A CONCEPT FOR MARITIME ACCIDENT PREVENTION BASED ON EXPERT SYSTEM

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Master's Degree Thesis

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This research is dedicated to those who lost their valuable lives in maritime accidents.

Acknowledgement

At first I express my heartfelt thankfulness and deepest appreciation to almighty Allah for giving me the opportunity to complete this research successfully in time.

On October 2012, I still remember the beautiful autumn morning, Professor Kazuhiko Hasegawa asked me to study accidents and come up with a new methodology that can deal with the accident problems. Since that day, my journey began and it has been a thrilling experience for me to go through many accident documentaries, reports and browsing into the swarm of information on the internet. I express my heartfelt gratitude to my Professor for his intelligent guidance and endorsing me to conduct such research. Professor Hasegawa has been an inspiration to me. His wittiness has always saved the day when I got stuck into a problem. His directions always worked for me when I felt lost. Indeed, Professor Hasegawa has not only been a supervisor but also been a good friend to me.

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Abstract

The problem of maritime accident is quite complex and researchers from various disciplines of science and engineering attempt to solve the problem. Most of the maritime accidents are resulted from variety of causes and the end result i.e. the accident is not evident until it reaches to a particular space and/or time. On the contrary, a particular type of accident problem may have many solutions with respect to space and time depending upon the perspective from which it is observed. Hence the problem cannot be addressed using a single formula like the Newton's law of motion, which basically is able to explain all the force and motion related phenomena in the universe. In order to deal with accident problems many accident theories have been proposed which range from short term to long-term solutions. In addition, studies on accident investigation reports reveal how human users/operators make wrong decision and how these contribute to the accident occurrence. In reality, many of the contributing factors disguise as innocent before the accident. This is the reason why an accident becomes invisible to human users/operators until there is nothing to be done. This research aims to study in this area to gain knowledge from real accidents and utilize it in an Expert System (ES) so that human operators/users may be warned in advance and a hidden but sure accident can be avoided. The study initiated with a literature review and established the novel approach of the current research theme. A new idea to detect hidden causes of an accident is proposed based on a kind of expert system technique. Following the chess game analogy, a position evaluation concept has been shown. A framework has been developed which can be utilized to build and run the system. Three different techniques have been proposed based on the application of the system. The accident of Costa Concordia (2012) in Italy and the accident of Bright Field (1996) in the United States are demonstrated using the proposed method explaining why and where the accidents invisibly start, even though at that time nothing strange happens. The study on this concept appears to be new but very useful. Further research and investigations however, are proposed as future recommendation.

Chapter 1

Introduction

The characteristics of maritime accidents are explained in this chapter. The tradition of dealing maritime accidents is also discussed. Thereafter the study focused on the motivation and the outline of the research.

1.1 The Maritime Accident Problem

Maritime accidents are quite devastating and the magnitudes of loss of resources are tremendous. In many instances accidents take place without significantly noticeable warnings. Some accidents occur due to failure of preventive measures, some occur due to a series of mistakes made by the crew, some are purely due to natural causes and similarly many more can be mentioned. According to the Cambridge Dictionaries Online [1], the word accident means “something bad that happens that is **not expected** or intended and that often damages something or injures someone”. The important keyword here is “**not expected**” or “**unexpected**”. Hence in general terms maritime accidents, similar to other accidents, are a problem of the occurrence of an unwanted event. Therefore, the solution of a maritime accident problem is preventing the unwanted event to take place. In order to achieve this, two important aspects are needed to be addressed:

1) Identification of the unwanted event and possible ways the event may take place.
2) Suggestion/advice to the crew to stop the unwanted event to take place.

Therefore, the accident problem branches out to two sub problems, one it to identify an accident and two is to find appropriate advice for the crew to stop the accident. With the help of accident investigation studies these aspects can be dealt. All accident investigations try to find out the reasons behind the “unexpected” event. As accident investigation progress the reasons behind the unexpected event clarifies gradually and the whole picture gets distinctly constructed with respect to a timeline. Only at that stage it becomes obvious that the accident could have been avoided if something was or was not done by someone responsible. The current research approaches accident from this perspective. The key concept of this research is to learn from the final moments of accidents and extract the knowledge in order to apply it to other type of ship (or even for the same ship) in the form of algorithm to prevent similar accidents to take place in the future.

1.2 Dealing with Accidents

Traditionally accidents are considered rooted out from faults of human beings and almost all the accident investigations converge into the theory of how the captain/crew made the mistake in the first place. Some investigations suggest that accidents occur not only because of a simple visible error but also due to complex unseen mistakes made by human operators over a significant period of time. Therefore, when the results of such studies are applied in real life, beneficial effects are immediately observed. But the problem is new technologies are emerging every day and new breed of accident problems are being derived thereafter. The dynamic socio-technical aspects also play a crucial role in this regard. Generally, leanings from previous accidents are transferred to the crew through training and education, which many may consider as a concrete solution to the problem. Therefore, researchers and professionals from various disciplines attempt to theorize the accident problems and derive solutions from those theories. Such endeavors give birth to new regulations, new training programs, new designs of ships and its components, new devices/gadgets and many more. Since the accident of RMS Titanic (15th April 1912) to the accident of Costa Concordia (13th January 2012) almost 100 years have passed; technological difference is enormous; yet the process of dealing accidents is almost the same. It has been observed that the types of accidents can be defined clearly, but how the accidents take place is always new and there are literally infinite ways an accident may take place. Fig. 1-1 illustrates this concept graphically. The figure shows that a ship at initial condition in space and time (x, y, z, t) may encounter a particular type of accident at another space and time (x_a, y_a, z_a, t_a) in many ways. For example, both the accident of Titanic and Costa Concordia, in general terms, can be defined as breach of hull integrity due to grounding. But the way accidents took place are different in space and time. As far as human knowledge is concerned, many accident pathways can be predicted by the captain and the crew of the ship. On the other hand, many pathways to this accident are also unpredictable and unknown. Therefore, when an accident takes place, the accident investigation attempts to discover the unknown paths together with the accident mechanism.

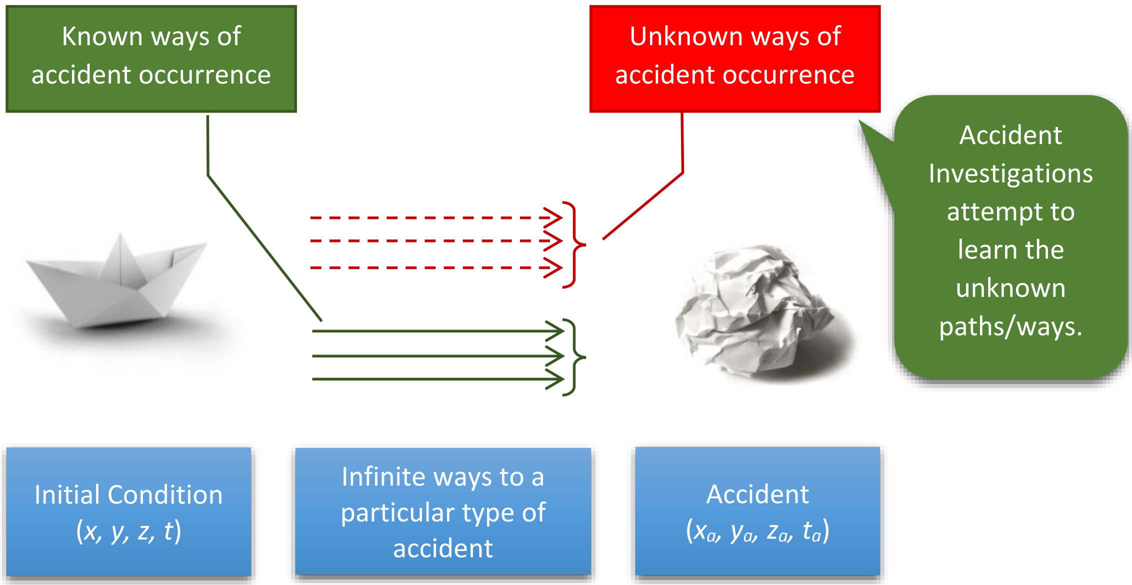

Fig. 1-1 Conceptual representation of the problem of maritime accident occurrence and role of accident investigation.

1.3 Motivation for Current Research

Accident investigations reveal that at the final moments before disaster how the captain and crew make mistakes and if they had been suggested at that time, the accident could have been avoided. Therefore, it appears to be useful to have knowledge on the mechanisms of accident and have it in a specially designed system which may provide sufficient suggestions/warnings to the crew of a ship so that the crew may take necessary action to avoid a certain accident. Such kind of system is unknown to date and similar concepts are extremely rare. Therefore, this research motivates to build a concept using sufficient logical analysis with real life examples. More specifically the principal objective of this research is to propose a concept and discuss the possibility of using expert system together with other mathematical models (such as ship maneuvering models) and suggest future research prospects.

1.4 Outline of the Study

This study begins with a literature review. This section studies various accident theories, risk analysis and other techniques/technologies that are associated with accident prevention. The study gives a better understanding of the accident theories and demonstrates the novel approach and originality of the research theme. Afterwards the study focuses on the fundamentals of Expert System, which is a branch of Artificial Intelligence that emulates the decision making ability of a human expert. Later the research work attempted to establish the new concept along with a framework for the development of expert system. Conceptual examples were exhibited utilizing the accident of Costa Concordia and the accident of Bright Field. Finally the possibilities of future research and development have been identified in the conclusion.

Chapter 2

Literature Review

2.1 Introduction

The maritime accident problem is quite diverse and the involved entities that contribute to accident occurrence are many. Therefore, dealing with accidents requires knowledge from multiple disciplines and sophisticated techniques that can merge the knowledge from different fields. Generally the contributing entities and their associated activities can be conceptually shown in Fig. 2-1. The figure depicts only a conceptual idea and it is indeed not necessarily depicting a total picture. The important fact in this figure is to recognize the contributing entities and describe an accident occurrence through these entities with the help of available accident theories.

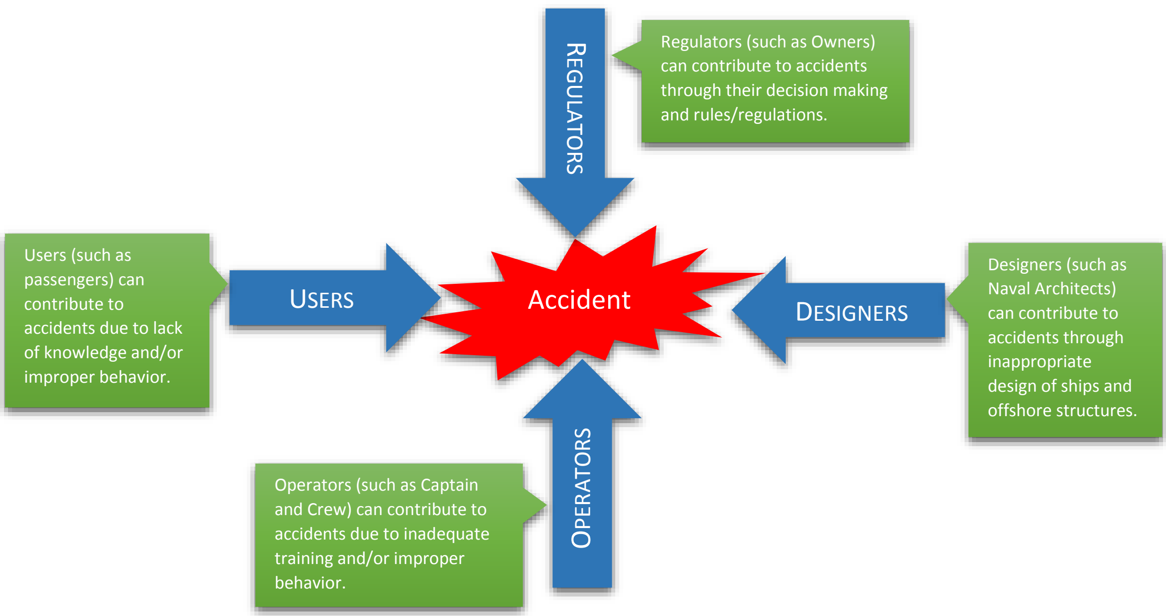

Fig. 2-1 The contributing entities to accidents and their roles.

In addition to understanding the accident theories, there are some conceptual questions which are required to be answered since this research is focused on the accident prevention:

1) How an accident takes place (Accident theories can explain)?
2) How to detect an accident (i.e. the necessary tools)?
3) Who can prevent it (i.e. identify the crew)?
4) How can it be prevented (i.e. the most logical suggestion)?

The literature review has been constructed with these questions in mind. Therefore, accident theories are discussed first. Thereafter, theories/tools for identifying risks and accidents are studied. The study included topics of risk analysis and technological devices for safe navigation. Finally studies on expert systems have been reviewed which may assist to find out the answers for the 3rd and 4th question.

2.2 Accident Theories

2.2.1 Types of Accident Theories

Literature review on accident theories suggests that there are varieties of accident theories derived from different perspectives of solving the accident problems. The knowledge on accident causation is still developing with the change in socio-technical aspects of human society. Therefore, so far no single accident theory has been able to establish itself strongly and contribute significantly over a longer period of time. For example Qureshi [2] suggested a classification of accident theories based on chronology and complexity. The study indicates that fundamentally there are three types of accident theories which show the evolution of theories over time. Such as:

1) Sequential Accident Models or Event Based Accident Models,
2) Epidemiological Accident Models and
3) Systemic Accident Models.

According to Qureshi, traditional accident modeling approaches are not adequate to analyze accidents that occur in modern socio-technical systems where accident causation is not the result of an individual component failure or human error. The study emphasized that traditional accident modeling approaches (such as the Sequential Accident Models and Epidemiological Accident Models) have limitations in the present context which the new system-theoretic approaches can overcome. In addition to this study, there are several types of accident theories which are mentionable. The following figure (Fig. 2-2) shows a classification of accident theories combined from different studies.

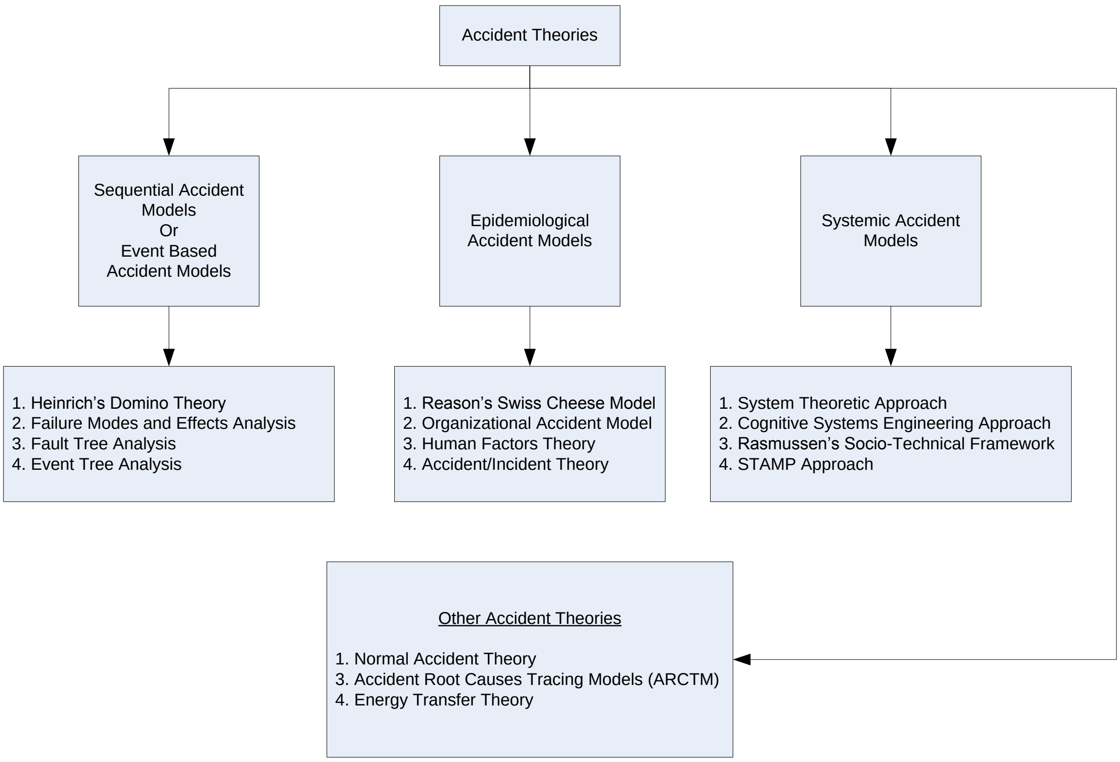

Fig. 2-2 Classification of accident theories.

In this research the Organizational Accident Model and the Accident/Incident Model have been considered. These models have been utilized in analyzing the two accident cases. The following sections describe the accident theories briefly.

2.2.2 Reason's Organizational Accident Model

The nature of organizational accidents has evolved in recent times under the pace of technological innovations, which have radically altered the relationship between systems and their human elements [3]. The concept of organizational accident applies to technological, highly hazardous and well-defended systems. Indeed an organizational accident entails the breaching of the defenses that separate hazards from vulnerable people and/or assets (losses). Fig. 2-2 depicts the concept.

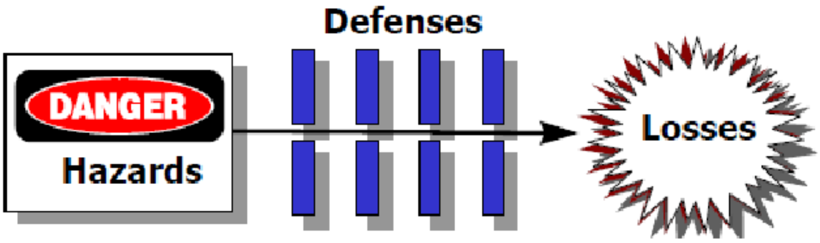

Fig. 2-3 Hazard, defenses and losses.

The defenses are a form of protection put in place by organizations, to ideally counterbalance productive pressure. Whereas productive processes are usually transparent and measurable, protective processes are often opaque and difficult to be monitored. This is because the increased level of complexity due to the introduction of defenses widens the distance between managers and the productive systems they control. This allows the creation of the so called latent conditions that together with active failures contribute to breach the defenses.

Active failures are the errors committed by humans at the sharp end of the system they operate. They can potentially reduce the safety margins of the whole system, and lead to negative consequences. But it is widely recognized that front line operators make errors for reasons that go beyond the scope of individual psychology. These causes are called latent conditions.

Latent conditions are to technological organizations what resident pathogens are to the human body. Like pathogens, latent conditions can lie dormant for many years before combining with active failures or external hazards, and eventually breaching the defenses. In the model of organizational accident, they are present at the workplace and at the organizational level. They arise not only as a consequence of organization’s decisions, but also as a by-product of top-level decisions of governments, regulators and equipment manufacturers. However, the stop rule (upper limit) for the analysis of organizational accidents is at the level over which the organization can exercise control and change things - that is the senior management level.

In the specific case of the Costa Concordia accident, the workplace is the ship’s bridge, and its latent conditions include design of bridge equipment, unworkable or missing procedures, shortfalls in training, and language differences. At the organizational level, latent conditions may be identified in various managerial processes, such as human resources management, the acquisition of technology, the delivery of training, and – most critically – the engineering of a safety culture.

It is important to note that latent conditions are always present in complex systems. Organizational decision makers cannot foresee all the possible patterns of latent conditions caused by the implementation of their strategies, both at the workplace and organizational level.

It is very important to investigate both latent conditions and active failures in an organizational accident because latent conditions might be the same for a number of different accidents. Trying to act only on active failures might be as difficult as catching mosquitos in a swamp. Whereas detecting and mitigating the latent conditions would be like draining the swamp.

The model in Fig. 2-4 presents the elements described above. Starting from the top, a horizontal arrow represents the accident trajectory breaching the defenses. The lower part links the various contributing elements into a sequence that runs bottom-up in causation, and top-down in investigation, thus translating the idea that human error is a consequence rather than a cause.

2.2.3 Accident/Incident Theory of Accident Causation

The accident/incident theory is an extension of the human factors theory. It was developed by Dan Petersen and is sometimes referred to as the Petersen’s accident/incident theory [4]. Petersen introduced such new elements as ergonomic traps, the decision to err, and systems failures, into the Ferrell's Human Factors Theory [4]. A model based on accident/incident theory of accident causation is shown in Fig. 2-5.

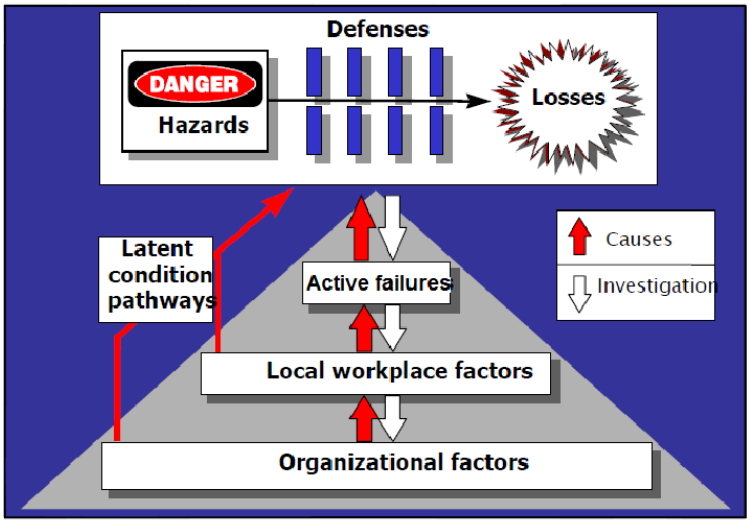

Fig. 2-4 Reason's Model of Organizational Accident.

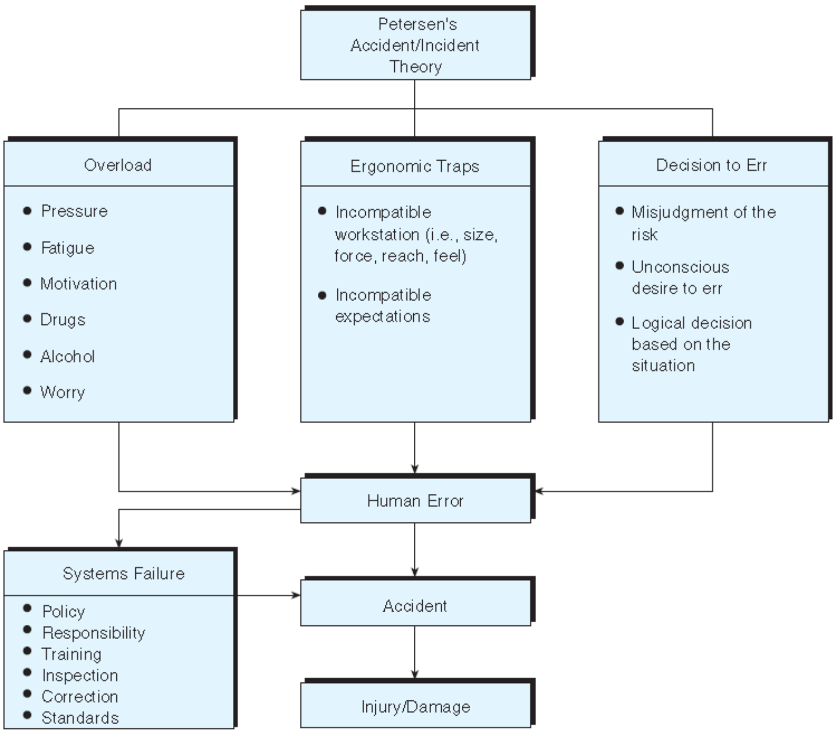

Fig. 2-5 Accident/Incident Theory by Petersen.

In this model, overload, ergonomic traps, or a decision to err leads to human error. The decision to err may be conscious and based on logic, or it may be unconscious. A variety of pressures such as deadlines, peer pressure, and budget factors can lead to unsafe behavior. Another factor that can influence such a decision is the “It won’t happen to me” syndrome. The systems failure component is an important contribution of Petersen’s theory. First, it shows the potential for a causal relationship between management decisions or management behavior and safety. Second, it establishes management’s role in accident prevention as well as the broader concepts of safety and health in the workplace. Following are some of the different ways that systems can fail, according to Petersen’s theory:

1) Management does not establish a comprehensive safety policy.
2) Responsibility and authority with regard to safety are not clearly defined.
3) Safety procedures such as measurement, inspection, correction, and investigation are ignored or given insufficient attention.
4) Employees do not receive proper orientation.
5) Employees are not given sufficient safety training.

2.3 Research on Maritime Risk Analysis

Perhaps one of the most widely studied areas for maritime safety is maritime risk analysis. A significant volume of published literature is available which attempts to quantify maritime accident risks (e.g. collision risk, grounding risk, etc.). Such studies may appear useful from management or decision maker’s perspective, but not useful from operational view point, particularly for the crew. Fundamentally the risk is measured using two terms: 1) Probability and 2) Consequence. Researchers try to understand and quantify the terms of Probability and Consequence so that necessary action cane be taken in the event of high risk. The definition of risk is given as:

$$Risk = Likelihood \times Consequence$$

The terms Likelihood and Consequence can be quantified using different approaches. For example, Macduff in 1974 proposed that the likelihood depends both on causation probability and geometric probability [5]:

Likelihood (collision or Grounding) = Causation Probability x Geometric Probability

Numerous researches have been published on determining the causation probability and geometric probability modeling. Some research on other areas indirectly contributed in this context as well. The following section briefly mentions the significant contribution of various research works in this regard.

2.3.1 Likelihood modeling

Causation Probability

For causation probabilities the following research works are mentionable:

1) Historical Data approach by Macduff [5], Kaneko [6] and Awal [7].
2) Fault Tree Analysis by Fowler & Sørgard [8].
3) Bayesian Network Model by Merrick & Dorp [9], Truccoa et al [10].

Geometric Probability

A number of Geometric Probability Models have been published and are available in the following literatures:

1) Macduff's Model [5].
2) Kaneko's Model [6].
3) Pedersen's Model [11].
4) COWI Model [12].
5) Chin & Debnath's Model [13].

As an alternate, simulation based accident probability estimation was also initiated by a group of researchers. Some of the notable researches are [14, 15]:

1) Uluscu et al [14].
2) Merrick & Dorp [15].

2.3.2 Consequence modeling

The consequence modeling largely depends on individual cases. Practically, general models are not suitable because of the complexity of ship geometry and other parameters.

Therefore, most research works show specific consequence models as examples. Some of the research works can be mentioned here as follows [16-25]:

1) Event Tree Analysis by Ronza [16] and IMO [17-20].
2) Mechanical model and Simulation:
    a. Minorsky [21] proposed relationship for kinetic energy during collision.
    b. Servis and Samuelides [22] developed Finite Element Modeling for collision damage;
    c. Pedersen and Zhang [23] determined ship damage considering external and internal dynamics;
    d. Chen [24] developed time domain simulation considering external dynamics and internal deformation mechanics;
    e. Islam and Awal [25] studied the capsizing of ships due to collision considering ship's dynamic motion;
    f. Others.

Once the likelihood model and consequence model produce practical results, risk of a particular case can be evaluated. However, the fundamental understanding about risk analysis, as described by Merrick et al. [26], is that the value of an analysis is not a precise picture rather it is an understanding of the system through identification of peaks, patterns, unusual circumstances and the changes in system risk by the application of interventions. Such analysis helps to take decisions.

2.4 Technological Devices for Maritime Safety

For safe navigation and overall safety of a ship there exists number of devices. These devices are developed over many years and evolved from mechanical to electrical. This section of the thesis reviews the various types of devices that are being used in ships in order to understand the role of these devices in accident occurrence. The following subsections explain some of the devices which range from simple units to complex devices.

2.4.1 Depth Sounding Systems

Depth sounding systems such as Sonar (sound navigation and ranging) is the acronym identifying those systems that rely for their operation on the transmission and reception of acoustic energy in water. The term is widely used to identify all modern systems that propagate acoustic or electromagnetic energy into seawater to determine a vessel’s speed or the depth of water under the keel [27]. Usages of sonars are quite common in large passenger and cargo/container ships and they play a vital role in preventing grounding. A conceptual diagram is shown in Fig. 2-6 which explains the functionality of sonar.

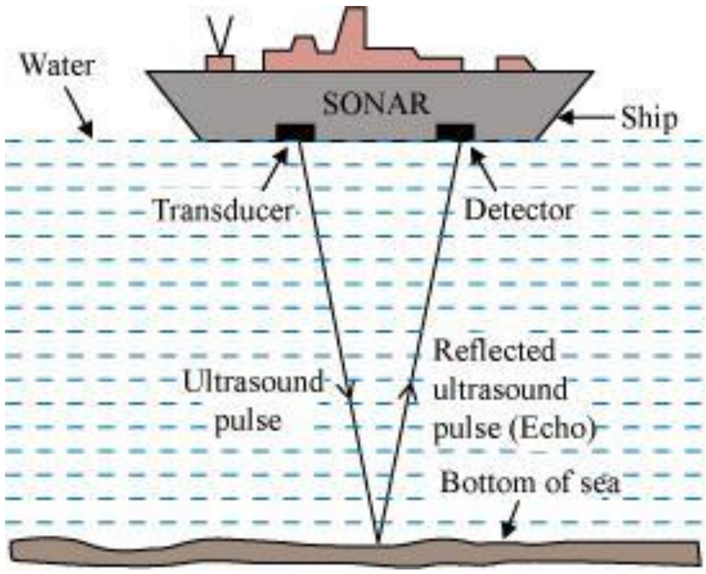

Fig. 2-6 Basics of Sonar functions.

2.4.2 Speed Measurement Devices

At sea, speed is measured with reference to the ocean floor (ground-tracking (G/T)) or water flowing past the hull (water-tracking (W/T)). Traditionally, maritime speed logging devices use water pressure, electromagnetic induction, or the transmission of low frequency radio waves as mediums for indicating velocity [27].

2.4.3 Satellite Navigation

The Global Positioning System (GPS) is a satellite-based navigation system that determines current location of a ship through GPS signals. The GPS navigation system is made up of a network of 24 satellites placed in orbit by the U.S. Department of Defense.

It provides reliable location and time information at any position on or near the Earth's surface, at any time, under all weather conditions. It is maintained by the Federal Government. Anyone with a GPS receiver can access the information for free. A typical GPS receiver for usage in ship is shown in Fig. 2-7.

Fig. 2-7 A typical GPS device set for maritime usage in ships [28].

2.4.4 Integrated Bridge Systems

The integrated bridge system is a complex system comprised of several units. According to IMO [29], an integrated bridge system (IBS) is defined as a combination of systems which are interconnected in order to allow centralized access to sensor information or command/control from workstations, with the aim of increasing safe and efficient management by suitably qualified personnel. Performance standards for integrated bridge systems were adopted by IMO in 1996 (Resolution MSC.64(67)). The revised SOLAS chapter V adopted in December 2000 and entering into force in July 2002 says in Regulation 19 Carriage requirements for ship borne navigational systems and equipment paragraph 6: Integrated bridge systems shall be so arranged that failure of one sub-system is brought to immediate attention of the officer in charge of the navigational watch by audible and visual alarms, and does not cause failure to any other sub-system. In case of failure in one part of an integrated navigational system, it shall be possible to operate each other individual item of equipment or part of the system separately.

To achieve optimum safety and efficiency in bridge operation, the classification society rules address the total bridge system that is considered to consist of four essential parts, namely the technical system, the human operator, the man/machine interface, and the procedures. The integrated bridge system should be designed and installed as a physical combination of equipment or systems using interconnected controls and displays. Workstations should provide centralized access to all nautical information. The type of operational function carried out from the bridge would include navigation, communications, automation and general ship operation. Manufacturers can provide shipbuilders and potential ship-owners with computer-generated drawings of how a particular bridge layout would look when installed. Fig. 2-8 shows a typical bridge layout.

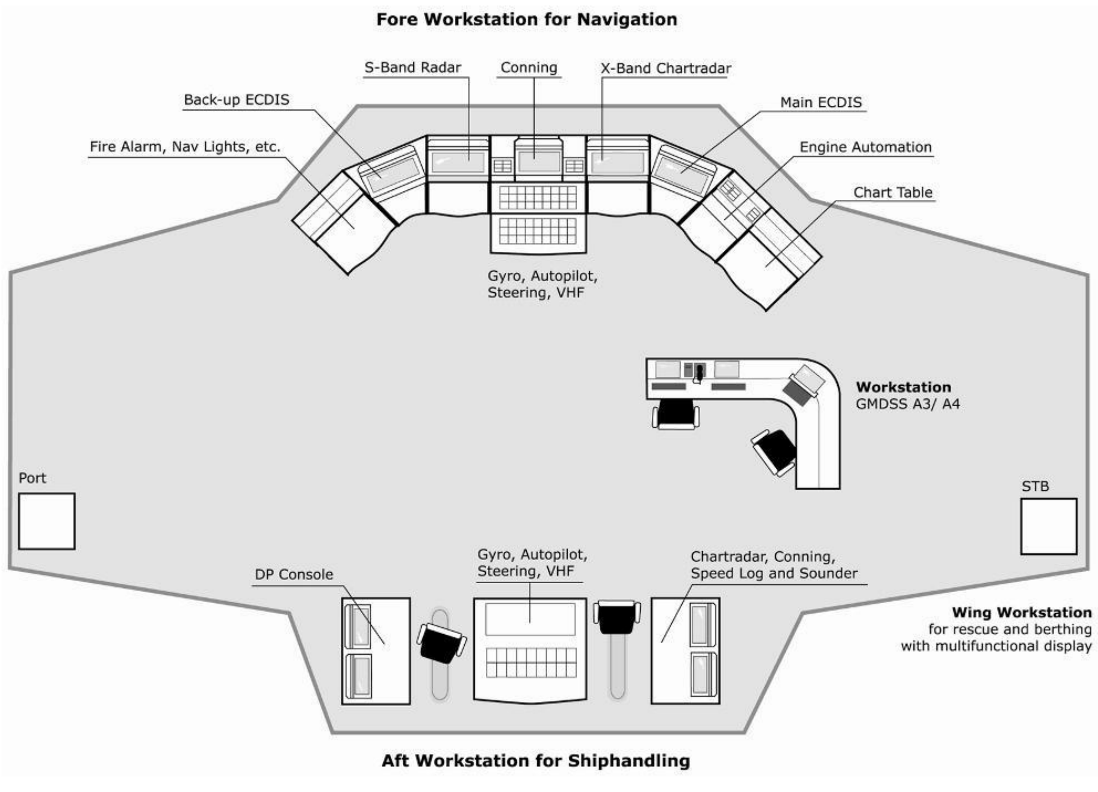

Fig. 2-8 A typical bridge layout [30].

According to International Electrotechnical Commission (IEC)'s definition, an integrated bridge system must be capable of carrying out at least two of the following functions [27]:

1) Navigation planning

2) Passage execution and maneuvering
3) Collision and stranding avoidance
4) Communications
5) Machinery control and monitoring
6) Loading and discharge of cargo
7) Safety and security
8) Management.

2.4.5 Electronic Charts and AIS

An electronic chart is one where chart data is provided as a digital charting system capable of displaying both geographical data and text. An electronic chart is ‘official’ if it is issued by or on the authority of a national hydrographic office. All other charts are ‘non-official’. An electronic chart may use raster data or vector data. Delivery of electronic chart data is via an Electronic Chart Display and Information System (ECDIS) which is a navigational information system, comprising hardware, software and official vector charts and must conform to ECDIS Performance Standards. Chart types available include privately produced vector, official raster and Electronic Navigational Chart (ENC). The ENC is the designated chart system for ECDIS. A Raster Chart Display System (RCDS) is one that displays official raster navigational charts (RNCs).

A dual fuel system is one that operates as an ECDIS or RCDS mode according to the type of chart data in use. Chart accuracy may depend on local datum that may differ from that used by satellite systems which use a global datum, e.g. WGS-84. Corrections may be necessary before a position is plotted on a chart. Electronic charts are updated regularly to ensure conformity with the SOLAS requirement that charts should be ‘adequate and up-to-date for the intended voyage’.

Automatic Identification System (AIS) is a ship borne transponder system that broadcasts information about a ship fitted with the system. The data generated may be used by other AIS-fitted ships and/or shore stations and such data may be passed to an electronic charting system where AIS fitted ships could appear as ‘targets’ on the electronic chart. Such targets could be interrogated to generate information such as ship’s speed, heading and other data. For any ECDIS system to operate, suitable software must be available to enable the function of an ECDIS system to meet performance standards as laid down by the regulatory bodies.

2.4.6 Automatic Radar Plotting Aid

A marine radar with automatic radar plotting aid (ARPA) capability can create tracks using radar contacts. The system can calculate the tracked object's course, speed and closest point of approach (CPA), thereby knowing if there is a danger of collision with the other ship or landmass. Development of ARPA started after the accident when the Italian liner SS Andrea Doria collided in dense fog and sank off the east coast of the United States. ARPA radars started to emerge in the 1960s and, with the development of microelectronics. The first commercially available ARPA was delivered to the cargo liner MV Taimyr in 1969 and was manufactured by Norcontrol. ARPA-enabled radars are now available even for small yachts. Fig. 2-9 shows an automatic radar plotting device [31].

Fig. 2-9 An automatic radar plotting device.

2.5 Evaluation of Maritime Safety Research

From the above study it is obvious that there has been tremendous research and development in the field of maritime safety and the contributions are quite diverse.

Numerous theoretical and technological advances have made navigation of ships much easier and safer. However, at the current state it is still extremely difficult to predict an accident and this still belongs to the judgment of expert human crew. No such theories/devices exist that can predict an accident based on available facts and situations and thereby, suggest possible course of action. Therefore, the current research theme appears to be new and studies on this topic are promising.

2.6 Research on Expert System

It has been established in the field of artificial intelligence that Expert Systems are capable of emulating human decision making ability and may produce satisfying results. Therefore, this research focuses on some of the applications of Expert System.

According to Wikipedia [32] expert systems were introduced by researchers in the Stanford Heuristic Programming Project. Principal contributors to the technology were Bruce Buchanan, Edward Shortliffe, Randall Davis, William vanMelle, Carli Scott and others at Stanford University. Expert systems were among the first truly successful forms of AI software. In the 1980s, expert systems proliferated as they were recognized as practical tools for solving real-world problems. Universities offered expert system courses and two thirds of the Fortune 1000 companies applied this technology in daily business activities. Interest was international with the Fifth Generation Computer Systems project in Japan and increased research funding in Europe. Growth in the field continued into the 1990s.

The development of expert systems was aided by the development of the symbolic processing languages Lisp and Prolog. To avoid re-inventing the wheel, expert system shells were created that had more specialized features for building large expert systems. Many companies began to market expert systems shells, some commercial developments of tools from universities, others written by venture capital backed startup companies. These claimed to allow rules to be written in plain language and thus, theoretically, allowed expert systems to be written without programming language expertise. The best known tools were Guru (USA inspired by Emycin), Personal Consultant Plus (USA), Nexpert Object (developed by Neuron Data, company founded in California), Genesia (developed by French public company Electricité de France and marketed by Steria), VP Expert (USA), Xi (developed by Expertech, UK) and Crystal (developed by Intelligent Environments, UK).

Although the expansion of application of expert systems were on different fields of science, engineering, commerce and etc., very few literature is found on accident prevention, particularly in maritime accident prevention. Study by Feng et al [33] presents application of fuzzy expert system for real-time process condition monitoring and incident prevention. Quian [34] et al developed an expert system for real-time fault diagnosis of complex chemical processes. Rahman [35] developed ExpHAZOP+ which is a Knowledge-based expert system to conducting automated HAZOP analysis. The author of this thesis have initiated studies that can utilized expert system in maritime accident detection and prevention [36], but the research is in the early stage.

2.7 Summary

So far numerous research and developments have been conducted all around the world to prevent maritime accidents. Various accident theories have been proposed and the development is still on going. Research in the form of risk modeling has progressed significantly over the years. These research works come handy for the policy makers but come of little help for the ship crew or the operator to prevent an accident at the final moments before disaster. On the other hand, significant research and development have been observed in the field of expert system. Expert systems are utilized in many industries for fault detection and prevention of accidents. But applications are very specific to process industries and therefore, they are not suitable for maritime accident prediction. Therefore, this research theme appears to be a novel one.

Chapter 3

Fundamentals of Expert System

3.1 Application Concept

It is pertinent to mention that accident investigations ultimately reveal the unnoticeable facts that can be considered as a symptom of an accident just like a disease in human body. For example, a person may sneeze if any foreign body gets into his/her nose. This may or may not be a symptom for illness. If this is a disease, the sneezing would be the starting point. Once the symptom is observed it is the only way to be certain about the disease through a diagnosis. The disease can be diagnosed certainly by an expert/experienced person, usually a doctor. And then the person can take necessary steps and prevent himself from becoming further ill. Similarly, in maritime accidents a captain or crew of a ship makes many decisions associated with the navigation of a ship. Essentially, all decisions are taken for the benefit of the interest but some decisions lead to accidents. If these decisions are considered as the symptoms of a disease, the diagnosis could be a series of computer simulations to ascertain the occurrence of an accident. In this view, an expert system for maritime accident prevention will be able to diagnose the faults and thereby, prescribe to the ship crew so that accidents could be avoided. Therefore, study on expert system is necessary in order to build an expert system for maritime accident prevention. The following sections describe the fundamental aspects of expert system.

3.2 Introduction to Expert System

Expert systems are knowledge-based computer programs instructed to function like a human expert does in solving a particular problem or in giving advice. This does not mean, however, that they have brain functions at their disposal which are similar to that of humans. It is yet far from understood how our brain functions and expert systems are only one way by which it is tried to simulate human performance. The more formal definition is given by Hayes-Roth et al [37], which says that an expert system is a program with a wide base of represented knowledge in a restricted domain, that uses inferential reasoning and, when necessary, user dialogue to perform tasks which a human expert could do.

The most interesting aspect of expert systems is that they offer a possibility to capture and organize human expertise and experience into a form that enables other people to employ it. Practical applications are also encouraging and interesting [38]. This is not only interesting for laymen, but also for the expert who offers his or her knowledge. Most experts spend a large percentage of their time on problems they consider simple and, therefore, less interesting. For them, solving such problems is a routine. If an expert system could take over a part of this routine, the expert get the opportunity to concentrate on difficult and more interesting problems and to engage in new challenges that can expand his knowledge.

3.3 Architecture of Expert System

Expert system applications differ from other computer programs in their tasks and architecture [39]. Applications which are built according to traditional programming methods consist of explicit and task-specific algorithms: they perform a task on the basis of a set of actions which are processed in a predefined order. Consequently, traditional programming methods can only be used for tasks that have an algorithmic nature. The expert system approach, on the other hand, has been designed to handle tasks which cannot be solved by straightforward and predefined procedures but by heuristic methods only. Heuristic methods are based on the concept of trial-and-error. They do not use formal problem solving procedures, but they simply test approaches of which it is uncertain whether they will lead to a solution. Expert systems employ actions that can be executed independently of each other and in a variable order. The application chooses the appropriate activities on the basis of the information that it receives from the external world. Consequently, the course of the program is automatically accommodated to the situations it is confronted with. This implies that an expert system application is more flexible than one which is built according to traditional programming methods.

Expert systems owe their flexibility to their architecture: they are composed of three elements that operate independently of each other. These elements are a knowledge base, an inference mechanism, and a user interface (illustrated in Fig. 3-1). The first element comprises the knowledge that an application requires. In a way, it can be compared with a database, because they are both storage facilities. The main difference, however, is that a knowledge base contains knowledge instead of raw data or information. Within the context of artificial intelligence research there has been much discussion on what 'knowledge' exactly is and it appears that it can have several forms, like defaults, facts, rules of thumb, strategies etc. In broad outline, knowledge can be separated into a static (or descriptive) and a dynamic (or procedural) part, representing respectively the facts and the conclusions that can be drawn from them. In the context of this study, knowledge is defined as facts and the relations between these facts.

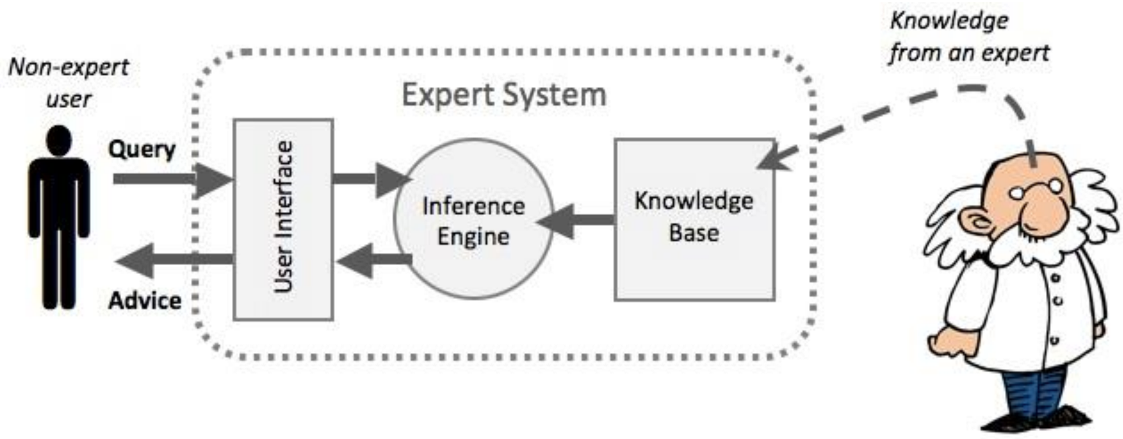

Fig. 3-1 Basics of an expert system [39].

The second element of an expert system is an inference mechanism. Whereas the knowledge base consists of domain dependent facts and relations, the inference mechanism consists of domain independent procedures. It can be seen as the central nervous system: it controls the reasoning process, i.e. the problem solving strategy. It selects the knowledge that is needed to solve the problem or to carry out the task. In other words, the inference mechanism makes sure that the appropriate knowledge is applied at the appropriate moment. An expert system employs its knowledge either to interpret new information or to collect information that may answer a question. They are data oriented or goal oriented, respectively. Both approaches use a specialized reasoning strategy. A data-oriented system has no predefined goal: it reacts to information that the system receives from the external world. The system will try to interpret this information by consulting its knowledge base for conclusions that can be drawn from it. This is called forward reasoning. A goal oriented system does the opposite, it 'reasons' in a backward direction in order to confirm a predefined goal. It will try to retrieve information from the external world that is required to confirm that goal. This can be done by questioning the user or by consulting an external data source such as a database. Since data-oriented systems can be used to interpret data or to react to (changes of) incoming information, they are most suitable for applications with analytical and educational purposes, especially for those that require an immediate reaction of a 'master'. A goal-oriented system can best be applied to situations in which a user either wants to have a hypothesis validated.

The third component of an expert system is a user interface. It handles the communication between an application and its users. Any application needs communication with the outside world in order to gather information that can help to solve the problem — or to perform a task — and to return its conclusions. Since the quality of the information is of decisive influence on the adequacy of the reasoning process and thus for the conclusions that the application can draw, it is very important that the dialogue between the system and its user does not cause misunderstandings. Therefore, the interface must be adapted to the level of the user and provided with explanatory facilities. The same counts for the transmission of the system's conclusions. A system can only present its suggestions and advices to its user through the user interface. In order to convince the person on the other side of the screen or to enable him or her to make the right decisions, the application must offer clear messages and additional information on how it reached its conclusion.

Irrespective of the fact whether an application is data oriented or goal oriented, the dialogue between system and user can be user initiated, computer initiated or a mixture of both. The first form is often used by systems designed to support users with a high level of experience on the domain. These users only ask the system for advice in case of difficult problems and they determine the system's role. A computer initiated dialogue is characteristic of systems designed to give direction to users without any domain experience. Depending on the degree of experience of the users, the dialogue is sometimes also alternating initiated by the user and the computer. It is this special architecture of expert systems that realizes the required flexibility. Due to the fact that the knowledge base and the reasoning mechanism are independent elements, the latter can consult the knowledge base whenever it is required and it can select only those facts and relations that are relevant for that particular situation. Moreover, the reasoning mechanism can either apply the facts and relations from the knowledge base for the purpose of drawing new conclusions from the known information or for the validation of a hypothesis.

An additional advantage of the division of expert systems into three elements concerns the aspect of maintenance. The algorithmic architecture of traditional programs makes maintenance a hazardous enterprise because all procedural actions relate to each other. If one single aspect of the program is changed, the entire program must be adapted or rewritten. Since the components of expert systems are independent, they can be updated or expanded without this having effect on each other. For instance, the inference mechanism can be changed from data oriented into goal oriented, but it will still be able to use the same knowledge from the knowledge base. Reversely, if the knowledge base is expanded with new facts or new relations the inference mechanism does not have to be adjusted as well: it will still be able to consult the knowledge. Furthermore, the user interface does not influence the reasoning process nor the contents of the knowledge base. If the lay-out of the application is improved, neither its knowledge is affected by this nor its reasoning strategies.

Chapter 4

Development of the Concept

One of the key aspects of any accident occurrence that involves human operator is the ability to take the right decision at the right time. This is basically a universal fact. For human operators like a bridge team of a ship this is even more complex due to involvement of multiple individuals. In critical situations human operators may make mistake in absence of specific/comprehendible guidelines. In many cases, critical situations arise suddenly without warnings. As systems go through many process/states, preparing guidelines for all conditions are impractical. In such cases Expert System based on Artificial intelligence may come useful. A human operator (like the Captain of a ship) may prevent an accident if he/she receives logically analyzed and rationally generated decisions by computers during a critical situation. In this perspective the concept of the model is constructed as described in the following sections.

4.1 Model Composition

Fundamentally the concept model is composed of three basic elements: 1) Human Operator Interface (HOI), 2) A Time Domain Simulator (TDS) and 3) A Pack of Accident Modules (PAM). These three components are interconnected according to Fig. 4-1 shown below. The arrow shows the direction of information flow. However, in addition to these three components, all the components may take input information from the World Parameters, which is basically a bank of information of the state of different parameters. Example of parameters may include ship speed, ship heading, wind speed, geographical location and many more. The following subsequent sections explain each of these three components.

4.1.1 Human Operator Interface

The Human Operator Interface (HOI) is the console where the human operator will provide input of various conditions and in return will obtain simulated results from the Time Domain Simulator (TDS) and expert advice (which may include warnings/suggestions) from the Pack of Accident Modules (PAM).

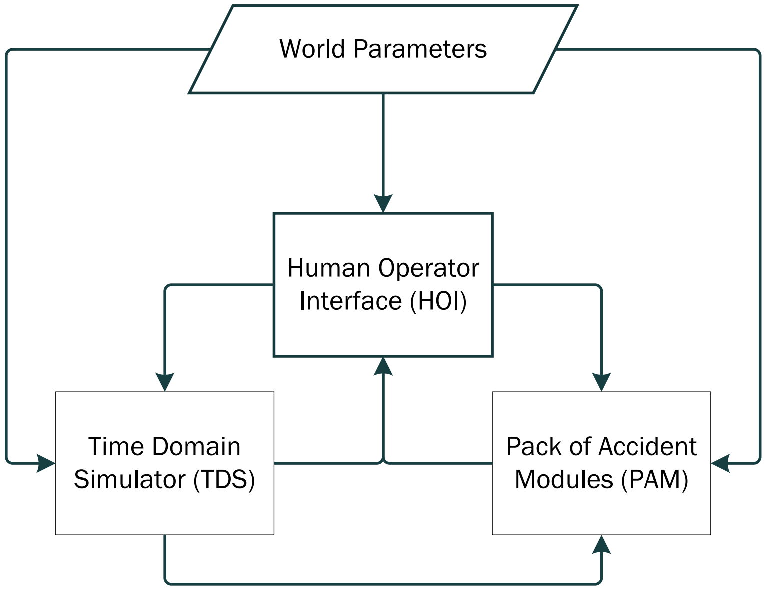

Fig. 4-1 Basic composition of the concept model.

As an example, if a captain of a ship wants to know where the ship will be and what are the potential threats after 10 minutes, he will ask through the HOI. In response, the model will run a time domain simulation of ship using various inputs like rudder angle, speed, etc. and generate outputs to the HOI. A set of outputs will also be given to PAM which will analyze the data and give its advice to HOI. Results may include warnings of possible grounding or collision or faults in decisions taken by the captain or the crew.

4.1.2 The Time Domain Simulator

The Time Domain Simulator (TDS) processes the change of system parameters with respect to time. TDS may utilize various maneuvering models like K-T, MMG or CFD based maneuvering models based on the strength of computational ability. TDS will take input both from the HOI and world parameters. TDS is basically a mathematical model that generates a set of numerical output values for a given set of numerical inputs. Fig. 4-2 shows the TDS process. The TDS is further discussed in section 4.2 Operation of the Model.

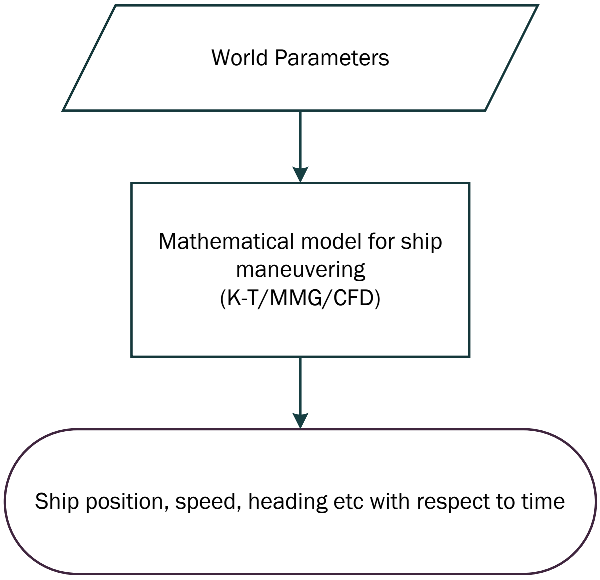

Fig. 4-2 Basic function of Time Domain Simulator (TDS).

4.1.3 Pack of Accident Modules

This segment contains accident modules, which are facts learnt from real life accidents. These facts are programmed as sequence of errors or as algorithms. This segment of the model is very critical and is different from conventional procedural/object oriented programming technique. Rather this segment requires heuristic or descriptive programming technique to construct which is also called logic programming. The fundamental objective of PAM is to host accident modules as one single unit. But each and every accident module will function independently and each module will be different from the other.

4.2 Operation of the Model

The model may run in continuous loop and provide continuous update to the HOI or run when commanded by the user. The time step for each loop may vary. This will depend on the time domain simulation technique and number of accident modules in the PAM. Just as a computer plays chess by running simulation of each chess piece movement and determines the best score, the model may run continuously and produce result of possible threats. The model may run in the following sequence as shown below:

1) Set initial value of ship (position, speed, heading, etc.) and surroundings (current, wind, etc.).
2) Run simulation (maneuvering/sea-keeping).
3) Obtain final values (position, speed, heading, etc.).
4) Run simulation using 'n' number of alternative options (rudder command/speed) and obtain final values (position, speed, heading, etc.).
5) Check accident modules for logical inference and show the results.
6) Run simulation for the next level (idea discussed in section 4.3 Evaluation with Respect to Ship's Position).
7) After certain time (t) there will be grounding/collision/accident.
8) At this stage show current path in timeline.
9) Obtain expert advice from the expert system and deliver to HOI.

For step number six a new concept of position evaluation may be introduced based chess playing technique. According to Shanon [40] computers use position evaluation functions to evaluate movements of each and every chess pieces and determines the best move based on the score calculated by the this function. Similar idea can be utilized in this case to evaluate ship's relative position and determine the safety situation. The following section discusses this aspect.

4.3 Evaluation with Respect to Ship's Position

The position evaluation of a ship shows a tree of possible trajectories at defined interval of times. The tree may be generated using different rudder command or different speeds of ship. Fig. 4-3 shows a tree of positions of a ship considering moving from left to right with 3 rudder command options (+5 degree, 0 degree and -5 degree at an interval of Δt). As P1 is the starting position and P14 to P40 are the final positions, each element of the tree contains three branches from one origin. There are 4 Levels in the tree, such as Level 1 (P1), Level 2 (P2 to P4), Level 3 (P5 to P13) and Level 4 (P14 to P40). The idea is to evaluate each position using the accident modules both numerically and logically. Thereby, the best path could be determined and followed to avoid accidents.

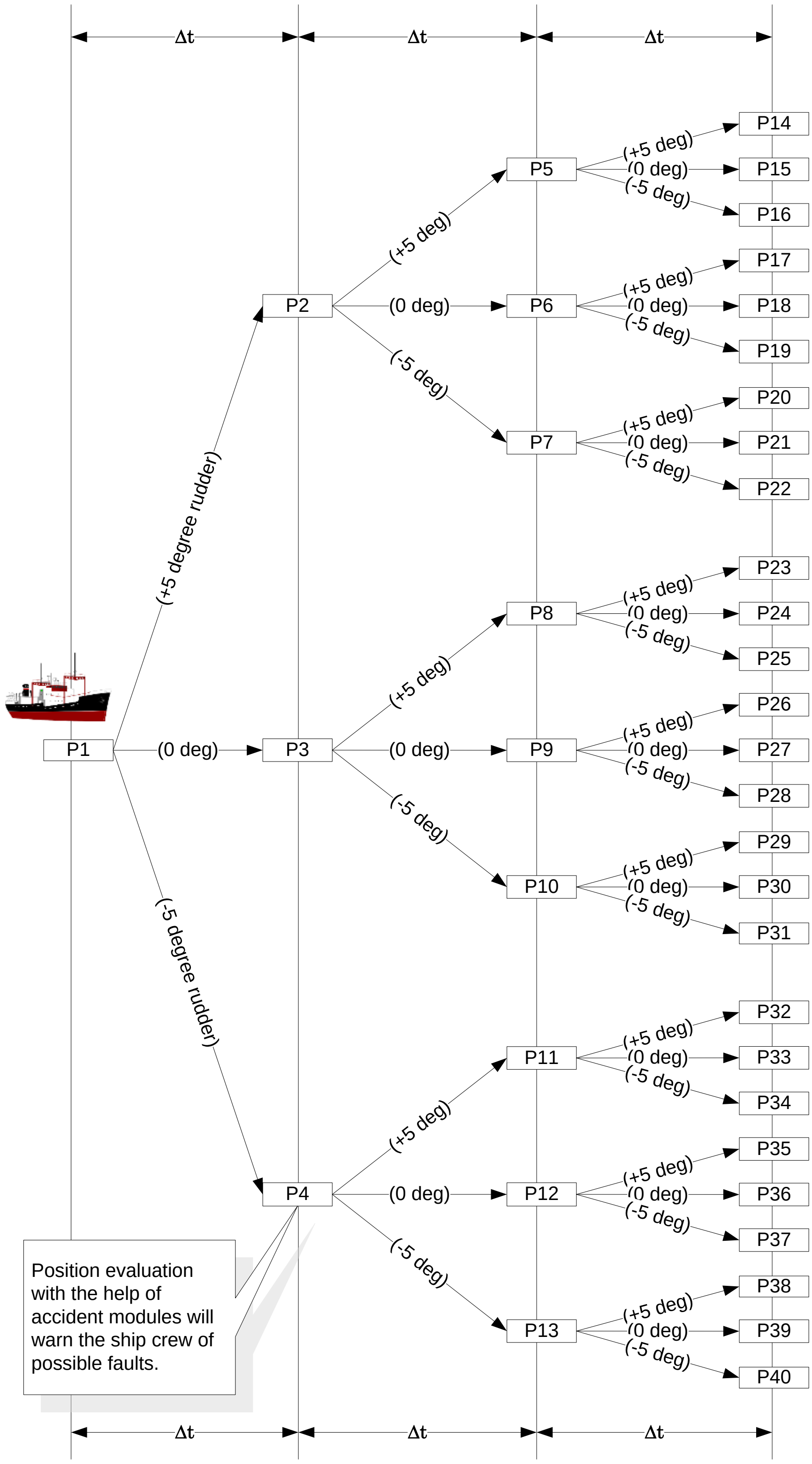

Fig. 4-3 Position of ships numbered in a tree.

4.4 Development of a Framework

In order to implement the concept, a framework has been developed that describes the methodology for formulating the expert system (shown in Fig. 4-4). 'Facts' of an accident can be extracted from accident studies and be used to formulate 'advices'. The advices can be programmed to appear to the concerned crew at different ship states (e.g. on voyage/idle) at different space and time. This concept is fundamentally in the form of if-then logic and essentially relies on particular accident theory. In order to conduct deeper thinking, the prospects of heuristic search and position evaluation are required to be researched for further development.

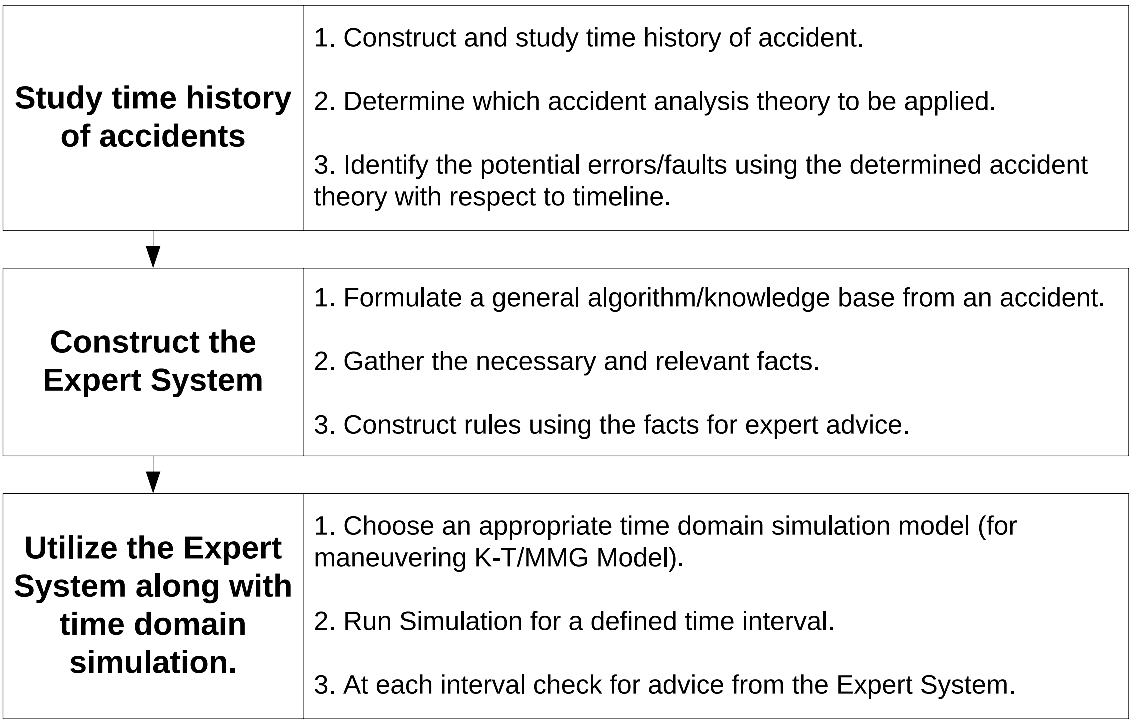

Fig. 4-4 Framework for building the expert system and its usage.

4.5 Proposed Techniques

The present research identifies three possible methods for developing an expert system:

1) Rule based simple error notification (RB-SEN)
2) Rule based simple advice generation (RB-SAG)
3) Heuristic search based complex advice generation (HSB-CAG)

The first two methods are similar in nature. The methods utilize if-then logic along with rule based facts. Various facts may act as constituents for different rules. These rules can either be advices or can be errors according to design. When the facts corresponding to a particular advice or error appear true, the advice or the error will be triggered. This is the fundamental functionality of the RB-SEN and RB-SAG. In this study these RB-SAG has been demonstrated in two cases.

While on the other hand, HSB-CAG is more complex in nature and may employ heuristic search techniques for advice generations. The method can be closely resembled with bin packing problem [41]. In bin packing problem objects of different volumes must be packed into a finite number of bins or containers in a way that minimizes the number of bins used. Many heuristics have been developed and applied in solving such problem. For example, the first fit algorithm provides a fast but often non-optimal solution, involving placing each item into the first bin in which it will fit. Other variant of techniques are the best fit decreasing and first fit decreasing strategies. The resemblance between bin packing problem and maritime accident problem is that the application of various navigation commands and decisions of different crew results in various outcomes in terms of ship position in space and time; thereby, evaluating the outcomes gives the best/worst possible combinations of decisions which may affect safety of the ship significantly.

Chapter 5

Application of the Concept

5.1 Introduction

In this chapter the application of the proposed concept is demonstrated. Two major accidents have been chosen in this regard: 1) The accident of Costa Concordia in Italy (2012) and 2) The accident of Bright Field in USA (1996). The developed framework is employed. The concept of Rule based simple advice generation (RB-SAG) has been applied in both the cases. Prolog programming is utilized and the codes are shown along with other analysis. For position evaluation two different flowcharts have been presented for the two accident cases.

5.2 The Accident of Costa Concordia

The accident of MS Costa Concordia took place on 13th January 2012. The ship grounded on the rocks Le Scole, near Giglio Island, Italy. The ship operated by Costa Crociere, a subsidiary of Carnival Corporation, was on route from Civitavecchia to Savona, carrying over 4200 people on board. Among them 32 people lost their lives and 60 people were injured. With its gross tonnage of 114.000, 13 decks, 290 meters of length, 35 meters of beam and 8 meters of draught, Costa Concordia was launched in 2006. At the time it was the largest Italian cruise ship ever built [42]. Fig. 5-1 demonstrates the final path of Costa Concordia near the island of Giglio, Italy.

Based on the study by Lieto [42], it is possible to develop a rule based “accident module”. Lieto followed the Reason’s Organizational Accident model and identified 6 errors. In this research suggestions are targeted against these errors and thereby RB-SAG is applied.

However, on the contrary RB-SEN could have been programmed that will only show the errors whether they are true or not.

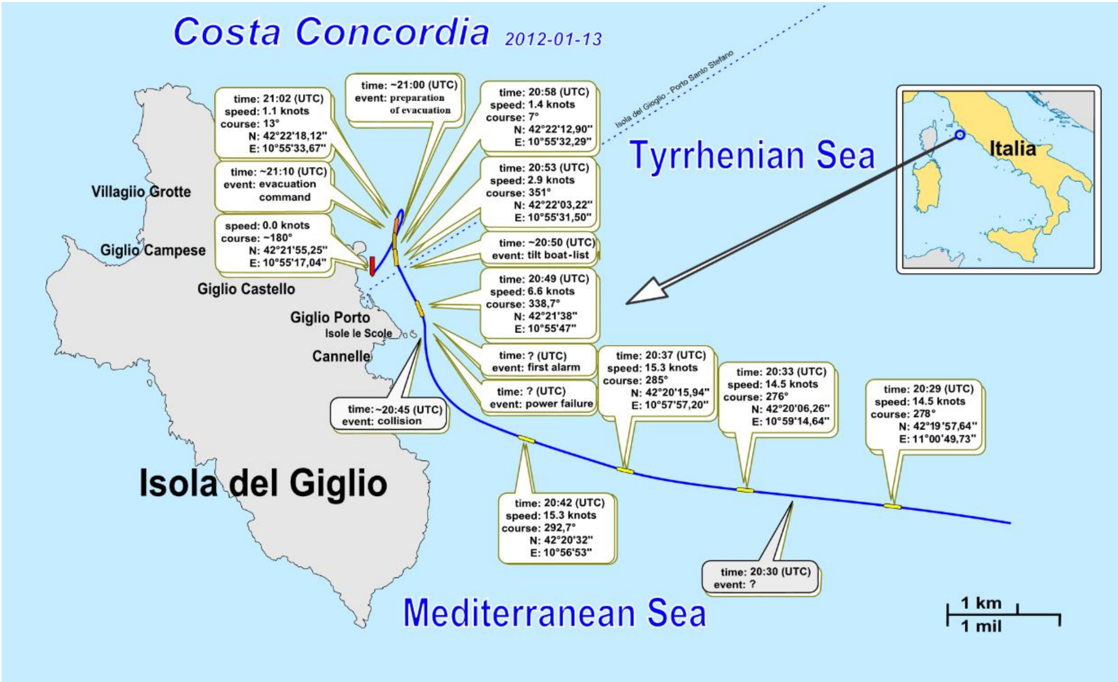

Fig. 5-1 Final path of Costa Concordia [43].

Nevertheless, various facts have been extracted by studying the final moments before the accident. For example Table 5-1 shows the facts associated with Organization, Workplace, Captain, Senior Officer of the Watch (SOOW) and Junior Officer of the Watch (JOOW). These facts are indeed in a simplified form, which are only concerned with navigational responsibilities. Obviously there are many other facts that could affect the safety, but for simplicity only navigational variables are considered. The facts are marked with alphanumeric tags. For example, '*O1*' means the first fact of Organizational factor that is '*do_not_allow_change_in_voyage_plan*'. The underscore is used for coherence with the variables of logic programming.

Table 5-2 reveals the list of errors constructed using the facts from Table 5-1. In addition Fig. 5-2 shows the snapshot of Prolog computer code module which has been developed in this study. For the first error, two relations are required. At first, *W1* and *W2* results *C1*. This means the external influence of paying a tribute to the mentor (*W1*) and a request to change in the voyage plan (*W2*) makes the captain to decide to change in the voyage plan (*C1*). However, the Organizational factors *O1(do_not_allow_change_in_voyage_plan)* and *O2(do_not_allow_without_prior_approval)* together with Captain's Decision *C1* and *C2(no_prior_approval)* make the Captain to decide to take informal procedure (*C3*) for the purpose. According to this definition, as soon as *C1* and *C3* are true, the model may generate a warning for the first error.

Table 5-1 Facts of the Costa Concordia accidents.

Facts Group	Facts in terms of logic programming variables
 Organizational facts	*O1. Organization(do_not_allow_change_in_voyage_plan).* *O2. Organization(do_not_allow_without_prior_approval).*
 Workplace Influence	*W1. Work_influence(tribute_to_mentor).* *W2. Work_influence(change_in_voyage_plan).*
 Captain's Decisions	*C1. Captain(change_in_voyage_plan).* *C2. Captain(no_prior_approval).* *C3. Captain(informal_procedure).* *C4. Captain(no_ins).* *C5. Captain(rudder_orders).* *C6. Captain(danger_observed).* *C7. Captain(no_danger)*
 Senior Officer of the Watch (SOOW)'s Decisions	*S1. SOOW(plan_on_small_scale_charts).* *S2. SOOW(plan_on_large_scale_charts).* *S3. SOOW(use_ins).* *S4. SOOW(ins_alarm_furthest_point_from_echo).* *S5. SOOW(ins_alarm_10m_line).* *S6. SOOW(no_crew_challenge).* *S7. SOOW(danger_observed).* *S8. SOOW(no_danger).*
 Junior officer of the Watch (JOOW)'s Decisions	*J1. JOOW(crew_challenge).* *J2. JOOW(no_crew_challenge).* *J3. JOOW(danger_observed).* *J4. JOOW(no_danger).*

For the second error limited time for modifying the voyage plan, *C3*(*informal_procedure*) and captain's reliance on SOOW results a decision of planning the voyage on large scale charts *S2(plan_on_large_scale_charts)*. Here the Captain could have intervened to draw the voyage on small scale charts where the danger of grounding could have been spotted. But the limited time and informal procedure resulted both the Captain and the SOOW to decide to plan the voyage on large scale charts.

Table 5-2 Rules constructed from the facts to identify errors.

Error	Rules constructed from facts
1st Error	*(W1, W2) = C1* *(O2, O4, C1, C2) = C3*
2nd Error	*(Limited Time, C3) = S2*
3rd Error	When JOOW helps SOOW fixing ship position on paper chart. *S2 = J3 Or J4* *J4, C3 = J2* When JOOW assist helmsman in translating the conning orders. *C3 = J2*
4th Error	*S4*
5th Error	*S3 = S7 or S8* *C4 = C7*
6th Error	*C7 = C5*

The third error triggers when there is no proper route monitoring. This happens in two cases along the voyage. Firstly, the JOOW didn't have "planned larger charts" to fix ships position. Therefore, JOOW couldn't detect any danger. As there is no observed danger (*J4*) and there is informal procedure (*C3*), the JOOW decides *J2(no_crew_challenge)*. Secondly, in another case JOOW left route monitoring and went to assist the Helmsman, as there was language/communication problem.

The fourth error was regarding to the route monitoring on the INS. The chart alarm was set to go on if the radar distance is 2000m or less from the ground. It was not set for crossing the 10 meter bathymetric line. If it was selected, the captain might have received a warning alarm and could take actions much earlier (as soon as 10meter draft compromised). As the official investigations are ongoing, the reason for choosing 2000m radar distance alarm is still unknown.

```
%== Facts as Input ==================================================
organisation_decision(no_change_in_voyage_plan).
organisation_decision(demand_prior_approval_for_change_in_voyage_plan).

captain_decision(informal_voyage).
captain_decision(soow_prepare_for_voyage).
captain_decision(joow_monitor_route).

water_area(sea).
% water_area(coastal).
% water_area(close_to_shore).

ship_state(sailing).
% ship_state(idle).

route_planning_state(incomplete).
% route_planning_state(complete).

%= Advices ==========================================================
advice(C,SC1):-
        C = captain,
        organisation_decision(no_change_in_voyage_plan),
        organisation_decision(demand_prior_approval_for_change_in_voyage_plan),
        captain_decision(informal_voyage),
        SC1= do_not_change_voyage_plan_without_prior_approval.

advice(C,SC2):-
        C = captain,
        ship_state(sailing),
        captain_decision(informal_voyage),
        SC2 = alert_all_crew_for_informal_voyage.

advice(C,SC3):-
        C = captain,
        water_area(close_to_shore),
        SC3 = adopt_rate_of_turn_command.


advice(S,SS1):-
        S = soow,
        organisation_decision(no_change_in_voyage_plan),
        organisation_decision(demand_prior_approval_for_change_in_voyage_plan),
        captain_decision(informal_voyage),
        SS1 = adopt_crew_challenge.


advice(S,SS2):-
        S = soow,
        captain_decision(soow_prepare_for_voyage),
        water_area(coastal),
        SS2 = plan_route_on_small_scale_charts.

advice(S,SS3):-
        S = soow,
        water_area(coastal),
        ship_state(sailing),
        SS3 = switch_on_INS_chart_alarm_for_BL_and_RADAR.

advice(J,JS1):-
        J = joow,
        organisation_decision(no_change_in_voyage_plan),
        organisation_decision(demand_prior_approval_for_change_in_voyage_plan),
        captain_decision(informal_voyage),
        JS1 = adopt_crew_challenge.

advice(J,JS2):-
        J = joow,
        captain_decision(joow_monitor_route),
        water_area(coastal),
        ship_state(sailing),
        route_planning_state(incomplete),
        JS2 = conduct_route_monitoring.
```

Fig. 5-2 Snapshot of Prolog code for the accident module of Costa Concordia.

At the final stage of the approach the Captain took over command form SOOW. But SOOW didn't challenge in any form. Captain's intentions and expected outcomes were not clear. Because of the presence of guests and hotel manager his role as a team leader was not fulfilled. The lack of challenge from the SOOW could be the fifth error.

When the Captain took over the control from SOOW, valuable time was lost. Within that very short span of time the ship crossed safety contour from 0.5 Nautical mile to 0.28 nautical mile. The captain was relying on eyesight and until he sees the first rock he was giving rudder orders instead of rate of turn orders, which was unfortunately not sufficient. This was the final error. Fig. 5-3 shows a simple time line study that indicates major decisions and facts.

In order to utilize the position evaluation concept, a flow chart has been developed as shown in Fig. 5-4. The figure represents a logical sequence for evaluation of ship's state based on Bathymetric chart data. A concept of 'P' value is shown which indicates a relative danger numerically. Zero means no danger and negative values indicate dangerous scenarios. This concept may be utilized to evaluate each position and provide the HOI with logical suggestions.

Fig. 5-5 shows the application of accident module at three different scenarios during an approach to Giglio Island. A snapshot of Google Earth is utilized over which the ships position is fixed. The position of ship is followed by the final path of Costa Concordia just before the accident. Three different states are shown in this figure. The accident module gives it's suggestions at these three steps after processing the input parameters (such as captain's decisions, ship's position and etc.). In the output the module advises the captain and individual crew. The crew who has no function according to the constructed rules, will have no advice. This is essentially a concept testing scenario and doesn't employ any maneuvering simulations. Rather this figure shows the accident module outputs for different input values at different space and time.

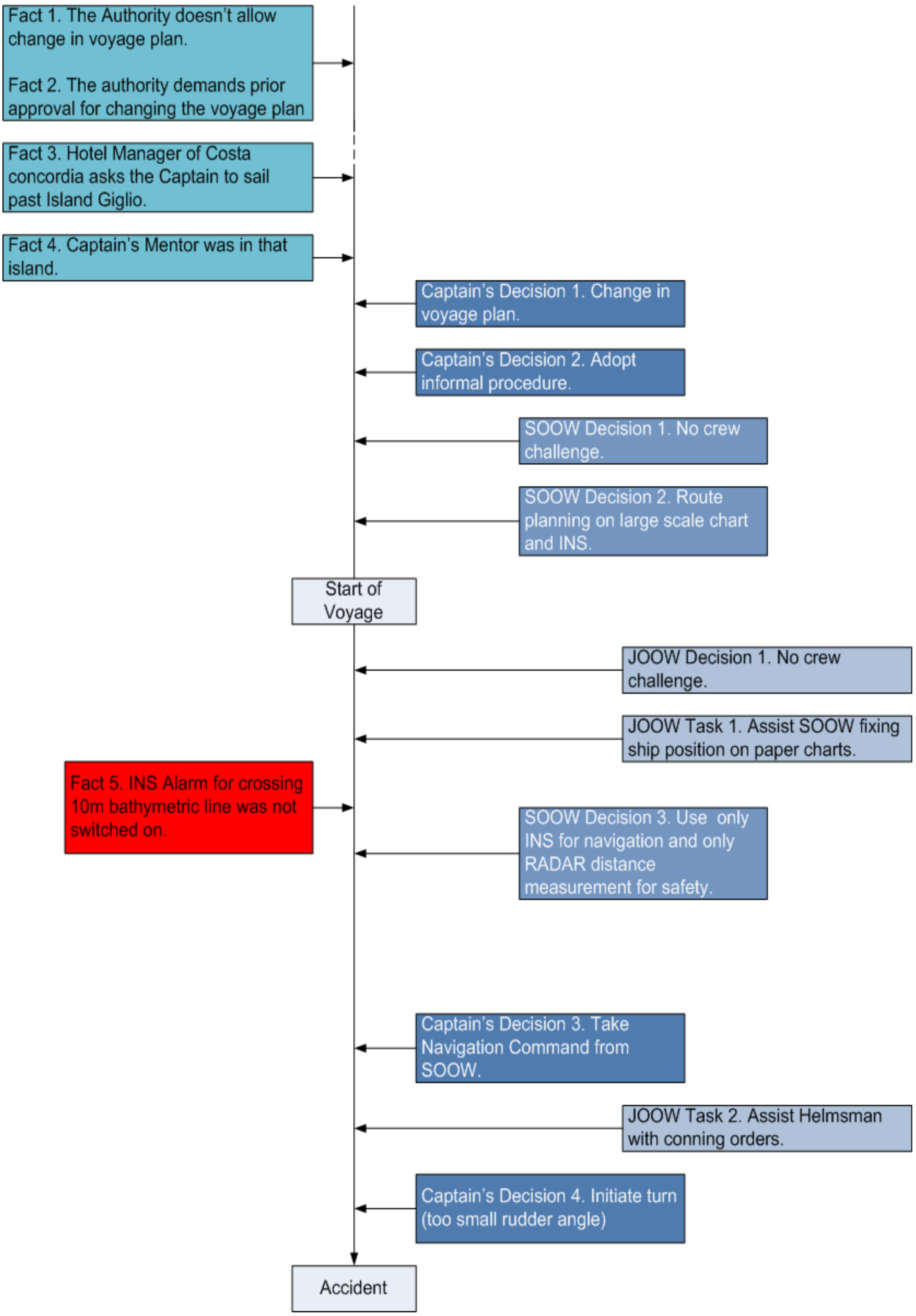

Fig. 5-3 Timeline study of the Costa Concordia accident.

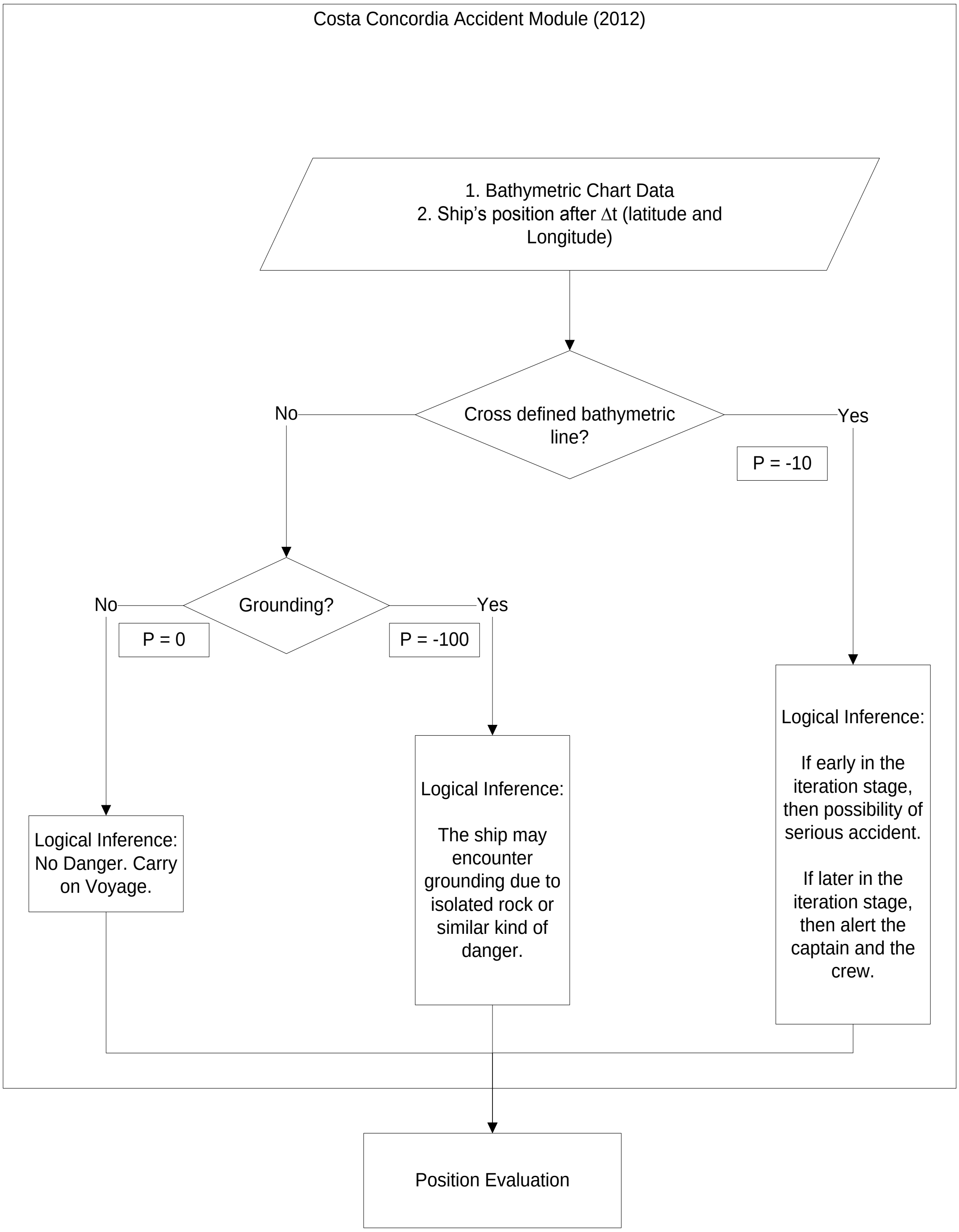

Fig. 5-4 Position evaluation using the module of the accident of Costa Concordia.

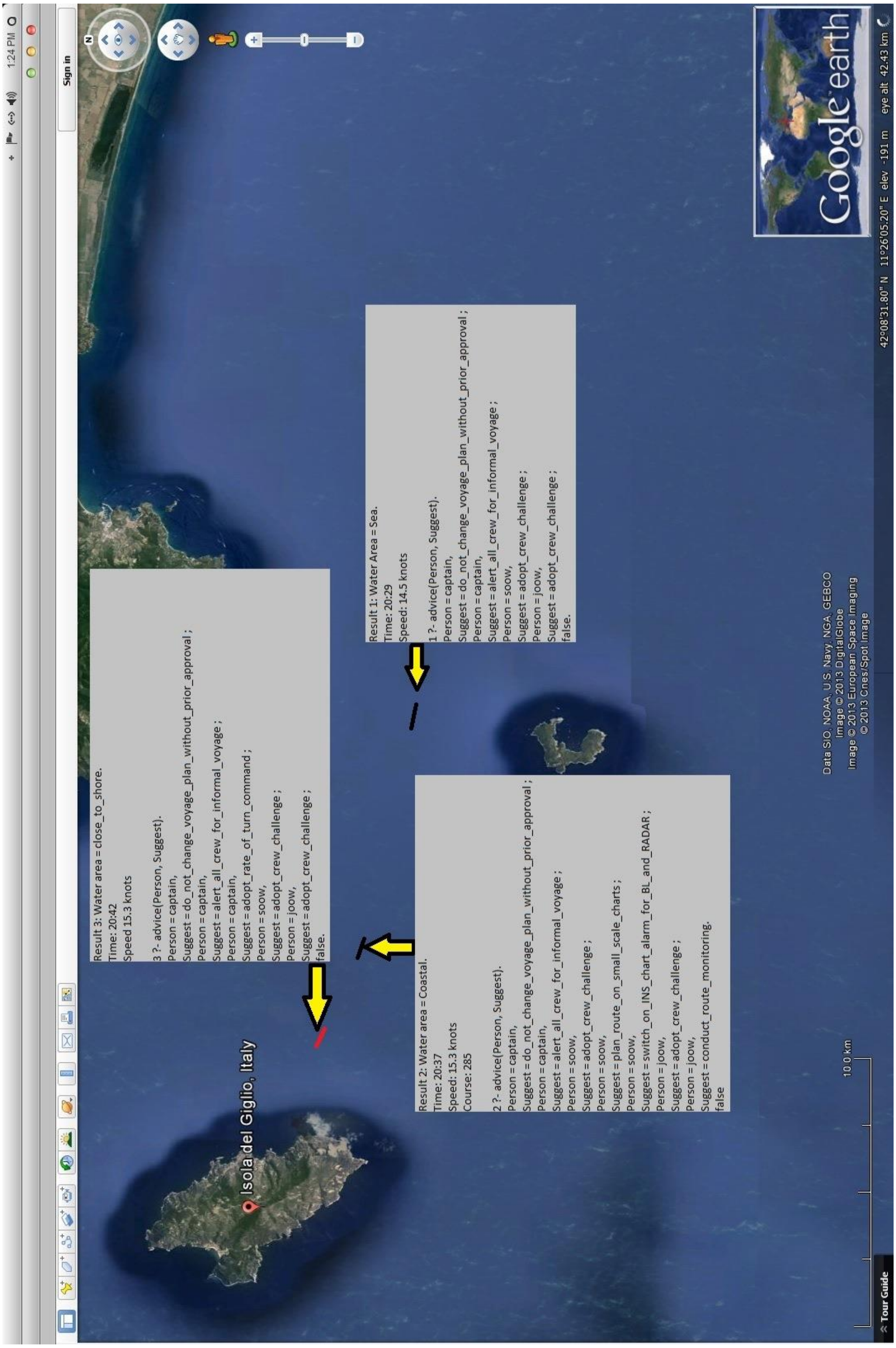

Fig. 5-5 Testing the concept accident module (not to scale).

5.3 The Accident of Bright Field

The accident of MV Bright Field took place shortly after 1400 hours on December 14, 1996. The fully loaded Liberian bulk carrier temporarily lost propulsion power as the vessel was navigating outbound in the Lower Mississippi River at New Orleans, Louisiana. The vessel struck a wharf adjacent to a populated commercial area that included a shopping mall, a condominium parking garage, and a hotel. No fatalities resulted from the accident, and no one aboard the Bright Field was injured; however, 4 serious injuries and 58 minor injuries were sustained during evacuations of shore facilities, a gaming vessel, and an excursion vessel located near the impact area. Total property damages to the Bright Field and to shore side facilities were estimated at about $20 million [44]. The final path and accident location of the Bright Field accident is shown in Fig. 5-6.

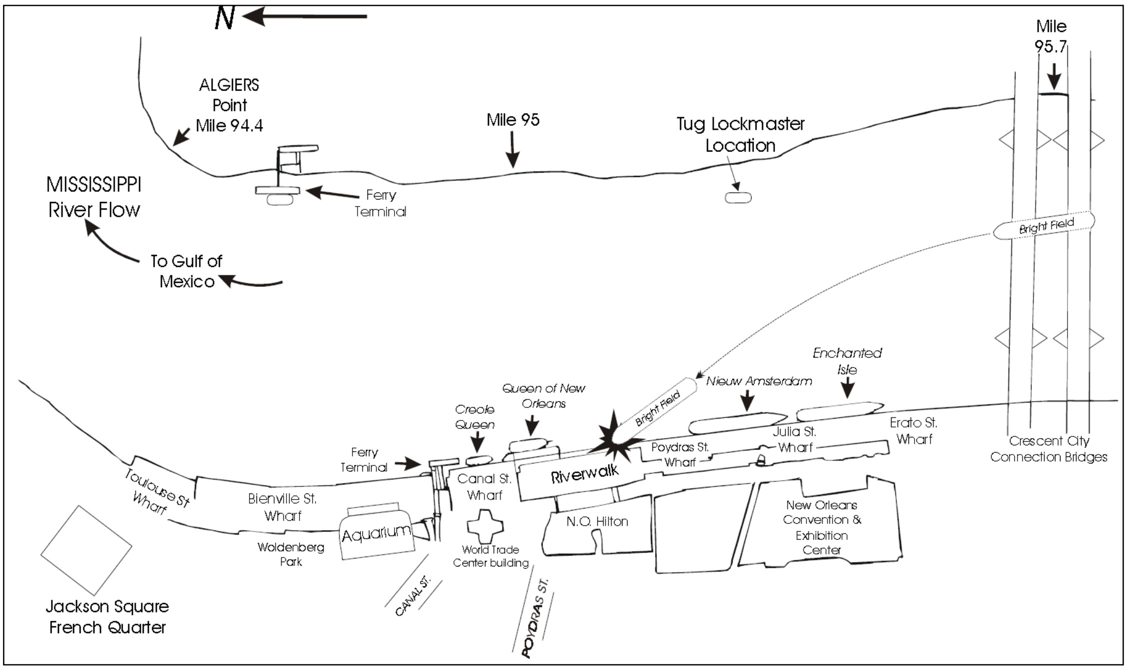

Fig. 5-6 Accident location of MV Bright Field [45].

According to the National Transportation Safety Board (NTSB) report [45] it was found that the ship had severe problems with its engine lube oil system prior to few days of the accident. At the open sea, in good weather, temporary malfunctions in the vessel's main engine may be tolerable; however, in the close quarters of the Mississippi River, where safe maneuvering is directly dependent upon a responsive main engine, a loss of power can, as it did in this instance, present an immediate threat to other vessels and to shore side facilities. Using the information available before the accident a time based events table can be constructed as shown in Table 5-3.

Table 5-3 Time based events of the accident of Bright Field.

Comments	Time	Person	Observation/Activity/Decision	Situation
Normal Procedure without any problem	Morning	Third Mate & Chief Electrician	Completes all pre-departure tests for both bridge and engineering, including testing the bridge main engine console lights and alarms.	Everything seems ok.
	0730	Pilot	Called for duty.	
	0943	Master	Orders standby engine.	
	1030			Ship's sailing time.
	1040	Pilot	Gets on board Bright Field.	
	1044	Pilot	Escorted by the Third Mate to the Master at the Bridge.	Normal procedures followed in the Bridge.
Pre-departure engine problems	1055	Pilot	Orders first engineering maneuvering bell (dead slow ahead).	
	1055	Third Mate	Attempts to execute the Pilot's order using the wheelhouse engine controls, but the vessel's main engine doesn't start. He then calls the engine control room and tells the Chief Engineer—in Chinese—that the engine is not starting. Engine control is transferred to the engine control room.	Both the Master and the Chief Engineer later states that their normal practice is to transfer engine control to the engine control room in the event of a nonemergency problem with the propulsion system.
	1055.5			Engines starts and the control is transferred to the wheelhouse.
		Pilot	Orders stop engine.	
	1110	Pilot	Orders dead slow ahead.	Again, the engine cannot be started from the wheelhouse, and again control is transferred to the engine control room, from which the engine is restarted. At this stage the Pilot not been advised of the difficulties in starting the engine from the wheelhouse, nor he is informed on those occasions when engine control was transferred to or from the engine control room. Lack of Communication have started to establish.
	1112			Bright Field departs La Place anchorage. Control is returned to the bridge.

Table 5-3 Time based events of the Accident of Bright Field (Continued).

Comments	Time	Person	Observation/Activity/Decision	Situation
Full Ahead and Sea Speed		Second Mate & Third Mate	Second Mate replaces the Third Mate.	
		Pilot	Orders full ahead maneuvering speed (56 rpm) in order to familiarize himself with the ship's responsiveness to rudder and engine orders.	
		Pilot	Orders sea speed (72 rpm) for better ship handling.	
	1159	Pilot	Orders full ahead maneuvering speed (56 rpm).	At this stage the engine rpm was increased to sea speed using wheelhouse controls.
		The Bright Field remains at full ahead maneuvering speed until it reaches the vicinity of Destrehan, Louisiana, when the Pilot again orders sea speed of 72 rpm, resulting in a ground speed (speed of the ship plus speed of the current) of about 16 knots.		
Moments before Engine Trip	1300	Pilot	Requests Master to send a seaman to stand by the anchor.	
		Master	Sends the ship's carpenter, with a handheld radio, to serve as anchor watch.	Serving as anchor watch was a regularly assigned duty of the Bright Field's carpenter.
		Master	Observes during the maneuvering of Bright Field the Pilot is over steering at times. But he didn't raise any voice.	Language & Communication Barrier
	1350	Pilot	Calls coast guard operator to get clearance of Algiers Point.	The Pilot was informed that there is a "sea going tow boat" in bound at that point.
		Pilot	As the ship passed under the Crescent City Connection Bridges, he allows the ship to acquire current induced swing to port to facilitate the upcoming maneuver around Algiers Point.	

Table 5-3 Time based events of the Accident of Bright Field (Continued).

Comments	Time	Person	Observation/Activity/Decision	Situation
Without Engine Power (3 Minutes till impact)	1406		Engine power drops.	Bright Field still passing under the bridges.
		Pilot	Notices the cessation of vibration in the engine.	Engine already Tripped.
		Pilot	Asks Master about the problem.	
		Master	Doesn't reply to Pilot because perhaps he was busy restoring rpm/language barrier prevented him responding.	
		Pilot	Could not make any additional navigational decisions.	
		Pilot	Realized the ship had lost power.	
		Master	Asks his mate to call engine room and demand an increase in power.	
		Chief Engineer	Observes lube oil pressure loss alarm.	The No. 2 pump starts as soon as he checks for it.
		Chief Engineer	Thinks except for the low rpm everything is normal. He decides to inform the bridge.	Perhaps he thinks the low rpm is from the bridge control.
		Second Mate	At the same time the second mate calls the Chief Engineer and demands increased power. But he doesn't relay the information of ship's heading and maneuvering situation to the Chief Engineer.	!!! – It seems the danger of collision or allision is not comprehended. Perhaps both the Master and the Second Mate thought the engine power would be back soon.
		Chief Engineer	As the Chief Engineer doesn't perceive any danger, like before, he suggests transfer of engine control from wheelhouse to engine control room.	
		Master	As he doesn't know about the pressurization problem, The Master agrees to transfers the control to the engine room.	But this decision is probably right in the sense that previously the engine showed starting problem and it was started from the engine room. There is no communication with the Pilot.
		Waste of valuable time: This transfer of control takes usually 20-30 seconds and must be completed before engine stopped can be restored. As soon as the lube oil pressure reached desired state, the engine could have been operable from the engine room.		
		Second Engineer	Could have increased engine rpm at this stage.	
		Master	Cannot determine his course of action.	He could have commanded increase rpm if he knew about the pressurization problem.
		Pilot	Totally unaware about the engine situation.	If he knew that the engine is able to produce power, he might have done crash maneuvering or else.

Table 5-3 Time based events of the Accident of Bright Field (Continued).

Comments	Time	Person	Observation/Activity/Decision	Situation
After engine power being restored (1 Minutes till impact)	1408			Bright Field's engine starts operating.
		Pilot	He is busy giving horn and alerting the vessels nearby for the eminent collision/allision.	Neither Master nor Mate informed about the restoration of engine power.
	1409.5	Pilot	Orders from bridge full astern and drop anchor.	
	1410			Engine control room answers of the order.
		Master	Could not establish communication with the Carpenter as the warning whistles were making noise. He goes out of the bridge and waves his hand to draw attention. But the Carpenter couldn't see the Master.	
		Master	Decides not to drop anchor and returns to bridge.	The Master thinks it may hit other ship by making a sharp turn.
		Master	Again decides to drop anchor.	By this time the ship proceeded a bit further.
The Allision	1411	The port bow of Bright Field strikes in between two docked ships at an angle of 40-45 degrees. The wharf adjacent to a populated commercial area included a shopping mall, a condominium parking garage and a hotel.		

The analysis in the above table suggest that the captain and the crew faced significant engine trouble during their voyage. Due to the engine problem they were following a standard procedure of starting the engine form the engine room rather than from the bridge deck. However, when the engine started the problem just around the Crescent City Connection bridges, they followed the standard procedure of engine restart. But there the time to make a safe maneuver was greater than the engine restarting time. If at this stage an expert system could have been employed, it would have performed maneuvering simulations and compared it with engine restoring time and finally could give a logical suggestion. Fig. 5-7 shows this concept. Here the concept of ‘P’ value is also utilized.

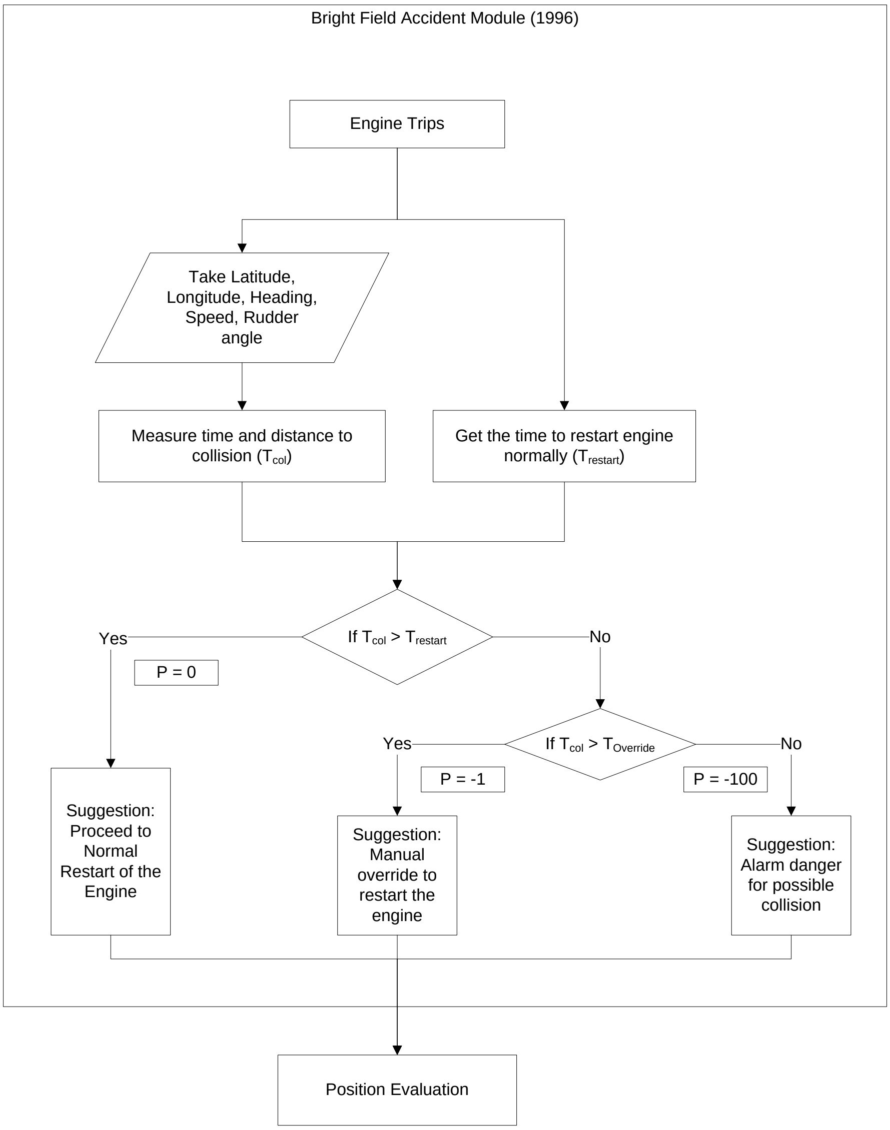

Fig. 5-7 Position evaluation using the module of the accident of Bright Field.

A prolog code is developed utilizing the above concept. In addition, advices for the Master and Chief Engineer of the ship is programmed. Fig. 5-8 shows a snap shot of the Prolog code.

```
%== Facts an Inputs ====================================
engine_status(starting_problem).
engine_status(stopped).
% engine_status(running).

% water_area(coastal).
% water_area(inland_river).
water_area(dangerously_close_to_shore).

ship_state(sailing).
% ship_state(idle).

pilot_status(oversteering).

%== Advices ==============================================

advice(M, MA1):-
        M = master,
        engine_status(starting_problem),
        MA1 = let_the_pilot_know_of_the_engine_problem.

advice(M, MA2):-
        M = master,
        ship_state(sailing),
        water_area(inland_river),
        pilot_status(oversteering),
        MA2 = inform_pilot_of_oversteering.

advice(M, MA3):-
        M = master,
        engine_status(stopped),
        ship_state(sailing),
        water_area(inland_river),
        MA3 = alert_all_crew_for_impact.

advice(M, MA4):-
        M = master,
        ship_state(sailing),
        water_area(coastal),
        engine_status(stopped),
        MA4 = proceed_normal_procedure_for_engine_restart.

advice(M, MA5):-
        M = master,
        engine_status(starting_problem),
        engine_status(stopped),
        ship_state(sailing),
        water_area(dangerously_close_to_shore),
        MA5 = brace_for_impact.

advice(CE, CE1):-
        CE = chief_engineer,
        engine_status(stopped),
        ship_state(sailing),
        water_area(inland_river),
        CE1 = determine_time_to_restart_engine_and_inform_captain.

advice(CE, CE2):-
        CE = chief_engineer,
        engine_status(stopped),
        ship_state(sailing),
        water_area(dangerously_close_to_shore),
        CE2 = manual_over_ride_for_engine_restart.
```

Fig. 5-8 Snapshot of Prolog code for the accident module of Bright Field.

Utilizing the above Prolog accident module, a test run has been conducted similar to the accident of Costa Concordia as mentioned above. A google Earth snap shot is taken for the location and the ships relative position in taken as input. The Prolog accident module provide suggestions to the Master and the Chief Engineer as shown in Fig. 5-9.

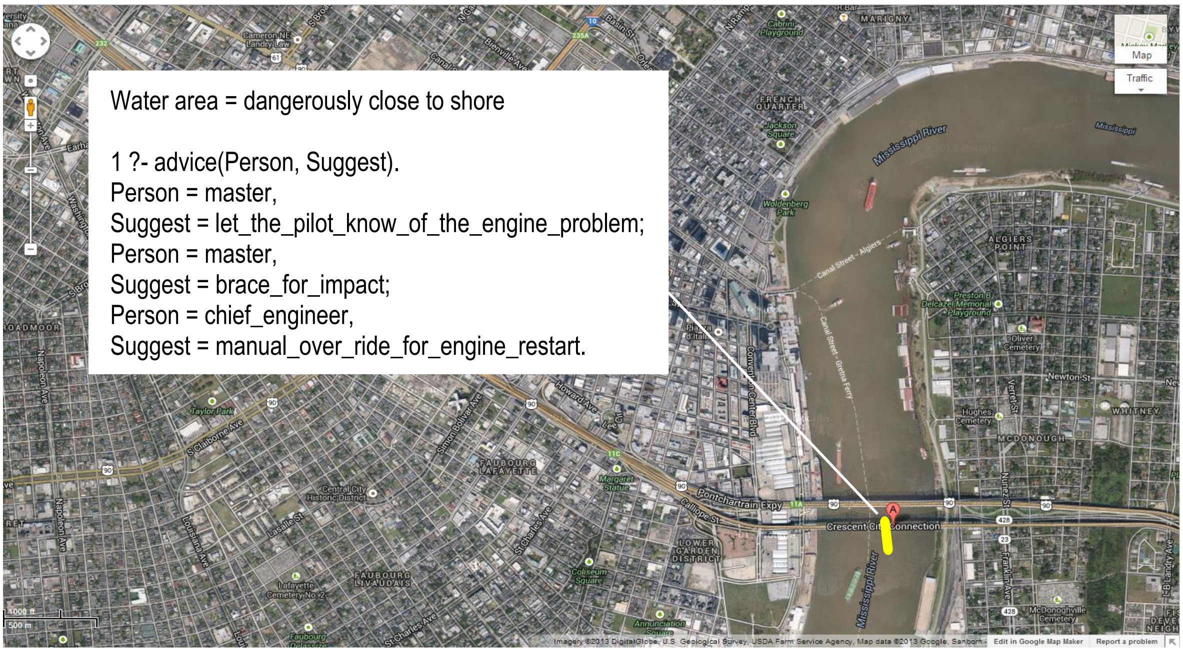

Fig. 5-9 Testing the concept accident module.

Chapter 6

Conclusions & Recommendations

The approach of dealing with accidents as shown in this research is quite unique as it attempts to utilize previous knowledge of accident occurrence to prevent occurrence of similar accidents in the future. As knowledge or experience of an accident is not easy to transfer to all the crew of a ship, such approach promises to be very useful and practical along with extensive training of the crew. In this regard, it is indeed recommended to carry on further extensive studies on the development and establishment of the proposed concept model.

There are two different areas of special knowledge in this concept. One is the utilization of maneuvering model for time domain simulation. For this segment careful selection of the an accurate model is necessary with consideration of all natural phenomena such as current, wind, wave, water depth and etc. Devices/sensors are necessary in order to provide real time inputs for running the simulation model. On the other hand for the expert system, it appears to be very important to develop practical and applicable algorithms for accidents.

A framework for developing an expert system is shown and necessary conceptual phases are graphically presented. The concept of position evaluation is introduced which will help the future research. The present research identifies three possible methods for developing an expert system:

1) Rule based simple error notification (RB-SEN)
2) Rule based simple advice generation (RB-SAG)
3) Heuristic search based complex advice generation (HSB-CAG)

The RB-SAG has been demonstrated successfully in this study. Both RB-SAG and RB-SEN are similar in their functionality. But HSB-CAG is more advanced and it may utilize heuristics. However, in order to establish the concept and perform successful implementation of the methods, further studies are required. Therefore, the following recommendations are made:

1) A unified tool needs to be developed that will combine the time domain simulator and the expert system. This will include development of a ship maneuvering and sea keeping model suitable for accident analysis. In addition it is also necessary to develop accident category wise knowledge bases for in depth analysis.
2) Incorporation of significant number of accident modules including different types of accidents such as collision, grounding, structural failure, capsizing and others would enrich the system.
3) Various game algorithms (such as Chess, Tower of Hanoi, etc.) or heuristics search techniques could be studied and applied in HSB-CAG.
4) Development of a physical system for successful testing and verification is necessary. Testing the system against real accident scenarios will strengthen the concept and concerned methods further.

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