural Language Processing (NLP) can also help to predict missing attributes for rule based and can also enhance the performance of FRBS. Using NLP can also enable prediction for emergency awareness with limited information available.

BIBLIOGRAPHY

1. IMO, ICAO. (2010). IAMSAR Manual Volume I. London.
2. IMO, ICAO. (2010). IAMSAR Manual Volume II. London.
3. Hovedredningssentralen. (2020, October 21). English. https://www.hovedredningssentralen.no/english/
4. JRCC, N. (2019). SAR Cooperation Plan (Part III, IV, V and VI).
5. Schreiber.G., Akkermans. H., et al, (1999), Knowledge Engineering and Management: The CommonKADS Methodology. The MIT press, https://doi.org/10.7551/mitpress/4073.001.0001
6. Zhang, Y., & Yang, X. (2014). Expert system based on fuzzy rules for maritime search and rescue. Computer Modelling & New Technologies, 18, 143–148. https://www.semanticscholar.org/paper/Expert-system-based-on-fuzzy-rules-for-maritime-and-Zhang-Yang/6b59560509dcb467da4c3a680e71e3ca0aaea667
7. Bellantuono, N., Camarda, P., Lisi, S., Caneva, P., Pontrandolfo, P., Romano, V., ... & Selex, E. S. (2016). Emergency management at sea: A decision support system for Search and Rescue operations. Journal of Software & Systems Development, 27-37.
8. Karatas, M., Razi, N., & Gunal, M. M. (2017). An ILP and simulation model to optimize search and rescue helicopter operations. Journal of the Operational Research Society, 68(11), 1335-1351.
9. Guo, Y., Ye, Y., Yang, Q., & Yang, K. (2019). A multi-objective INLP model of sustainable resource allocation for long-range maritime search and rescue. Sustainability, 11(3), 929.
10. Abi-Zeid, I., Lamontagne, L., & Yang, Q. (1999, July). Is CBR applicable to the coordination of search and rescue operations? A feasibility study. In International Conference on Case-Based Reasoning (pp. 358-370). Springer, Berlin, Heidelberg.
11. Ligęza, A. (2005). Logical Foundations for Rule-Based Systems. Volume KU 0146.
12. Grosan C., Abraham A. (2011) Rule-Based Expert Systems. In: Intelligent Systems. Intelligent Systems Reference Library, vol 17. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-21004-4_7
13. Welbank, M. (1990). An overview of knowledge acquisition methods. Interacting with computers, 2(1), 83-91.
14. AMSA. (2018, February). National Search & Rescue Manual. Australian Maritime Safety Authority (AMSA).
15. Barr. A., Feigenbaum. E. A., (1981). The Handbook of Artificial Intelligence. Butterworth-Heinemann

16. B.Stabell, C. (1987). Decision support systems: Alternative perspectives and schools. Decision Support Systems, Vol 3, 243 - 251.
17. Boose, J., Gaines. B.R. (1985). A knowledge acquistion program for expert systemsbased on personal construct psychology. International Journal of Man-machine studies , 525-595.
18. D., S. (2000-2001). Leveraging tacit organizational knowledge. Journal of Management Information Systems Winter vol. 17, 9 - 24.
19. Davis, R. Shrobe, H & Solovits, P. (1993). What is Knowledge Representation? AI Magazine, 14, 1 , 17 - 33.
20. Hadjimichael. D., Tsoukas. H. (2019). Toward a Better Understanding of Tacit Knowledge in Organizations: Taking Stock and Moving Forward. Academy of Management Annals.
21. Alotaiby. F.A., Foda. S. G. (2011). Chemical threats diagnosis expert system (CTDES). Advanced Materials Research, 396 - 398.
22. Iqbal, M. (2019). Specialization Report: Artifical Intelligence in Search and Rescue. Unpublished.
23. Jamtii, B. O. (2018). SAR in Norwegian Arctic. Hovedredningssentralen.
24. Lamy. J.B., Ellinis. A., et al. (2010). Testing Methods for Decision Support Systems. IntechOpen.
25. Peffers. K., Tuunanen. T., et al. (2006). The design science research process: A model for producing and presenting information systems research.
26. Martinez, M. V. (2017). Knowledge Engineering for Intelligent Decision Support. Proceedings of the Twenty-Sixth International Joint Conference on Artificial Intelligence , (pp. 5131 - 51315).
27. Mendel, J. M. (2017). Uncertain Rule-Based Fuzzy Systems. Springer, Cham.
28. Meyer, B. (2008). Seven principles of software testing. IEEE Computer Volume 41, 99 - 101.
29. Nalepa, G. J. (2017). Knowledge Engineering with Rules. In Modeling with Rules Using Semantic Knowledge Engineering (pp. 27 - 48). Springer, Cham.
30. Nonaka, I. (1998). The knowledge creating company. Harvard Business Review on Knowledge Management.
31. Rajkovic, V., Efstathiou, J., Bohanec, M. (1987). A Concept of Rule-Based Decision Support Systems. In Optimization Models Using Fuzzy Sets and Possibility Theory (pp. 292--299). Springer Netherlands.
32. Røstad, E. (2019, March 25). Marerittdøgnet på «Viking Sky». Retrieved from Nrk: https://www.nrk.no/norge/xl/marerittdognet-pa-_viking-sky_-1.14489408
33. Wielinga, B., et al. (2012). Towards a Unification of Knowledge Modelling Approaches. Second Generation Expert Systems, 299-336.

9 APPENDIX

The code for the Aggregate based model proposed for the awareness stage is written in MATLAB. The implemented code for the model is as follow:

```
clc, clear
%Storing questions in string array

quest = ["Define the source of call? ","Is vessel id known or unknown? ","Number of subjects on board? ","What is age of the subject? ","Medical condition of the subject? ","The experience profile of the subject(s) on board? ","What is the equipment profile on board? ","Define the weather profile? ","Is geographical hazard profile of the area is known or unknown? ","Is location of the vessel known? ","Event is defined as: "];

%disp(quest(1,2));

%Storing answer and question in structure

%answers = struct('answ1',value1);
answers = struct('answ','value');

answers(1).answ =["1.PoB", "2. MEDICOS", "3. CRS", "4. GMDSS", "5. Observer on sea", "6. Unknown"];
answers(1).value =[1, 1, 2, 1 , 2,  3];

answers(2).answ =["1. Known", "2. Unknown"];
answers(2).value =[2, 1];

answers(3).answ= ["1. Single person on board", "2. <1 person on board"];
answers(3).value=[1, 2];

answers(4).answ =["1. <18 years", "2. 18 to 55 years", "3. >55 years"];
answers(4).value =[1, 2, 1];

answers(5).answ =["1. Healthy", "2. Known illness or require medication","3. Suspected Injury"];
answers(5).value =[3, 2, 1];

answers(6).answ = ["1. No Experience - not familiar with area", "2. No Experience - familiar with area", "3. Experience - not familiar with area", "4. Experience - familiar with area"];
answers(6).value = [1, 2, 3, 4];

answers(7).answ =["1. Inadequate for more than 4 hours","2. Adequate for more than 4 hours", "3. Well Equipped"];
answers(7).value = [1, 2, 3];

answers(8).answ = ["1. Hazardous weather on sea", "2. Hazardous forecast (8 hours or less", "3. Hazardous forecast (more than 8 hours","4. No hazardous weather forecast"];
```

```
answers(8).value =[1, 2, 3, 4];

answers(9).answ = ["1. Known hazard", "2. Unknown hazard", "3. No hazard"];
answers(9).value = [1, 2, 3];

answers(10).answ = ["1. Longitude & Latitude Known", "2. Start & end point known", "3. Unknown"];
answers(10).value = [1, 2, 3];

answers(11).answ = ["1. Mayday", "2. Technical Error or fire", "3. Medical emergency", "4. Delayed"];
answers(11).value = [1, 2, 3, 4];

%userinput stored in array
%disp(length(quest));
i = 1;
while (i <= length(quest))
    disp(quest(1, i));
   disp(answers(i).answ);
   %disp(answers(i).value);
    userInput(1, i) = input('Answer: ');
    %disp(userInput(1,i))
    %input(userInput(1,i));
     i = i+1;

end

%disp(userInput)

%user's answers are now stored in userInput array next we will be evaluating
%the results according to answers

%flag = false;
result = 0;

j=1;
while (j <= length(userInput))
 %   if(userInput(1,j) == 1)

           % flag =true;
            %break;
    %end

     result = result + answers(j).value(userInput(1, j));

            j = j+1;
end
%if (flag==true)
%disp("This is highest emergency");
%else
    disp(result);
    if (result>=1)&&(result<=17)
        disp("The state of emergency is Distress")
```

```
    elseif(result>=18)&&(result<=25)
        disp("The state of emergency is Alert")
    elseif (result>=25)&&(result<=33)
           disp("The state of emergency is uncertainty")
    end


   Y = userInput;
   %Y1 = result;
plot(Y, 'r');
%plot(Y1, 'b')
```

NTNU
Norwegian University of
Science and Technology