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A Concept for Expert System Based Accident Prediction Technique for Ship Maneuvering

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ABSTRACT

So many accidents happen in the past years. Each time big accident happens, new regulations, apparatus/devices and systems are mandated/recommended. However, the number of accidents does not reduce. New types of accidents happen, maybe because most of accidents happen by human errors directly/indirectly. Although the word 'accident' means anything that happens suddenly or by chance without an apparent cause, most of the maritime accidents that took place over the past decades are resulted from many causes and the end result (i.e. the accident) is not evident until it reaches to a particular space and/or time. Many accident analysis methods are already proposed, but most of them are based on probabilistic analysis or fault-tree analysis. It is quite difficult to include human error occurrence in these methodologies. Therefore, this research is a step towards identifying those underlying causes particularly the decisions that lead to the accidents. A new idea to detect hidden causes of an accident is proposed based on a kind of expert system technique. Expert systems are programs instructed to function like a human expert that solve a particular problem or in giving advice. 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 why and where the accidents invisibly start, even though at that time nothing strange happens. A concept model is described in this paper and further necessary developments are recommended.

INTRODUCTION

Maritime accidents are often extravagant by nature and in many instances 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 (2013), the word accident implies as "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 "not intended". All accident investigations try to find out the reasons behind this "not expected" 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 in the form of algorithm to prevent similar accidents to take place in the future.

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 could be (or could not be) a symptom for a serious disease. 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. This is exactly the area where the current research attempts to investigate. Therefore, in order to deal with this problem, this research proposes utilization of expert system technique (developed from the knowledge of real accidents) and ship maneuvering model. A concept has been developed and explained in this paper. Two example cases are utilized, such as the accident of the cruise ship Costa Concordia (2012) in Italy and the accident of the cargo ship MV Bright Field (1996) in USA.

LITERATURE REVIEW

So far numerous research and developments have been conducted all around the world to prevent accidents. Research in the form of statistical analysis has progressed significantly over the years. These research works comes 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. Some significant research works studied may be mentioned here as Wang et al (2005), Awal (2007), Awal et al (2010), Hakkinen et al (2013) and others. Some research works studied and compiled accident analysis technique comprehensively such as Ylitalo (2010) and Li (2012). These research presents significant compilation of maritime accident/risk modelling theories. The use of fault tree and Bayesian network model in accident analysis is quite significant as observed in the research works of Fowler & Sørgard (2000), Merrick & Dorp (2006) and Trucco et al (2008). Significant developments have also been made in the field of marine traffic simulation to predict and avoid accidents. Leading research works include Hasegawa et al (2001) and Hasegawa et al (2013).

On the other hand, significant research and development has been observed in the field of expert system. Expert systems are utilized in many industries for fault detection and prevention of accidents. Some notable research works may include: Wang (2012), Rahman et al (2009), Qian et al (2003) and others. But most applications are very specific to process industries and therefore, they are not suitable for maritime accident prediction. Nevertheless, Hasegawa (1993) and Endo & Hahegawa (2002) have utilized expert knowledge for harbor maneuvering and passage planning. But research works on accident prediction with respect to human decision making is very rare. Very recently Awal & Hasegawa (2013) proposed the use of expert system in accident prediction. Based on the idea this paper proceeds further in to the concept.

DESCRIPTION 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.

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 figure 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. The following subsequent sections explain each of these components.

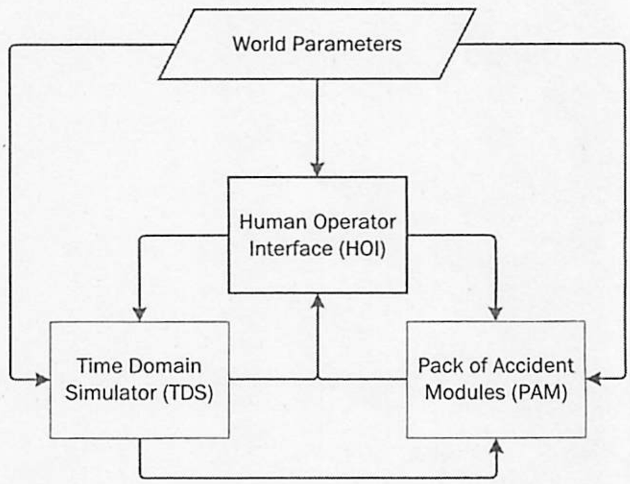


Fig. 1: Basic composition of the concept model.

Human Operator Interface (HOI)

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).

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.

The Time Domain Simulator (TDS)

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. figure 2 shows the TDS process. The TDS is further elaborated in the OPERATION OF THE MODEL section.

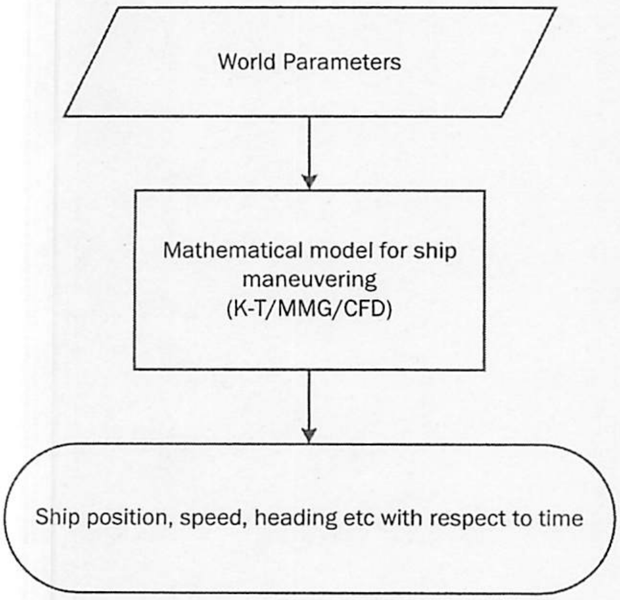


Fig. 2 Basic function of TDS.

Pack of Accident Modules (PAM)

This segment contains accident modules, which are real life accidents programmed as sequence of errors or in 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. The idea of PAM is further elaborated in the CONCEPT OF THE EXPERT SYSTEM section

OPERATION OF THE MODEL

The model may run in continuous loop and provide continuous update to the HOI. 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 determining the best score, the model may run continuously and produce result of possible threats.

Evaluation with Respect to Ship's Position

It is essential to evaluate ship's position during its voyage at regular intervals of time. Therefore, figure 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-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.

The model may run in the following sequence at any origin and generate output for the 3 branches 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.) for 3 possible positions.
4. Check accident modules for logical inference and show the results.
5. Run simulation for the next level.
6. After certain time (t) there will be grounding/collision/accident.
7. At this stage show current path in timeline.
8. Obtain expert advice from the expert system and deliver to HOI.

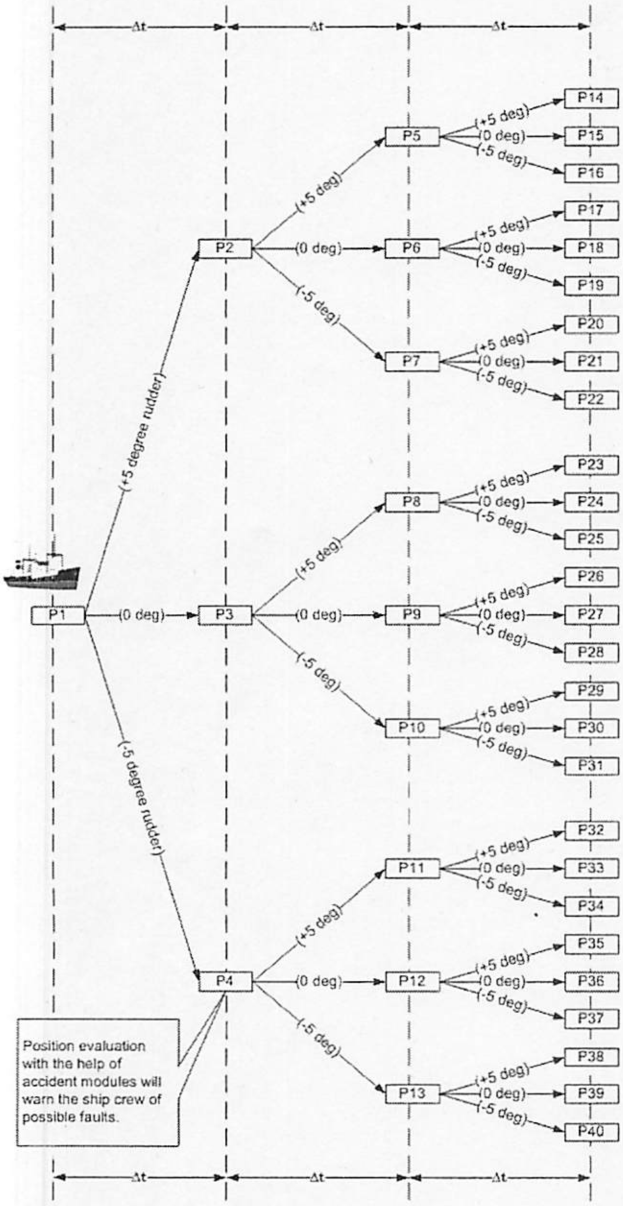


Figure 3: Position of ships numbered in a tree.

CONCEPT OF THE EXPERT SYSTEM

An expert system is computer software that attempts to act like a human expert on a particular subject area (IGCSE ICT, 2013). Expert systems are often used to advise non-experts in situations where a human expert in unavailable (for example it may be too expensive to employ a human expert, or it might be a difficult to reach location). Therefore, the idea in this research is to utilize the knowledge of a previous accident and use it in the expert system so that next time a ship crew can be warned for similar type accident.

An expert system is made up of three parts as shown in the figure 4 and described as following:

(1) A User Interface - This is the system that allows a non-expert user (here it could be the ship crew) to query (question) the expert system, and to receive advice. The user-interface is designed to be as simple to use as possible.

(2) A knowledge base - This is a collection of facts and rules. Here it will be the algorithms from previous accidents. The knowledge base is created from information provided by human experts.

And finally (3) an inference engine - This acts rather like a search engine, examining the knowledge base for information that matches the user's query.

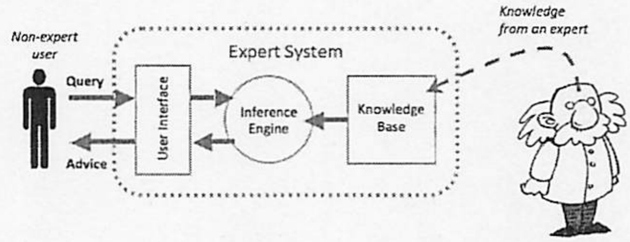


Fig. 4: Basics of an expert system (IGCSE ICT, 2013).

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. 32 lost their lives and 60 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, and at the time it was the largest Italian cruise ship ever built (Lieto, 2012).

Based on the study by Lieto (2012) on the Costa Concordia accident, it is possible to develop a knowledge base "accident module". For the knowledge base, facts may be derived by studying the final moments before the accident. For example Table 1 shows the facts associated with Organization, Workplace, Captain, Senior Officer of the Watch (SOOW) and Junior Officer of the Watch (JOOW). This is indeed 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 1: Facts of the Costa Concordia Accidents.

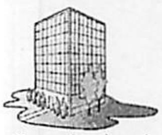
Facts Group	Facts in terms of logic programming variables
 Organizational facts	O1. Organization(do_not_allow_change_in_voyage_plan). O2. Organization(do_not_allow_without_prior_approval).
 Workplace Influence	W1. Work_influence(tribute_to_mentor). W2. Work_influence(change_in_voyage_plan).
 Captain	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)	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)	J1. JOOW(crew_challenge). J2. JOOW(no_crew_challenge). J3. JOOW(danger_observed). J4. JOOW(no_danger).

Table 2 shows the list of errors constructed using the facts from Table 1. For the first error, two relations are required. At first, W1 and W2 results C1. This means when 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 2: Rules constructed from the facts to identify errors for the accident of the Costa Concordia.

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*

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 Senior Officer of the Watch (SOOW) to decide to plan the voyage on large scale charts.

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 barrier.

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.

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. Figure 5 shows the final path of Costa Concordia near the island of Giglio.

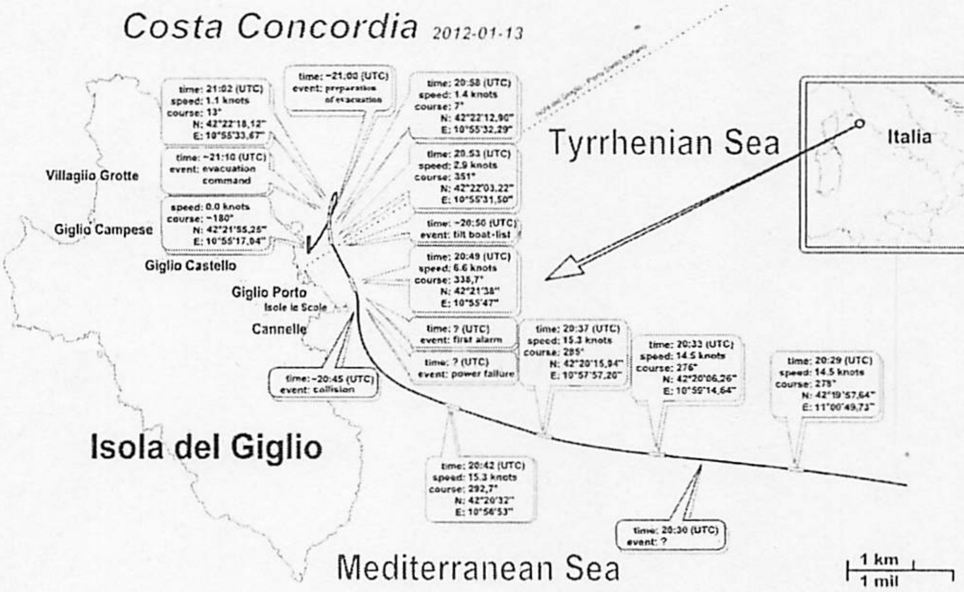


Figure 5: Final path of Costa Concordia (Wikipedia, 2013).

Hence, utilizing the above mentioned concept of knowledge base the following position evaluation sequence may be developed as shown in figure 6. This sequence will evaluate each position and provide the HOI with logical suggestions.

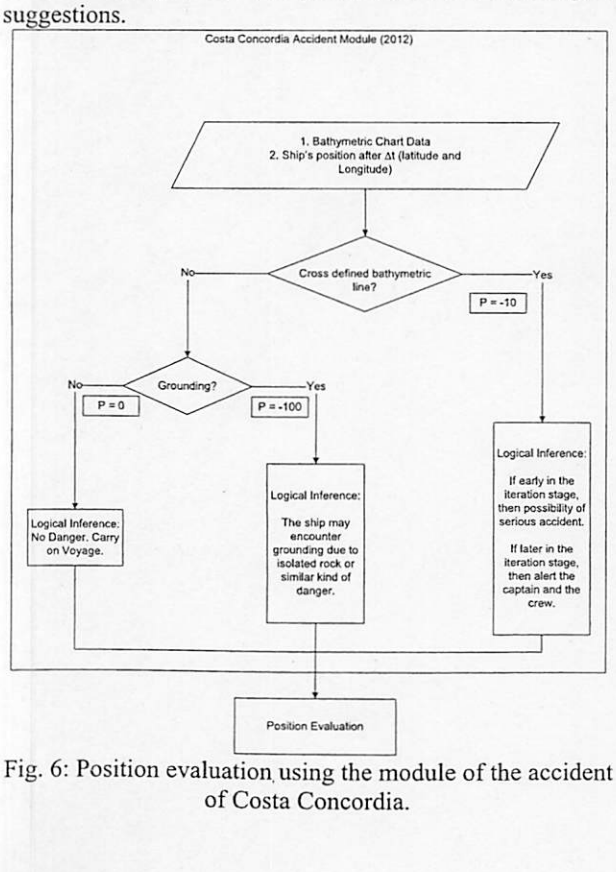


Fig. 6: Position evaluation using the module of the accident of Costa Concordia.

The Accident of Bright Field

The accident of MV Bright Field took place shortly after 1400 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 (NASA, 2010).

According to the National Transportation Safety Board (NTSB) (1996) report it was found that the ship had severe problems with its engine lube oil system prior to few days of the accident. On 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 shoreside facilities. Using the information available for the final 4 minutes before the accident a time based events table can be constructed as shown in Table 3.

Table 3: Time history of events for the last 4 minutes.

Comments	Time	Person	Observation/Activity/Decision	Situation
Without Engine Power (3 Minutes till impact)	1406		Engine power drops.	Bright Field passing under a bridge.
	1406+	Master	Asks his mate to call engine room and demand an increase in power.	
	1406+	Chief Engineer	Thinks except for the low rpm everything is normal.	He possibly thinks the low rpm is from the bridge control.
	1406+	Second Mate	The second mate calls the Chief Engineer and demands increase 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.***
	1406+	Chief Engineer	As the Chief Engineer doesn't perceive any danger, he suggests transfer of engine control from wheelhouse to engine control room as a usual practice.	
	1406+	Master	As he doesn't know about the particular cause of the problem, The Master agrees to transfer the control to the engine room.	This decision seems right one in the sense that previously the engine showed starting problem and it was started from the engine room.
	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.			
	1407+	Chief Engineer	***The Chief Engineer could have increased engine rpm at this stage.***	But the Master cannot determine his course of action. Due to language barrier he wasn't fluent with the pilot who was navigating the ship.
The Allision	1411	***Engine power came back on 1408. But the crew realized very late that allision is inevitable.*** The port bow of Bright Field strikes a wharf adjacent to a populated commercial area included a shopping mall, a condominium parking garage and a hotel.		

Utilizing the above mention information, a logical flow diagram is developed for position evaluation as shown in figure 7.

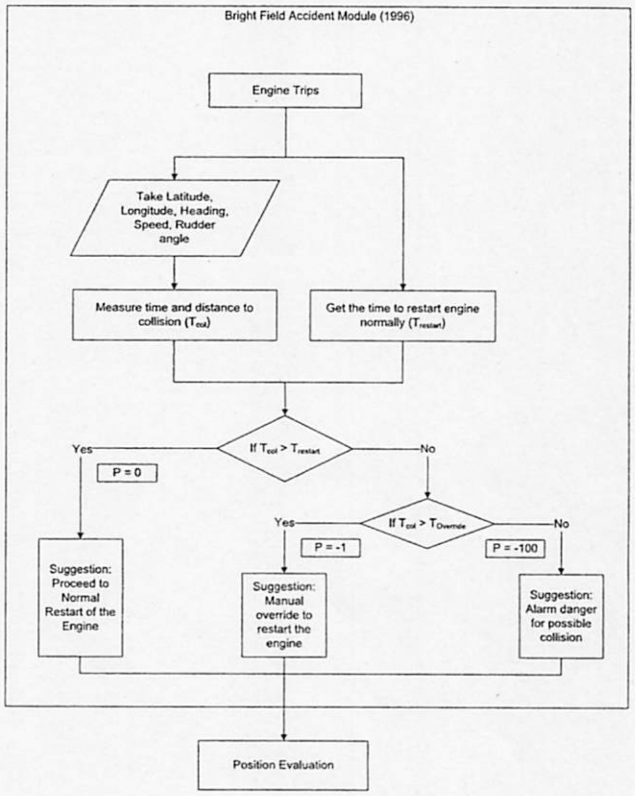


Fig. 7: Position evaluation using the module of the accident of Bright field.

The accident location of MV Bright Field is shown in figure 8. Hence by utilizing the above mentioned accident modules, position evaluation for all the possible nodes (as shown in figure 3) can be conducted. Once the captain and the crew are aware of the possible dangers along with their decisions or their perceptions, they may change it accordingly. Thus the position evaluation accomplishes its role.

The approach of dealing with accidents 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.

CONCLUSIONS & RECOMMENDATIONS

Thus this concept needs to be further studied in detail and methodologies are required to be established with comprehensive studies. 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 most accurate model is necessary with consideration of all natural phenomena such as current, wind, wave, water depth and etc. On the other hand for the expert system, it appears to be very necessary to develop practical and applicable algorithms particularly for the marine accidents. The next step of the research may include the following arrears of interest:

- Development of a practical ship maneuvering and see keeping model suitable for this type of accident analysis.
- Development of accident category wise knowledge bases for in depth analysis.
- Development of testing of facility in the form marine traffic simulation.

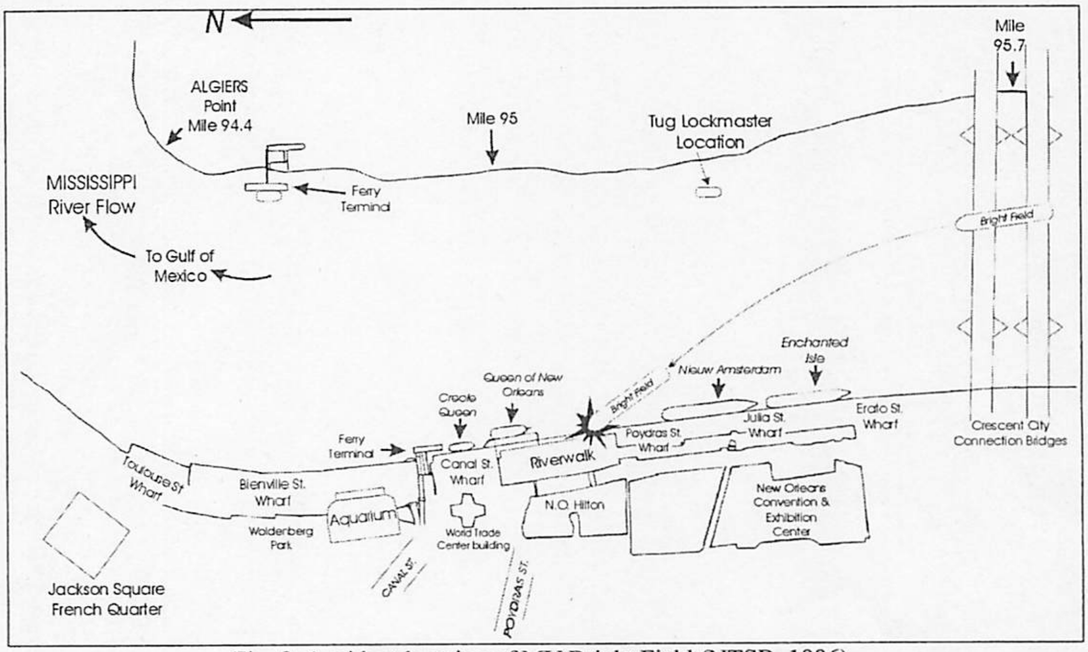


Fig. 8: Accident location of MV Bright Field (NTSB, 1996).

REFERENCES

Awal, Z. I., (2007). A Study on Inland Water Transport Accidents in Bangladesh: Experience of a Decade (1995-2005), International Journal for Small Craft Technology (IJSCT), The Transactions of The Royal Institution of Naval Architects (RINA), London, Vol. 149, Part B2, pp 35-42.

Awal, Z.I. and Hasegawa, K. (2013), Bridge Resource Simulator - A New Tool for Ship Accident Analysis, Proceedings of the Japan society of Naval Architects and Ocean Engineers (JASNAOE), Vol. 16, pp. 51-54.

Awal, Z.I., Islam, M.R. and Hoque, M.M., (2010), Collision of marine vehicles in Bangladesh: a study on accident characteristics, Journal of Disaster Prevention and Management, Vol. 19, No. 5, pp. 582-595.

Cambridge Dictionaries Online (2013), [Web address: http://dictionary.cambridge.org/dictionary/british/accident?q=Accident].

Endo, M. and Hasegawa, K. (2002), Automatic Passage Planning for Vessels Based on Expert Knowledge, Proc. of the 8th IEEE International Conference on Methods and Models in Automation and Robotics, (MMAR 2002), Vol2, pp.829-833, Sep., 2002.

Fowler, T. G. and Sørgård, E. (2000), Modeling Ship Transportation Risk, Risk Analysis, Vol. 20, No. 2, pp. 225-244.

Häkkinen, J.M. and Posti, A.I. (2013) Overview of Maritime Accidents Involving Chemicals Worldwide and in the Baltic Sea, Chapter 1. Pollution at Sea, Cargo Safety, Environment Protection and Ecology, Maritime Transport & Shipping Introduction. Maritime Transport & Shipping, pp. 15-25.

Hasegawa, K. (1993), Knowledge-based Automatic Navigation System for Harbour Manoeuvring, Proc. of Tenth Ship Control Systems Symposium, pp.2:67-90, Ottawa, Oct., 1993.

Hasegawa, K. and Yamazaki, M. (2013), Qualitative and Quantitative Analysis of Congested Marine Traffic Environment – An Application Using Marine Traffic Simulation System, the International Journal on Marine Navigation and Safety of Sea Transportation, Volume 7, Number 2, June 2013, pp. 179-184.

Hasegawa, K., Tashiro, G., Kiritani, S. and Tachikawa, K. (2001), Intelligent Marine Traffic Simulator for Congested Waterways, Proc. of 7th IEEE International Conference on Methods and Models in Automation and Robotics, Miedzyzdroje, Poland, Aug., 2001.

IGCSE ICT (2013), Web based online resources on computer science and information & communication technology, [Web address: http://www.igcseict.info/theory/7_2/expert/].

Li, S., Meng. Q. and Qu, X. (2012), An Overview of MaritimeWaterway Quantitative Risk Assessment Models, Risk Analysis, Vol. 32, No. 3, pp. 496-512.

Lieto, A. D. (2012), Antonio: Costa Concordia Anatomy of an organisational accident, Retrieved 20th August 2012, from [web address: http://www.enav-international.com/wosmedia/273/costaconcordiaanatomyofanorganisationalaccident.pdf].

Merrick, J. R. W. and van Dorp, R. (2006), Speaking the Truth in Maritime Risk Assessment, Risk Analysis, Vol. 26, No. 1, pp. 223-237.

National Aeronautic and Space Administration (NASA) (2010), System Failure Case Studies, Vol 4, Issue 10.

National Transportation Safety Board (NTSB) (1996), Allision of the Liberian Freighter Bright Field with the Poydras Street Wharf, Riverwalk Marketplace, and New Orleans Hilton Hotel in New Orleans, Louisiana, PB98-916401, NTSB/MAR-98/01, Washington, D.C. 20594.

Qian, Y., Li, X., Jiang, Y. and Wen, Y. (2003), An expert system for real-time fault diagnosis of complex chemical processes, Expert Systems with Applications 24, pp. 425–432.

Rahman, S., Khan, F., Veitch, B. and Amyotte, P. (2009), ExpHAZOP+: Knowledge-based expert system to conduct automated HAZOP analysis, Journal of Loss Prevention in the Process Industries 22, pp. 373–380.

Truccoa, P., Cagnoa, E., Ruggerib, F. and Grandea O. (2007), A Bayesian Belief Network modelling of organisational factors in risk analysis: A case study in maritime transportation, Reliability Engineering and System Safety 93 (2008) 823–834.

Wang, F. and Gao, J. (2012) A novel knowledge database construction method for operation guidance expert system based on HAZOP analysis and accident analysis, Journal of Loss Prevention in the Process Industries, Journal of Loss Prevention in the Process Industries 25, pp. 905 - 915.

Wang, J., Pillay, A., Kwon, Y. S., Wall, A. D., & Loughran, C. G. (2005). An analysis of fishing vessel accidents: Accident Analysis & Prevention Vol 37(6) Nov 2005, 1019-1024.

Wikipedia (2013), Costa Concordia disaster, Retrieved on 21st March 2013, [Web Address: http://upload.wikimedia.org/wikipedia/commons/2/23/Costa_Concordia_map_13-1-2012.svg.]

Ylitalo, J. (2010), Modelling Marine Accident Frequency, Master's Thesis, School of Science and Technology, Faculty of Information and Natural Sciences, Aalto University.