Bridge Resource Simulator - A New Tool for Ship Accident Analysis

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1. INTRODUCTION

Over the years numerous research and development have taken place in the field of maritime risk modelling and reliability analysis. Some risk models have also been practically applied and utilized in various engineering applications including large projects[1]. Despite numerous research & developments, accidents are still taking place quite often in alarming scale and also in unexpected manner[2]. While we think that new technology is about to make systems safer, risk of accidents are still there to be evaluated and dealt with. In this perspective many researchers endeavor in analyzing and developing risk models[3]. Most of these models are based on the fundamental concept of probability or chance of event occurrence. But this might not be a skilful practice particularly where it involves human lives and valuable resources. Eventually it appears that many accidents are now occurring through this chance or probability of event occurrence. At this age of relatively super fast computing power and advanced artificial intelligence, we are now able to analyze many possibilities of event occurrence deterministically and avoid uncertainties. This research is an attempt to find a new direction for accident analysis, which may be able to predict an accident beforehand more accurately with the help of artificial intelligence and time domain simulation.

2. CONCEPT OF THE MODEL

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. For this there are obvious challenges. The parameter "decision with respect to time" is extremely difficult to model due to complex nature of the system. For example, Fig. 1 shows a timeline where for an unforeseeable reason a Captain may make a wrong decision based on effects from an external event which may eventually lead the ship to an accident. The figure shows Captain's decision making options (a, b, c, d & e) and options for external events (p, q, r, x & y). Along the timeline of voyage the captain needs to make decisions and he makes decisions from the information he retrieves from his surroundings, crew members, passengers and so on. These external influencing factors contribute to Captain's decision making process in a complicated way. Modeling such system is extremely complex and numerical programming cannot deal decision based parameters easily.

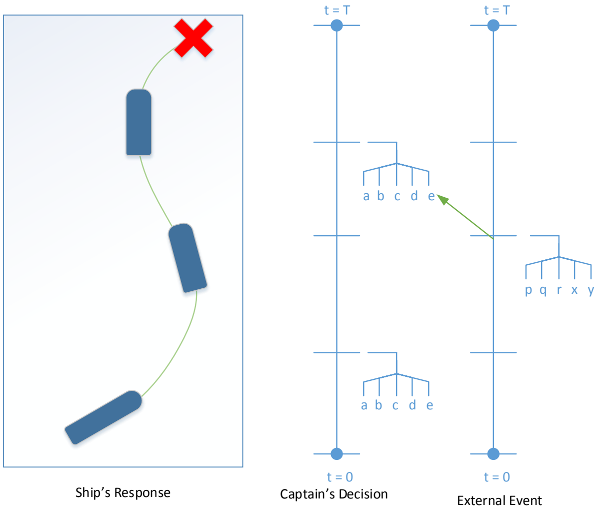

Fig. 1 A timeline showing decision tree and ship response.

Therefore, in this research it has attempted to simply this complex procedure using logic programming technique. The paper demonstrates a simple technique to analyze the decisions in terms of "accident modules" which may be utilized along with the time domain simulation for accident prediction. As there are many possible outcomes for many possible events, utilization of computer chess algorithms may result an efficient analysis of such scenarios. Also identification of potential dangers for each decision is somewhat similar to playing a chess game. Therefore, this paper focuses on the necessity of understanding the analogy of chess game with respect to ship navigation.

2.1 Chess Game Analogy

In order to utilize the chess game, it is essential to find the

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similarities and dissimilarities between chess game and marine transportation. In chess, players play against each other in a structured and rule based procedure where reaching a state results victory or loss. There are certain objectives e.g. checkmate for the chess and in transport problem reaching a destination without an accident. In order to fulfill the objectives, each chess piece needs to move in a defined pattern, which is to some extent similar to the movements of different types of ships. Just like the movement of ships within shallow/restricted waterways or canals where degree of freedom for movement is limited. However, the fundamental similarity is that both of the systems are driven by decisions; and this decision eventually leads to the final result.

The problems that chess game and perhaps also the marine accident deal with are not fundamentally numerical, rather than logical in nature. The recent accident of the cruise liner MS Costa Concordia also shows how decisions result into active errors in the context of latent conditions[4]. These errors logically create a successful pathway for the accident to take place. An example is stated in section 3 of this paper.

However, a fundamental aspect of any accident is the time parameter, which affects the whole scenario. The lack of time to react in any accident scenario is essentially different from chess game where the time to react doesn't affect the game. A chessboard will stay still until a player decides to play a move. Whereas, in accident conditions, decisions need to be taken within a time constraint otherwise accidents become obvious. Hence, identification of such similarities and dissimilarities yield a better understanding on the model development.

2.2 Model Composition

Fundamentally the 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. 2 shown below. The arrow directions show the direction of information flow. However, in addition to these three components, all the components 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.

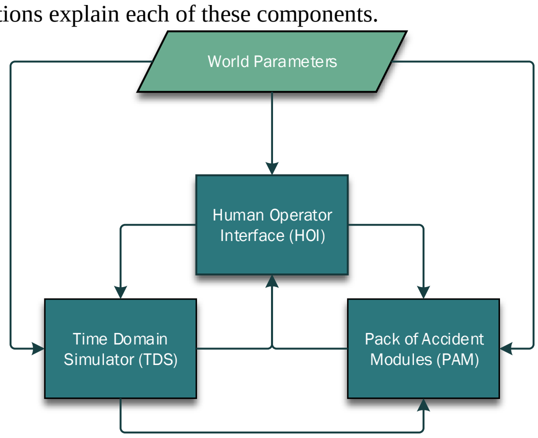

Fig. 2 Basic composition of the model.

(1) 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 will be the potential threats, 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.

(2) 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 of computer. 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. 3 shows the TDS process.

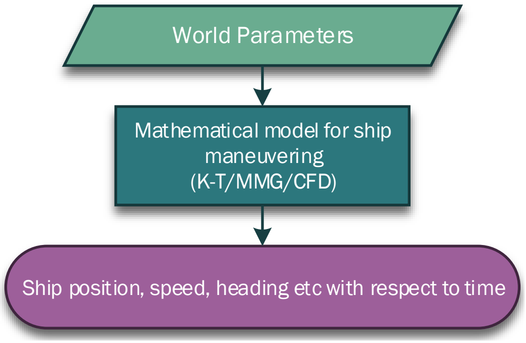

Fig. 3 Basic steps of TDS.

(3) Pack of Accident Modules (PAM)

This segment contains accident modules, which are real life accidents programmed as sequence of errors. 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. Section 3 of the paper discusses an accident module in detail with the example of the accident of MS Costa Concordia.

2.3 Model Run

The model may run in continuous loop and provide continuous update to the HOI. The time step for each loop run 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. 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. Check accident modules at time step (Δt). If no accident, run simulation again for Δt.
4. After certain time (t) there will be grounding/collision/accident.
5. At this stage show current path in timeline.
6. Go to initial value change speed/heading/etc.

7. Run simulation again.

By running similar loops for different decision options of different crew members of the ship may also result an array of accidents and successful paths. These could be used to avoid accidents and achieve an objective.

3. APPLICATION OF THE MODEL IN COSTA CONCORDIA ACCIDENT

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 accident demonstrated that catastrophe may occur even with ships that are considered masterpieces of modern technology and despite more than 100 years of regulatory and technological progress in maritime safety since the accident of the Titanic[5].

Based on this accident an “accident module” is developed using Prolog, which can predict the errors with respect to decisions. Table 1 shows the variables of Organizational Decisions, Workplace or External Influence/Decisions, Captain’s Decisions, Senior Officer of the Watch (SOOW)’s Decisions, Junior Officer of the Watch (JOOW)’s Decisions and Helmsman’s Decisions. In addition, the table also shows what decisions the Captain, SOOW and the JOOW agree and what tasks do JOOW and Helmsman perform. This is indeed a simplified form, which are only concerned with navigational responsibilities. Obviously there might be many other variables that could affect the safety, but for simplicity only navigational variables are considered. The strikeout variables show that they are not applicable in this example but they may be utilized in other cases. The variables are marked with alphanumeric tags. For example, ‘O2’ means the second variable of Organizational Decisions that is ‘do_not_allow_change_in_voyage_plan’.

Table 2 shows the list of errors and how the decisions/agree/tasks relate to these errors. Due to limitation of space only first two errors are discussed. 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 O2 (do_not_allow_change_in_voyage_plan) and O4 (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 Prolog code will generate a warning for the first error.

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.

Similar analysis and programming technique may show how the rest of the errors took place. 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.

Table. 1 Variable parameters of the Prolog code explaining the decisions, agreements and tasks of crew of the ship.

Organizational Decisions	**Work Place or External Influences/Decisions**	**Captain Decisions**	**SOOW Decisions**	**JOOW Decisions**	**Helmsman Decisions**
Organizations have specific guidelines for changing voyage plan and requires prior approval. ~~O1. allow_change_in_voyage_plan~~ O2. do_not_allow_change_in_voyage_plan ~~O3. allow_without_prior_approval~~ O4. do_not_allow_without_prior_approval	The mentor of the captain was in the Giglio Island. Also the hotel manager requested the captain to make a change in the voyage plan. W1. tribute_to_mentor W2. change_in_voyage_plan	Captain may make the following decisions: C1. change_in_voyage_plan C2. no_prior_approval C3. informal_procedure C4. no_ins C5. rudder_orders C6. danger_observed C7. no_danger	SOOW thinks this is an informal voyage so he may decide the following: ~~S1. plan_on_small_scale_charts~~ S2. plan_on_large_scale_charts S3. use_ins S4. ins_alarm_furthest_point_from_echo ~~S5. ins_alarm_10m_line~~ S6. no_crew_challenge S7. danger_observed S8. no_danger	JOOW thinks this is also an informal voyage so he may decide the following: ~~J1. crew_challenge~~ J2. no_crew_challenge J3. danger_observed J4. no_danger	Not considered.
		Captain Agrees	**SOOW Agrees**	**JOOW Agrees**	
		CA1. Captain agrees whatever SOOW decides regarding voyage plan/charting *(CA1 = S1 or S2)*	SA1. SOOW agrees to whatever captain decides as it is an informal voyage.	JA1. JOOW Agrees whatever the Captain/SOOW orders him.	
				JOOW Task	**Helmsman Task**
				JT1. Help SOOW fixing ship position on paper chart. JT2. Assist helmsman in translating the conning orders.	HT1. Execute whatever Captain/SOOW commands for navigating the ship

Table. 2 Errors Table (Errors are based on the study of reference no. 4).

	First Error	Second Error	Third Error		Fourth Error	Fifth Error	Sixth Error	
Description	The captain decides to change the original voyage plan just few hours before the voyage. This is because his mentor was in Giglio island and he was influenced by the Hotel manager.	Limited time and informal practice resulted in incomplete route planning on large-scale paper charts.	The route monitoring on paper chart was done by JOOW. Firstly, she didn't have "planned larger charts" to fix ships position and detect any danger. Secondly, she left route monitoring and went to assist Helmsman as there was language barrier.		Route monitoring on INS had a fundamental flaw. Chart alarm was set to go on if the radar distance is 2000m or less. The alarm was not set for crossing 10m bathymetric line.	At the final stage of the approach the Captain took over command form SOOW. But SOOW didn't challenge. 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. Nobody thus challenged captain's decision.	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 his rudder order was very little.	**Accident**
Logical Relations	*(W1, W2) = C1* *(O2, O4, C1, C2) = C3*	*(Limited Time, C3, CA1) = S2* *CA1 = S1 or S2*	When JT1 *S2 = J3 Or J4* *J4, C3 = J2*	When JT2 *JA3, C3 = J2*	*S4, JA1*	*S3 = S7 or S8* *~~S3~~, C4 = C7*	*C7 = C5*	

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. This was the final error.

Now performing a time domain simulation and utilizing the accident module it is possible to recreate the accident (similar to Fig. 4). However, by making alterations in the decision variables, it is possible to predict beforehand which sequences of decisions result the accident and which do not. Also, the logic program may alert the crew regarding the errors during the voyage so that accident may be avoided. Hence by simulating the bridge resources (such as the crew and command controls) an accident may be analyzed, predicted and prevented before it actually takes place.

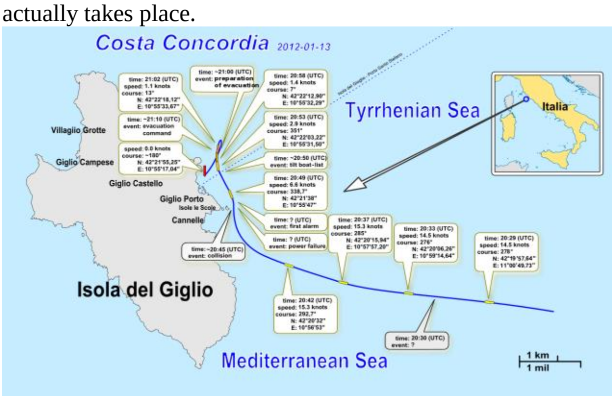

Fig. 4 Timeline representation of the accident of Costa Concordia[6)].

4. CONCLUDING REMARKS

This research paper is proposing a new technique for accident analysis and prediction. The primary focus of this paper is to share the idea of this new technique based on simulating the bridge resources. Many aspects of this technique are still required to be developed in detail. Extensive research is required to obtain the knowledge on how to construct the HOI, TDS and PAM. At the same time efficient utilization of chess algorithms are needed to be studied and tested. However, the presented model shows to have many potentials for future applications in maritime safety. As computing technology improves, the application of expert system widens. This simple model may lay the foundation stone for more advanced and complex model. Indeed further in depth research has to be validated using experimental testing. Some immediate specific recommendations may be made as follows:

1. Development of more accident modules with higher degree complexity (e.g. more nodes/branches in the decision tree) for the PAM so that it may handle various scenarios. The constraint of computational time also needs to be considered while writing computer codes.
2. Development of a comprehensive artificial intelligence based computer program that can be implemented in model testing such as free running experiments.
3. Development of a new mathematical/logical analysis technique that can establish the logical relationships among events that cause accidents.

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