A New Approach to Accident Analysis: Multiple Agent Perception-Action

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The economic and social impact of maritime accidents are enormous and devastating. In recent times the world experienced some grievous accidents which put serious challenges to the existing methods of safety evaluation. Over the years many research has been conducted on risk analysis and improvement of safety standards. Yet accidents are taking place and human elements are the major contributing factors. This paper proposes a new technique based on logic programming (e.g. Prolog) method. It is considered that an accident is an unwanted event which initiates from hidden causes (e.g. various action(s)/perception(s) of ship crew). It is, therefore, discussed that using intelligent agents for evaluation of the actions/perceptions of ship crew may result in uncovering of the hidden root causes behind an accident. Intelligent agents are essentially computer programs which acts or behaves rationally according their percepts. The perception and action sequence of an intelligent agent depends on the given environment and knowledge base. Study reveals that such a technique may assist ship crew in evaluating their decisions for making a safe voyage. The merits and demerits of the method are discussed briefly and future recommendations are made.

KEY WORDS: Maritime Accidents, Multiple Agent, Perception-Action, Logic Programming.

INTRODUCTION

According to International Maritime Organization (IMO) report, around 90% of world trade is carried by the international shipping (IMO, 2012). Without shipping the import and export of goods on the scale necessary for the modern world would not be possible. Interestingly, the shipping is estimated to be done by 1.5 million seafarer from almost all nations worldwide. This number of seaman is as much as (or perhaps greater than) the total population of small Europeans countries such as Estonia or Cyprus (Wikipedia, 2015a). Therefore, the safety of shipping that includes the safety of ship crew, the ship itself, the environment and others is a major concern for the society.

However, recent maritime disasters such as MV Costa Concordia accident in 2012 (Wikipedia, 2015b) and MV Sewol accident in 2014 (Wikipedia, 2015c) have raised terrifying worries within the maritime community. The fundamental issue that concerns all that the state of the art ships and well trained dedicated ship crew are often unable avoid accidents. It is important to mention that in this study an accident is considered as an event of destruction of lives and resources where no criminal activity is involved. That is an unintentional event which was unforseeable and unavoidable. The hidden faults within the system and/or procedures are to blame rather than an individual and it is essential to develop techniques which can identify these hidden faults.

The quest for a better technique of safety evaluation is primary focus for many research groups. In this view, this paper attempts to present a new accident analysis method based on logic programming technique (LPT). The study includes a literature review on accident theories which discusses the fundamental aspects of accident causation. Afterwards, the paper presents the basic concepts LPT for model development. The results obtained from the model run is presented and discussed later. The concluding remarks are given based on the current state of the research and the future prospects.

LITERATURE REVIEW

The literature review of this paper includes several segments. At first the definitions of accident, accident analysis and accident model is explored. The development of accident theories and their chronological order of appearance are studied. The literature review suggested that the accident models are evolving over the past few decades and developments are ongoing. It has been observed that these accident models attribute many limitations where prospects for further developments are wonderful. The need for introducing new methods and techniques is also realized in this section.

Accident, Accident Analysis and Accident Model

The domain of accident analysis is comparatively young considering other disciplines of science and engineering. During the past one hundred years or so researchers have become interested in accident modelling. However, one of the earliest definition of accident was given by Heinrich in 1931 which has been referenced by Ward (2012). The definition is “An accident is an unplanned and uncontrolled event in which the action or reaction of an object, substance, person, or radiation results in personal injury or the probability thereof”. However, one may derive a simpler definition out of it - an accident is an unforeseen and un-planned event or circumstance that causes damage and/or injury.

According to Stringfellow (2010) accident analysis is the process by which the reasons for the occurrence of an accident are uncovered. Information and lessons learnt from accident analysis are used to re-engineer the same or other systems so that future accidents (which may or may not be the form) do not occur.

Typically, an accident model provides a conceptualization of the characteristics of the accident that normally shows the relation between causes and effects (Qureshi 2008). Since, an accident event is the result of some cause or causes, therefore, the challenge for accident analyst is to identify the relationship between these causes and effects within the system.

An accident model or accident theory provides a hypothesis of accident causation and attempts to validate the hypothesis through extensive investigation. However, to validate these theories, there are several tools for accident analysis that essentially does not propose any hypothesis rather provide theoretical instruments for analyzing accidents. Fault Tree Analysis (FTA) (Vesely, Goldberg, Roberts and Haasl 1981), AcciMap (Rasmussen and Svedung 2000), and Coloured Petri nets (Vernez, Buchs and Pierrehumbert 2003) are just a few mentionable examples. These tools also allow investigators to explain the causation of accidents and assist in prevention of disasters.

Development of Accident Theories

Traditional approach towards accident analysis, maritime accidents in particular, is using statistical tools to study the probability of accident causation with respect to different uncontrollable variables such as weather, geographical features etc. (e.g. Awal 2007; Awal, Islam and Hoque 2010). However, from a general perspective, many accident theories are being proposed over the years by many researchers which are able to explain maritime disasters and other accidents as well.

The literature review reveals that over the past few decades many accident theories and accident analysis tools have been proposed and developed. Some theories survived and some did not. This fact suggest that the interaction between man and machine is continuously changing and so are the causation of accidents. It is interesting to note that different branches of knowledge (such as ergonomics and human factors, organization theory, industrial psychology, medicine, environmental sciences, law etc.) can be utilized to explain accident phenomena. From the accident causation perspective, these fields are overlapping and originate complexities. Therefore, the accident analysis techniques vary widely. Khanzode, Maiti and Ray (2012) and Qureshi (2008) reviewed accident/injury theories and made respective classifications. For example, Khanzode, Maiti and Ray (2012) classified the accident theories as follows:

- 1st Generation: Accident proneness based
- 2nd Generation: Domino theory based
- 3rd Generation: Injury epidemiology based
- 4th Generation: System based

The study by Qureshi (2007) reveals another type of classification of accident models. Such as:

- Traditional approaches to accident modelling (sequential models)
- Epidemiological/Organizational models of accident causation
- Systemic accident models

A study by Awal and Hasegawa (2015) explored the chronological order of development and classification of accident theories all together, as shown in Figure 1. The study depicts an overall picture of the historical appearance and their characteristics in single form. It is evident that in recent time more complex system theoretic models are proposed compared to earlier sequential/epidemiological models.

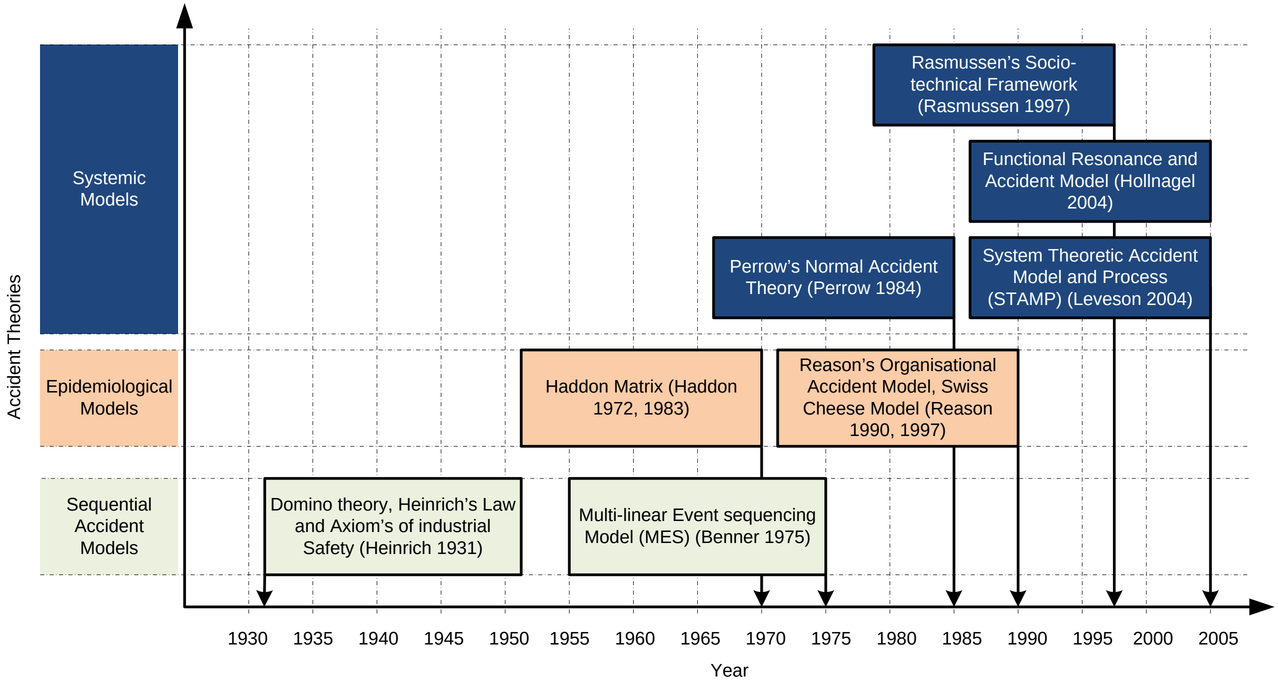

Figure 1. Development of accident theories in chronological order (Awal and Hasegawa, 2015).

Most of the modern day accident models adopt the fact that accident takes place in a complex sociotechnical system in order to combine the social and technical attributes in the analysis (Qureshi 2008; and Khanzode, Maiti and Ray 2012). Most models are subjective by nature and requires extensive brainstorming for producing applicable results. So far very little computational techniques have been developed that can efficiently analyze accidents in an established programming domain. Such technique is believed to improve operational safety and extend the capacity of an accident analyst as well. Recent studies by Awal & Hasegawa (2014a, b) and Hasegawa & Awal (2013) describes the need for and progress of such an approach. Research works reveal that the potentials of utilizing logic programming technique in accident analysis is tremendous.

Conclusion of Literature Review

The development of accident theories can be related to the change in sociotechnical context over the years. The rapid industrialization, change in interaction between men and machine is giving birth to new types of accidents. Therefore, new generation of accident analysis techniques are required to be introduced. It is also essential to extend the capacity of accident analyst with the help of powerful computational techniques and devices.

MODEL DEVELOPMENT

In this section the hypothesis of the accident analysis technique is described. The fundamental issues such as definition of logic, agents and theirs characteristics are described in order.

Hypothesis of the Model

The hypothesis adopted in this study is that Logic Programming Technique (LPT) can be used to analyze and deduce the perception/action of human agents using deductive logic along with simulation of the concerned system in order to find out the unknown causes of a particular type of accident.

Definition of Logic

Logic may be defined as the science of reasoning. Reasoning is a special mental activity called inferring, what can also be called making (or performing) inferences. A useful and simple definition of the word ‘infer’ may be given as 'To infer is to draw conclusions from premises'. In order to simplify the understanding of reasoning, logic treats both premises and conclusions in a single term called 'statements'. Logic correspondingly treats inferences in terms of collections of statements, which are also called 'arguments'. The definition of 'argument' that is relevant to logic is given as - 'an argument is a collection of statements, one of which is designated as the conclusion, and the remainder of which are designated as the premises'. Therefore, the reasoning process may be thought of as beginning with input (premises, data, etc.) and producing output (conclusions).

Agent: Definition and Types

An agent can be anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators (Russel and Norvig 2010). For example, a software agent receives keystrokes, file contents and network packets as sensory inputs and acts on the environment by displaying on the screen, writing files, and sending network packets. In general, for an agent, choice of action at any given instant may depend on the entire percept sequence observed to date but not on anything that it has not perceived. Mathematically, an agent’s behavior is described by the agent function that maps and given percept sequence to an action.

According to Russel and Norvig (2010) there are several types of agents with different characteristics:

- Simple reflex agent
- Model-based reflex agent
- Goal-based agent
- Utility-based agent
- Learning agent

In this study, simple reflex agents are considered for discussing the logic programming technique.

Design of an Agent

The characteristic of a simple reflex agent is that such an agent selects action(s) based on the current percept, ignoring the rest of the percept history. The agent uses the condition-action rule or situation-action rule. The simple reflex agent needs to have a library of rules so that if a certain situation should arise and it is in the set of condition-action rules the agent will know how to react with minimal reasoning. A schematic diagram of simple reflex agent is shown in Figure 2. An example of simple reflex agent could be the reaction of a person to fire. A person pulls his or her hand away without thinking about any possibility that there could be danger in the path of his/her arm. This is called reflex action. Similar to a person’s reaction to fire, a simple reflex agent behaves relative to the situation and does not consider previous percept.

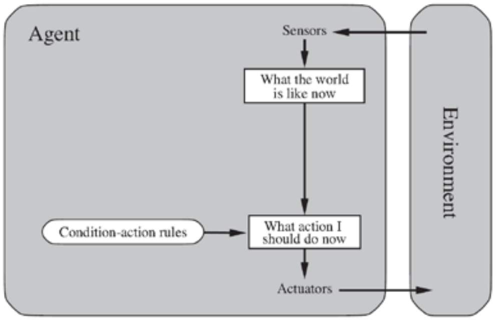

Figure 2. A schematic diagram of simple reflex agent (Russel and Norvig 2010).

Ship Crew as Agents

An example of ship crew in an organogram for a hypothetical ship is shown in Figure 3. There are two departments of crew such as the deck side and the engine side. The deck side crew is responsible for navigation, watch keeping etc and the engine side crew are responsible for propulsion, power generation and etc. It is important to comprehend that for a safe and optimum operation of a ship, communication among the ship crew is absolutely vital. In this study this communication is considered in the form of perception-action cycle. For instance, during a voyage each crew is assigned some responsibility according to their qualification and designation. The chief engineer is responsible for maintaining the required power as needed and commanded by the Captain of the ship. Therefore, the communication between these two are vital when there is engine problem involved. A wrong perception from the Captain may result in a wrong command and the Chief Engineer may execute that wrong command without hesitation. This is also true in the opposite way as well. However, when all the crew are involved in this perception-action cycle, the scenario becomes very complicated for human comprehension. One of the main focus of this study is to identify the faults in this complex human perception-action cycle using logic computations.

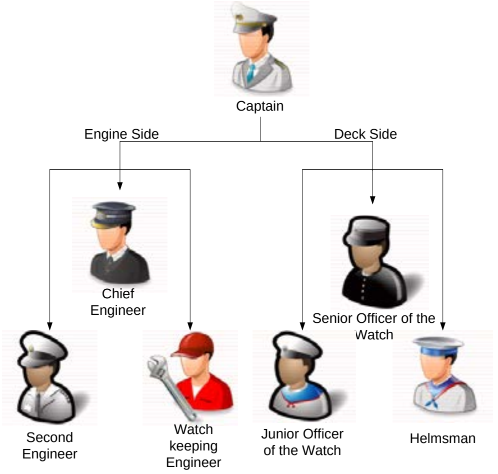

Figure 3: An example of ship crew in an organogram for a hypothetical ship.

In this context an initial yet most significant step for agent design is to specify the task environment as fully as possible. Task environments are essentially the ‘problems’ to which the rational agents are the ‘solutions’ (Russel and Norvig 2010). The general practice for designing agents is to define or describe PEAS (Performance, Environment, Actuators and Sensors) as fully as possible. In this study, several agents are considered based on the maritime context. Table 1 depicts a description of the agents in terms of PEAS. In this table, six simple reflex agents are shown as an example; including the ship itself and five ship crewmembers, such as a Captain, a Senior Officer of the Watch (SOOW), a Junior Officer of the Watch (JOOW), a Helmsman and a Chief Engineer. The following sections briefly describe the properties of these agents.

Ship Agent

A ship agent is a mathematical model of ship maneuvering. In this study ship is considered as a simple reflex agent because the ship behaves according to its given commands and does not behave based on its behavior history. For example, the ship receives the rudder command given by helmsman and using this rudder command the ship agent computes its next position in the water, considering the speed, heading and turning rates are initially given. The ship will always compute its next position based on the given inputs and will not consider the new position based on old input values. Thereby the ship agent behaves like a simple reflex agent. Figure 4 shows the definition of ship agent.

The mathematical model for ship response to rudder commands is determined by Nomoto’s linear K-T model (Tzeng and Chen 1999; Journée and Pinkster 2002). The cardinal equations are given as follows:

$$T\ddot{\psi} + \dot{\psi} = K\delta_r \tag{1}$$

Where,
$\psi = Course\ angle$
$\delta_r = Rudder\ angle$
$T = \acute{T}\frac{U_0}{L}$
$K = \acute{K}\frac{U_0}{L}$
$U_0 = Initial\ forward\ speed$
$L = Ship\ length$
$\acute{T}\ \&\ \acute{K}\ are\ non\ dimensional\ maneuvering\ coefficients$

Table 1. Example of PEAS definition of different agents.

Name of Agent	Performance	Environment	Actuator	Sensor
Ship	Calculate ship position and heading, evaluate status (sailing, grounded, etc.)	Coastal water Underwater rocks	Rudder angle and speed	Rudder command and Speed command
Captain	Visual observation inside and outside the ship, listen to ship crew, Command to ship crew	Bridge deck	Verbal command and manual operation	Vision and hearing
SOOW	Visual observation inside and outside the ship, communicate with ship crew.	Bridge deck	Verbal command and manual operation	Vision and hearing
JOOW	Visual observation inside and outside the ship, communicate with ship crew and monitor route.	Bridge deck	Exchange information and manual operation	Vision and hearing
Helmsman	Visual observation inside and outside the ship, communicate with ship crew and execute command from Captain at the helm.	Bridge deck	Exchange information and manual operation	Vision and hearing
Chief Engineer	Visual observation inside the engine room, communicate with ship crew and command engine room crew.	Engine Room	Verbal command and manual operation	Vision and hearing

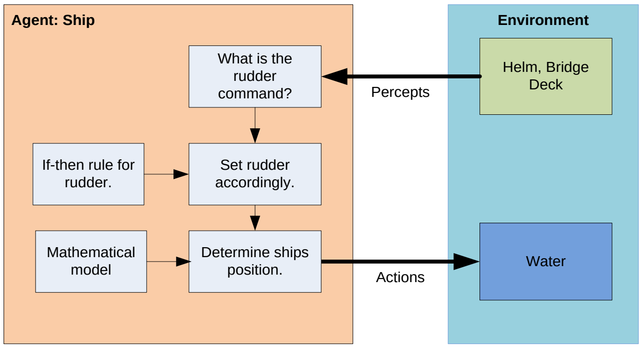

Figure 4. Definition of ship agent.

Captain Agent

The captain of a ship is responsible for every action and its consequences that occur on-board. The Captain must control all the crew and the ship itself. In this study, the captain agent perceives the actions of ship crew and the action of the ship agent itself. Based on this perceptions and simple if-then rules the captain agent takes actions. Actions usually involve giving commands to other crew and manual operations such as controlling the engine rpm. The captain agent necessarily requires to have a set of situation-action rules based on which the agent can perceive and take action. These rules may be derived from the existing regulations and practices. Figure 5 defines the captain agent.

SOOW Agent

In a ship, the senior officer of the watch needs to follow the tasks assigned by the Captain. For example, in the case of MV Costa Concordia, the SOOW was assigned to conduct ship maneuvering and route monitoring at different times during its voyage. In this study, the SOOW agent works under the captain and his working environment is inside the bridge deck. The agent perceives from the actions of other ship crew and visual observation from bridge deck gadgets. He may order the JOOW and conduct manual operations (e.g. route planning). Figure 6 defines SOOW agent.

JOOW Agent

In a ship, the Junior Officer of the Watch (JOOW) usually works under the Captain and the SOOW and executes the orders of his or her superiors. For ex-ample, the JOOW may conduct route monitoring on the paper chart during a voyage or may execute any other command given by the Captain. In this study, the JOOW agent can perceive from the orders and actions from the ship crew. His own actions will be executing the orders from his superiors and ordering to his juniors. He may perceive from the surrounding world as well. Figure 7 defines the JOOW agent.

Based on the above mentioned agents it is however, possible to deduce the occurrences of events in chronological order. The following section briefly describes the logical deduction of accident by multiple agent perception-action.

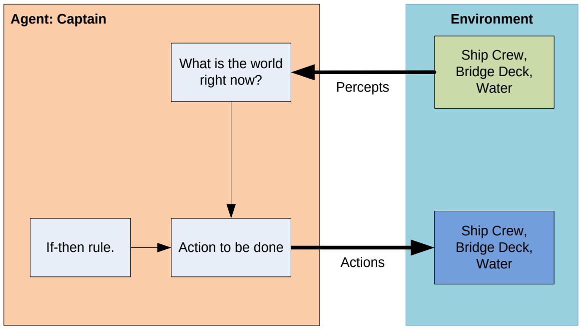

Figure 5. Definition of captain agent.

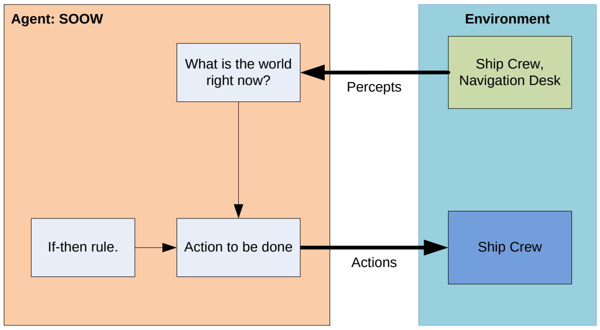

Figure 6. Definition of SOOW agent.

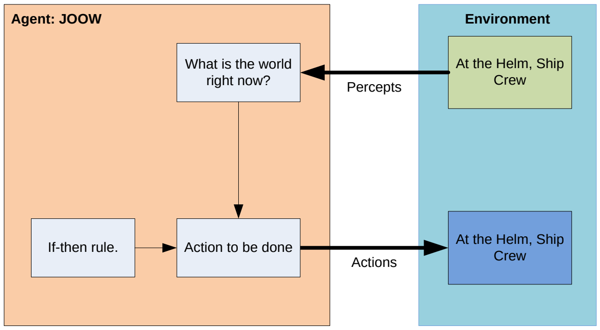

Figure 7. Definition of JOOW agent.

RESULTS AND DISCUSSIONS

This section describes the results obtained by model run. One of the principal objectives of this study is to demonstrate the potentials of logic computation along with numerical simulation in the same programming domain. Therefore, at first, the assumptions are discussed briefly. The knowledge of the human agents are discussed in tabular form where the arguments are presented. Each argument is presented using with one premise (with P bullet) and one conclusion (with C bullet). In this particular study the agents are given very limited knowledge of perceptions and actions.

Scenario Assumptions

In this study a simplified scenario is considered such as the following:

- Action-perception cycle of three crew members are studied in this simulation: (1) Captain, (2) Senior Officer of the Watch (SOOW) and (3) Junior Officer of the Watch (JOOW)

- The ship's original starting position in space is considered as (0, 0) where the vertical axis represents advance distance of ship and horizontal axis represents transfer distance of ship.
- There is a zone of scattered rocks visible from 2000 m in clear daylight but not visible at night. If the ship enters that zone, grounding accident is assumed to take place.
- The scattered rocks are located at a coordinate of (0, 3000), that is vertically 3 kilometer away from the starting position.
- The captain agent of may see the scattered rocks at night from a distance of 500 meter or less.

Assumptions for Ship Maneuvering Model

For the ship maneuvering motion, the transition phase between dead stop to full ahead speed is not considered. The initial conditions are given in Table 2.

Table 2. Assumptions for ship maneuvering model.

No.	Item		Value	Unit
1.	Initial position in X axis		0	Meter
2.	Initial position in Y axis		0	Meter
3.	Initial heading		0	Degree
4.	Initial yaw rate		0	Degree/second
5.	Initial rudder angle		0	Degree
6.	Steady state speed		3	Meter/second
7.	Maneuvering indices	K	0.005	
		T	300	Second

Captain's Knowledge

The captain agent's knowledge of perceptions are presented in Table 3. The knowledge is shown in terms of arguments where there are two parts: a premise and a conclusion. The actions of captain are shown in Table 4. Here the captain agent plays the role of overall command.

SOOW's Knowledge

The SOOW agent's knowledge of perceptions and actions are presented in Table 5 and Table 6 respectively. The SOOW plays the role of route planning and monitoring on navigation charts.

Table 3. Captain's perceptions.

Logic No.	Statements	
1	P	Conduct route planning on small scale chart
	C	Ship is ready for voyage
2	P	Conduct route planning on large scale chart
	C	Ship is ready for voyage
3	P	Declare danger ahead
	C	Need to change heading
4	P	Lift anchor
	C	Anchor lifted
5	P	Declare danger ahead
	C	Danger ahead

Table 4. Captain's actions.

Logic No.	Statements	
1	P	Need to make a sail past
	C	Command SOOW to change voyage plan for sail past
2	P	Ship is ready for voyage
	C	Command JOOW to lift anchor
3	P	Anchor lifted
	C	Command JOOW - Full Ahead
4	P	Danger ahead
	C	Command JOOW 10 degree starboard

Table 5. SOOW's perceptions.

Logic No.	Statements	
1	P	Command SOOW to change voyage plan for sail past
	C	Need to change voyage plan for sail past
2	P	Need to change voyage plan for sail past
	C	Need to conduct route planning

Table 6. SOOW's actions.

Logic No.	Statements	
1	P	Need to conduct route planning
	C	Conduct route planning on small scale chart
2	P	Need to conduct route planning
	C	Conduct route planning on large scale chart
3	P	Danger ahead
	C	Declare danger ahead

JOOW's Knowledge

The JOOW agent is responsible for executing the commands from his/her superior such as lifting the anchor, speed of the ship and executing rudder command. The JOOW agent's knowledge of perceptions are presented in Table 7 and the knowledge of actions are shown in Table 8.

Table 7. JOOW's perceptions.

Logic No.	Statements	
1	P	Command JOOW to lift anchor
	C	Need to lift anchor
2	P	Command JOOW - Full Ahead
	C	Need to execute command - Full Ahead
3	P	Command JOOW 10 degree starboard
	C	Need to execute 10 degree starboard

Model Run and Discussion

Based on the above mentioned assumptions and scenario settings the model is constructed and executed in Prolog environment. The objective is to find out which decision made by the crew may result in a possible accident. A scenario is considered as shown in Figure 8 where at a voyage begins at night. The voyage had an original route planned but the route is required to be changed due to some reason. The reason is beyond the scope of this study. Figure 8 shows the path ship for of two cases where in one case the SOOW decided to use small scale chart and in the other case the large scale chart. The characteristics of these two charts are such that the small scale chart shows some scattered rocks and the large scale chart doesn't show the scattered rocks.

Table 8. JOOW's actions.

Logic No.	Statements	
1	P	Need to execute 10 degree starboard
	C	Execute 10 degree starboard
2	P	Need to lift anchor
	C	Lift anchor
3	P	Need to execute command - Full Ahead
	C	Execute command - Full Ahead

The logical deductions derived from the perception-action of agents are shown iteratively in Table 9 and Table 10. It is evident from Figure 8 that the ship following small scale chart easily avoids the scattered rocky zone. The logical deduction shown in Table 9 reveals the reason. In small scale charts the rocky region is clearly marked and SOOW who is following the route notices and declares the danger ahead (iteration no. 72). The captain perceives and responds to SOOW and orders JOOW for 10 degree starboard rudder command (iteration no. 73). The JOOW responds immediately and executes the rudder order. Hence the grounding is avoided.

On the other hand, when the SOOW decides to utilize large scale chart, the scenario is quite different. As it is shown in Table 10 that the danger is not observed by the SOOW on his chart. However, the Captain who was on the watch himself could look and anticipate the danger and order the JOOW for 10 degree starboard rudder order (iteration no. 172). Yet the decision was not sufficient enough to avoid the scattered rocky zone as shown in Figure 8.

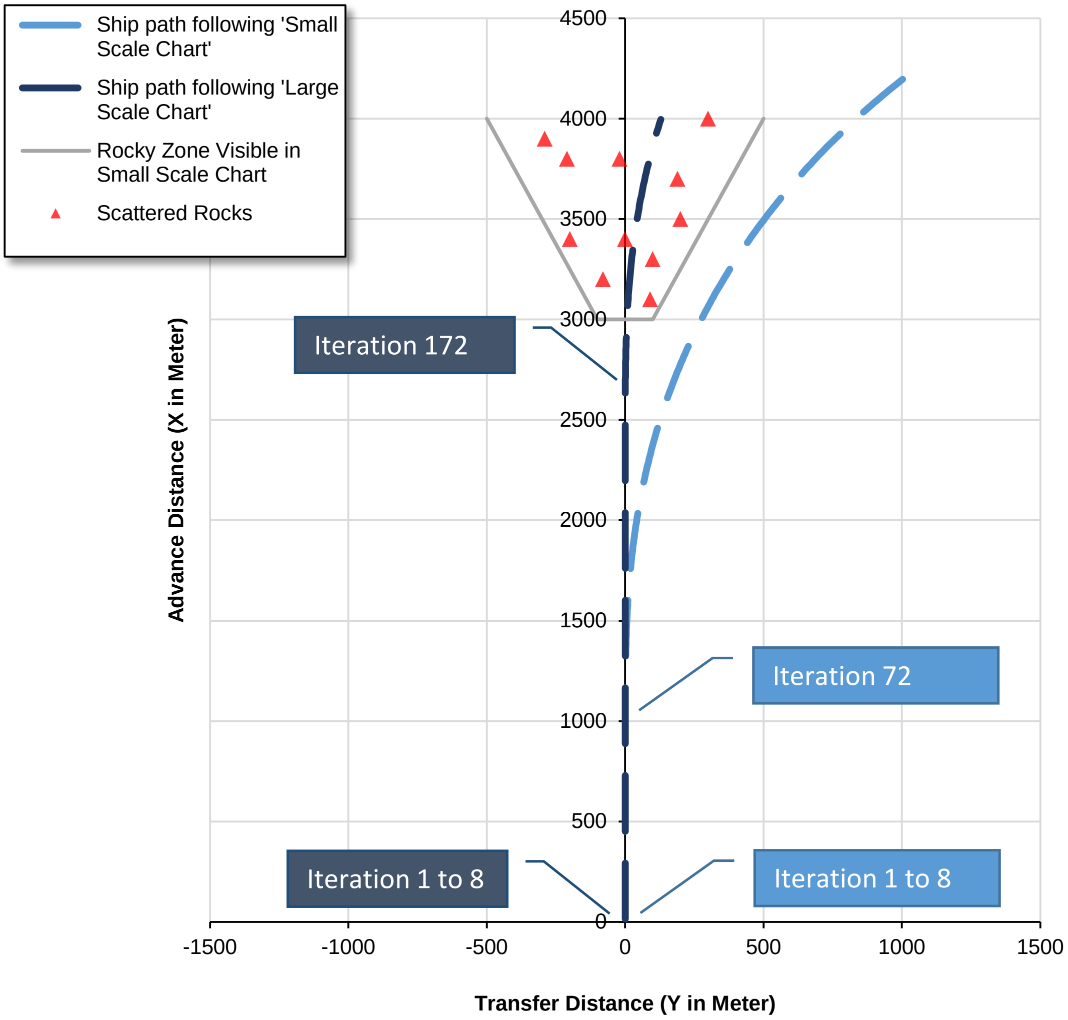

Figure 8. Ship's path 2 cases: Following small scale chart and following large scale chart.

Table 9. Results of logical deductions of crew perception-actions (small scale chart chosen for navigation)

Ship following 'Small scale chart'										
Iteration No.	Captain Perception	Captain Action	SOOW Perception	SOOW Action	JOOW Perception	JOOW Action	Elapsed Time since voyage started (sec)	Advance Distance (m)	Transfer Distance (m)	Heading (deg)
1	Need to make a sail past	Command SOOW to change voyage plan for sail past	Need to change voyage plan for sail past							
2			Need to change voyage plan for sail past							
3			Need to conduct route planning	Conduct route planning on small scale chart						
4	Ship is ready for voyage									
5	Ship is ready for voyage	Command JOOW to lift anchor			Need to lift anchor					
6					Need to lift anchor	Lift anchor				
7	Anchor lifted									
8	Anchor lifted	Command JOOW - Full Ahead			Need to execute command - Full Ahead	Execute command - Full Ahead				
9							6	15	0	0
71							336	1005	0	0
72			Danger ahead	Declare danger ahead			341	1020	0	0
73	Danger ahead	Command JOOW 10 degree starboard		No Action	Need to execute 10 degree starboard	Execute command - Full Ahead	416	1245	1	0
88							421	1260	1	1
300							1481	4196	1002	42

Table 10. Results of logical deductions of crew perception-actions (large scale chart chosen for navigation)

Ship following 'Large scale chart'										
Iteration No.	Captain Perception	Captain Action	SOOW Perception	SOOW Action	JOOW Perception	JOOW Action	Elapsed Time since voyage started (sec)	Advance Distance (m)	Transfer Distance (m)	Heading (deg)
1	Need to make a sail past	Command SOOW to change voyage plan for sail past	Need to change voyage plan for sail past							
2			Need to change voyage plan for sail past							
3			Need to conduct route planning	Conduct route planning on large scale chart						
4	Ship is ready for voyage									
5	Ship is ready for voyage	Command JOOW to lift anchor			Need to lift anchor					
6					Need to lift anchor	Lift anchor				
7	Anchor lifted									
8	Anchor lifted	Command JOOW - Full Ahead			Need to execute command - Full Ahead	Execute command - Full Ahead				
9							6	15	0	0
171							836	2505	0	0
172	Danger ahead	Command JOOW 10 degree starboard			Need to execute 10 degree starboard	Execute 10 degree starboard	841	2520	0	0
178							906	2715	1	0
300							1516	4512	285	21

It is visible in Table 9 and Table 10 that out of 300 iterations not all iterations are shown. This is because of two reasons. Firstly, due to limited space. And secondly, not all iterations result in significant change in the simulation. For instance, in Table 10, iteration number 9 to iteration number 171 there is no change in the perception-action cycle except for the motion of the ship. There for, portraying all the iteration steps are unnecessary.

Anyhow, the iterations shown in the tables above provides a glimpse of the activity that takes place during a voyage.

Although the results are hypothetical deduction and the knowledge of the agents is very limited, yet the idea presented in this study reveals the complexity of accident analysis. It is needless to mention that with the increase in number to ship crew and intricate natural environment the problem space for accident analysis becomes very difficult and goes beyond human comprehension. Therefore, a computational technique as such could extend the capability of real ship crew and accident analyst as well.

CONCLUSION

This paper presented a brief history of the development of accident theories and attempted to develop a new methodology for accident analysis. The study proposed application of logic programming domain and agent based concepts to model human perceptions-actions.

It is demonstrated that logical deductions of human perception-action using multiple agents combined with mathematical model of ship maneuvering motions can result in a good instrument for maritime accident analysis. The technique is thereby named logic programming technique (LTP). However, in order to utilize LPT as a risk mitigation tool and apply it in the real world scenario, further elaboration of the concept and its application bearing in mind the practical working arrangements on board ships need to be studied and tested extensively.

This kind of approach to accident problems is very new and appears to have a lot of potentials. Particularly in accident cases where the problem space is very large and complicated, this logic programming technique may become very useful for identifying the root causes and prevention of accidents. In this view the following recommendations are made for the future studies:

- Further development of the methodology and framework for such kind of analysis is necessary.
- Enriching the agent's knowledge with more perception and action arguments will be realistic.
- Constructing more agents following actual world scenario will assist dealing with realistic accident problems.
- Utilizing more sophisticated ship maneuvering model where more naturalistic variables can be incorporated, such as wave, wind, drifting of ship, etc.
- And finally, identifying the barriers for practical application of this technique will be very beneficial.

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