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ANALYSIS OF MARINE ACCIDENTS BY LOGIC PROGRAMMING TECHNIQUE

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ABSTRACT Maritime accidents are catastrophic and costs significantly to the environment and human lives. So far many research has been conducted on maritime safety with particular focus on risk analysis which extend from transport systems to individual components (e.g. engine) failure. However, compared to risk analysis there exist very few, if none, computational techniques which can logically interpret and predict maritime accidents in terms of human decisions. In this paper the authors attempt to present a method for analyzing maritime accidents by logic programming technique (e.g. Prolog) which examines the decisions of human operators that lead to accidents. A concept is developed and applied to solve the accident prediction problem in an expert system. The research findings suggest that this technique has the potential to dig deep into the human decision making process and find out the root causes and sequence of decision errors that lead to accidents.

Keywords: Maritime Accident, Logic Programming, Expert System

1. INTRODUCTION

Accidents are unwanted events or chain of events which often result in personal injuries and economic consequences. Whenever an accident takes place, the instinctive idea that works on peoples' mind is 'how we can stop this accident in the future from occurring again?'. This query triggers the analysis of accidents in both macro and micro perspective. Hence, various tools of accident research and risk analysis are being utilized and new techniques are developed. So far, over the last century, a number of new accident theories have been proposed like the domino theory(1), the organizational accident theory(2), System Theoretic Accident Modeling and Process (STAMP)(3) and others. These theoretical models give insight into the mechanism of accident occurrence. When it comes down to practical application, many engineering systems conduct risk analyses considering these accident models and often achieve appreciable results.

Nonetheless, regarding risk analysis there are some fundamental issues and limitations which need to be addressed and discussed further. For example, the results of risk analysis provide probability or chance of occurrence of a particular type of accident over a defined period of time(4) (e.g. the number of accidents take place per year). Similarly, statistical analysis(5) provide overall picture of accident nature against different variables (like time, vessel type, location etc.). Nevertheless, these analyses are not able to predict how and when an accident may take place. The fact is that some accident theories are able to answer such questions, but the fundamental deficiency is that there is no computational technique or tool developed yet which can implement and demonstrate the theory into practice.

In this perspective, the authors have initiated research on developing new technique for accident prediction and analysis using logic programming technique(6)(7). The studies are still in the elementary stage and recommend further research and developments. In this paper, the authors attempt to demonstrate recent developments as continuation of previous using two accident cases. The following sections explain the concepts in detail.

2. CASE STUDY: TWO ACCIDENT CASES

In this research work two accident cases have been selected and investigated for the logic program model. The first accident case(8) is the accident of MV Bright Field which occurred at the Mississippi river, New Orleans, Louisiana on 14th December 1996. The second accident case(9) is the accident of MV Planet V which collided with a pontoon at Westerschelde, The Netherlands on 26th of May 2012. The similarity between these two accidents is that both accidents involve engine failure which combined with human decisions resulted in collision/allision. Using logical arguments it is demonstrated here in this paper that how both of the accidents were avoidable.

2.1 Accident of MV Bright Field

The accident of MV Bright Field took place shortly after 1400 hrs 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[10].

According to the report[8] it was found that the ship had 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 shore side facilities. Using the information available for the final 6 minutes before the accident a time history of events can be constructed as shown in Table 1.

Table.1 Time history of events for the last 6 minutes[7][8]

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. 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 including a shopping mall, a condominium parking garage and a hotel.		

A schematic diagram of the ships final path and the surrounding location is shown in Fig. 1 which gives an overall idea on the accident site.

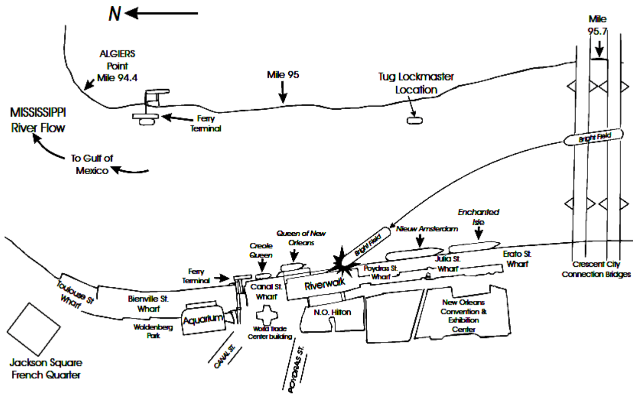

Fig. 1 Allision of MV Bright Field[8]

2.2 Accident of MV Planet V

The accident of MV Planet V took place on 26th May 2012 at the Westerschelde, The Netherlands. The motor vessel lost its engine power and collided with a towed pontoon while an Able-bodied Seaman (AB) lost his life trying to reduce the ship speed by dropping anchor[9]. Fig. 2 shows a snapshot from the wheel house of MTS Vantage taken just moments before the collision between MV Planet V and the pontoon of MTS Vantage. In Fig. 3 the simulated position of the AB is shown where the AB stood on the electric motor of the starboard side anchor winch prior to his fatal injury. And finally, Table 2 shows a list of major events that took place prior to the occurrence of the accident.

Fig. 2 A snapshot from the wheel house of MTS Vantage: Just moments before the collision [9]

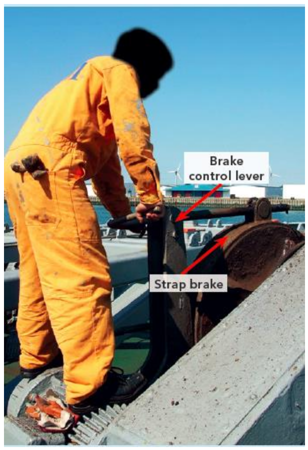

Fig. 3 Simulated position of the Seaman on the electric motor of the starboard side anchor winch[9]

Table.2 Timeline of major events before collision[9]

Time	Event
16:30	The Chief Officer carried out a routine test of the navigation systems on the bridge deck. Nothing unusual observed.
40 min	Voyage preparation was made using a Voyage Plan (*Before departing for sea, the captain has to draw up a voyage preparation document, which is referred to as Voyage Plan*).
17:10	A tugboat MTS Vantage leaves for its destination with its pontoon tow.
8 min	The Pilot of the MTS Vantage contacts the Pilot of MV Planet V by VHF to inform about the tugs intentions.
17:18	Main engine of MV Planet V is started.
6 min	At this time two auxiliary engines for the auxiliary generators were running. The shaft generator was also running which was used to provide power for the bow thruster.
17:24	The ship departs the harbor.
17 min	The Captain informed the engine room crew that the bow thruster was no longer required. The Chief Engineer, therefore, shut down the auxiliary engines and used the shaft generator for necessary power.
17:41	MTS Vantage passes the Sloehaven harbor entrance with a speed of 6 knots.
17:45	MV Planet V passes the harbor entrance. The speed was 11 knots.
17:48	MV Planet V is along the starboard side of the pontoon. The speed of Planet V was knots.
17:48:23	The main engine of MV Planet V fails. Immediately the electrical systems onboard failed and the ship went into total blackout.
16 seconds	The ship started to turn port after the electrical failure.
	The crew and the Pilot observed that the rudder angle indicator showed starboard rudder angle.
	The Pilot of MV Planet V informs the Pilot of MTS Vantage about the situation and requests 'full speed ahead' for the tug to prevent collision.
17:48:39	The Captain of Planet V instructs AB to return to forecastle, and prepare the anchor.
17:49:34	The Captain orders to drop the anchor via VHF. The pilot was not consulted with about this. The intention of the Captain is to slow down the ship and accelerate its turn to the port in an attempt to pass the tug and the tow at its stern.
21 seconds	The tug started increasing speed and turning to port in an attempt to increase its distance from MV Planet V.
	The Captain orders AB not to run out of chain any further.
	AB tightens the anchor winch brake. Despite this the anchor chain continues to run out at high speed.
	To apply additional force AB climbed onto the electrical motor of anchor winch.
17:50:05	MV Planet V hits the pontoon amidships on its starboard side.
	After collision MV Planet V moved along the pontoon while the anchor chain continued to run out. The loose bitter end of the chain flew out of the sparling pipe and fell overboard. AB standing on the electric motor was hit and fatally injured by the anchor chain.

The timelines shown in Table. 2 and Table. 3 suggest that the accidents could have been prevented if appropriate decisions were made by the crew at the right time. For example, the allision of MV bright field could have been prevented if the Chief Engineer knew about the danger ahead and took emergency restart of the engine. On the other hand, in the Planet V case, if the auxiliary generators were kept running then the bow thruster could have been used to avoid the collision and the Seaman could have saved his life by avoiding the emergency anchor maneuver or standing in a different spot. The principal idea that this paper attempts to demonstrate is that such accident avoiding measures can be deduced using logic programming technique by developing a suitable system.

3. THE PROBLEM AND CONCEPT FOR SOLUTION

In this study the accident problem is viewed as a logic problem and therefore, the sequence of events are viewed and analyzed using arguments. The idea is to construct a logic model and then post queries to the model to obtain answers on how an accident may take place and how it can be prevented. The event timelines of the two accidents are utilized for this purpose. In the previous research a concept for analyzing accidents in expert system was proposed[6][7] which is shown in Fig. 4. As a continuation of the research work this study could be considered as the development and analysis of Pack of Accident Modules (PAM).

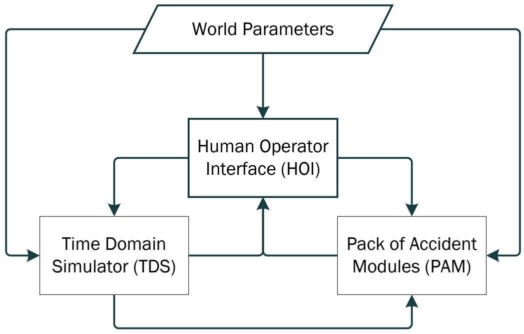

Fig. 4 Basic components of the expert system model[6][7]

In order to develop the PAM using logic programming technique some basic concepts of the logic model are discussed in the following sections.

4. LOGIC MODEL

At first the fundamental aspects of logical inferences are discussed. Thereafter, two sets of arguments are constructed based the actual accidents and the given definitions.

4.1 What is Logic?

Logic may be defined as the science of reasoning. However, this is not to suggest that logic is an empirical (i.e., experimental or observational) science like physics, biology, or psychology. Rather, logic is a non-empirical science like mathematics. 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' – 'To infer is to draw conclusions from premises'.

Inferences are made on the basis of various sorts of things – data, facts, information, states of affairs. In order to simplify the investigation of reasoning, logic treats all of these things in terms of a single sort of thing called 'statements'. Logic correspondingly treats inferences in terms of collections of statements, which are 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'.

The reasoning process may be thought of as beginning with input (premises, data, etc.) and producing output (conclusions). In each specific case of drawing (inferring) a conclusion C from premises P1, P2, P3, ..., the details of the actual mental process is not the proper concern of logic, but of psychology or neurophysiology. The proper concern of logic is whether the inference of C on the basis of P1, P2, P3, ... is warranted (correct) or not.

4.2 Types of Logic

Logics can be classified in several ways. But fundamentally there are two types of logic: (1) Deductive Logic and (2) Inductive Logic. Deductive logic or deductive reasoning is the process of reasoning from one or more general statements (premises) to reach a logically certain conclusion. The truth of the premises guarantees the truth of the conclusion and vice versa. Inductive reasoning (as opposed to deductive reasoning) is reasoning in which the premises seek to supply strong evidence for (not absolute proof of) the truth of the conclusion. While the conclusion of a deductive argument is supposed to be certain, the truth of the conclusion of an inductive argument is supposed to be probable, based upon the evidence given. In other words, in inductive reason the truth of the conclusion does not necessarily guarantee the truth of all the premises.

4.3 Logical Arguments

Based on the accident case of MV Bright Field a table of logical arguments are constructed and presented in Table 3. The arguments have one or more premises and have only one conclusion (typed in bold italic).

Table. 3 Logical arguments based on MV Bright Field case

Type of Logic	Premises and Conclusion
Deductive Logic	Ground is nearby. Ship has speed. Ship is uncontrollable. ***Ship will hit ground.***
Inductive Logic	Engine not delivering enough power. Rudder is not functional. ***Ship is uncontrollable.***
Inductive Logic	Engine not delivering enough power. ***Ship is uncontrollable.***
Inductive Logic	Rudder is not functional. ***Ship is uncontrollable.***
Inductive Logic	Engine automatic shutdown. ***Engine not delivering enough power.***
Inductive Logic	Engine manual shut down. ***Engine not delivering enough power.***
Inductive Logic	Lubricating oil pressure low. ***Engine automatic shutdown.***
Inductive Logic	Lubricating oil pump fails. ***Lubricating oil pressure low.***

Similarly, Table 4 presents the logical arguments constructed based on the accident of MV Planet V.

Table. 4 Logical arguments based on MV Planet V case

Type of Logic	Premises and Conclusion
Deductive Logic	Ship has speed. Another ship is in collision course. Ship is uncontrollable. ***Ship will collide with another ship.***
Inductive Logic	Ship has speed. Engine shutdown. Bow thruster shutdown. ***Ship is uncontrollable.***
Inductive Logic	Engine shutdown. ***Faulty regulator.***
Deductive Logic	Shaft generators shutdown. Auxiliary generators shutdown. ***Bow thruster shutdown.***
Deductive Logic	Commanded to shutdown auxiliary generators. ***Auxiliary generators shutdown.***
Deductive Logic	Engine shutdown. ***Shaft generators shutdown.***

4.4 Structure of Logic

The logical arguments shown in the above tables are transformed into Prolog codes. The general structure of the predicates are shown below:

```
logic(Conclusion, Premise1, Premise2, Premise3):-
   Premise1   = _________,
   Premise2   = _________,
   Premise3   = _________,
   Conclusion = _________.
```

4.5 Structure of query

The query is used to enquire whether there will be any accident or not for a given set of facts. The structure of the query is given as follows:

```
how:-
        logic(C, P1, P2, P3).
```

5. RESULTS AND ANALYSIS

This study represents ideal scenarios in order to explain the model in simplistic manner. The world that has been constructed in this study has some assumptions. Such as:

1. The crew of the ship is ideal i.e. they exercise all the regulations as it is and do not disobey any rule or conduct any crime.
2. ‘Ground is nearby.’ means the crew is able to see ground by bare eye.
3. ‘Ship has speed.’ means that the ship is in normal forward motion.
4. ‘Ship is uncontrollable.’ means there is no possible way of keeping desired ship’s speed and heading.

5. In case of emergency bow thruster is able to change course and avoid collision with another ship.

Three different sets of results are presented in this study for simple demonstration. The first case is where a ship is in normal forward motion which is given as a fact ‘Ship has speed.’. The ship is sailing through inland waters where the crew can easily see the ground. The ship is considered to have functional rudder and will remain functional during the study. Under the circumstance, a query on how an accident may occur will result in a set of logical outputs which as shown in Fig. 5.

Input

```
fact('Ship has speed.').
fact('Ground is nearby.').
fact('Rudder is functional.').
```

Output

```
1 ?- how.

Ship will hit ground. This is because of the
following premises:
    1. Ground is nearby.
    2. Ship has speed.
    3. Ship is uncontrollable.
true ;

Ship is uncontrollable. This is because of the
following premise:
    1. Engine not delivering enough power.
true ;

Engine not delivering enough power. This is
because of the following premise:
    1. Engine automatic shutdown.
true ;

Engine automatic shutdown. This is because of
the following premise:
    1. Lubricating oil pressure low.
true ;

Lubricating oil pressure low. This is because
of the following premise:
    1. Lubricating oil pump fails.
true ;
false.
```

Fig. 5 Input and output for Case 1

The output of the logic model is executed through ‘how’ predicate which is discussed in the earlier section. This predicate attempts to find a match within the constructed logics with the given facts. At first it obtains a match and delivers the first logical conclusion that the ‘ship will hit ground’. The predicate generates the reasoning based on three premises 1. Ground is nearby, 2. Ship has speed and 3. Ship is uncontrollable. Then the how predicate backtracks and attempts to find another logic which may match with the facts. Hence it concludes that ‘Ship is uncontrollable’ because ‘Engine not delivering enough power’. In this way the how predicate continues until all the logic predicates are exhausted. This analysis suggest that the ship crew may comprehend the possible danger through the expert system and if possible may take necessary action which are allowable within the regulations to avoid an accident. For example in this case the Chief Engineer may have reacted much earlier by manually restarting the engine power rather than wasting time in transferring engine control.

In the second case the input facts are changed as shown in Fig. 6. It is considered that there are two ships in collision course. One of the ship has a faulty engine regulator and that ship has shut down its auxiliary power units after leaving port. The ship has a bow thruster which are usually powered using the auxiliary power units and can also be powered using engine shaft generator.

Input

```
fact('Ship has speed.').
fact('Another ship is in collision course.').
fact('Commanded to shutdown auxiliary
generators.').
fact('Faulty regulator.').
```

Output

```
2 ?- how.

Ship will collide with another ship. This is
because of the following premises:
    1. Ship has speed.
    2. Another ship is in collision course.
    3. Ship is uncontrollable.
true ;

Ship is uncontrollable. This is because of the
following premises:
    1. Ship has speed.
    2. Engine shutdown.
    3. Bow thruster shutdown.
true ;

Engine shutdown. This is because of the
following premise:
    1. Faulty regulator.
true ;

Bow thruster shutdown. This is because of the
following premise:
    1. Shaft generators shutdown.
    2. Auxiliary generators shutdown.
true ;

Auxiliary generators shutdown. This is because
of the following premise:
    1. Commanded to shutdown auxiliary
generators.
true ;

Shaft generators shutdown. This is because of
the following premise:
    1. Engine shutdown.
true.
```

Fig. 6 Input and output for Case 2

Now by posting a query 'how' the accident may occur will result in a set of arguments outputs. At first the 'how' predicate obtains a match and delivers the first logical conclusion that the 'ship will collide with another ship' because 1. Ship has speed, 2. Another ship is in collision course and 3. Ship is uncontrollable. Then the how predicate backtracks and attempts to find another logic which may match with the facts. Hence it concludes that 'Ship is uncontrollable' because 1. Ship has speed, 2. Engine shutdown and 3. Bow thruster shutdown. Similarly the logical arguments are deduced which are differ from case 1. The analysis suggest that ship became uncontrollable because of the failure of engine regulator. Since the auxiliary power units were shut down, the bow thruster was not operational. In an ideal world such a scenario this will lead to an accident.

In this hypothetical model world it is assumed that the bow thruster action is sufficient to maneuver the ship out of collision course. Therefore, if the auxiliary power units were kept running, it can be logically deduced that the ship will not be uncontrollable anymore and hence the ship may avoid a collision. Fig. 7 shows this analysis where the fact('Commanded to shutdown auxiliary generators.') is no longer true in the input section. Therefore, logically it can be deduced that the bow thruster is operable and emergency maneuvering no longer necessary. As the crew are ideal crew, they will apply the bow thruster to change course and avoid a collision. Therefore, the 'how' predicate could not match any of the logic that can prove the truth of an accident. Hence, the output deduces nothing i.e. no accidents in the ideal world.

Input

```
fact('Ship has speed.').
fact('Another ship is in collision course.').

%fact('Commanded to shutdown auxiliary
generators.').
```

Output

```
3 ?- how.
false.
```

Fig. 7 Input and output for Case 3

6. CONCLUSIONS

This study reveals the capability of analyzing marine accidents using logic programming technique. It may be understood quite easily that the study applies ideal cases which need significant modifications to be applied in real life scenario. For example, the logic model presented here is static and it is unable to deal with dynamic facts within the predicates. However, it has to be kept in mind that the objective of this research is to investigate the potentiality of logic programing technique in maritime accidents. So far the research findings appear satisfactory and the future potentials are very good. In future the following recommendations could be considered:

1. Consideration of crew actions and perceptions in predicate logics could yield more realistic modelling. According to the scenario demand, such action-perception predicates can be used for ship crews both individually and cumulatively.
2. Consideration of a dynamic world where the facts are constantly changing and comprehended by the crew through perception predicate could result in a more dynamic and realistic output.
3. For future applications, integration of ship maneuvering numerical simulations along with the logical deductions will be very useful. This will enhance the applicability and easy understanding of the system.

It can be argued that most accident problems originate from wrong decisions made by the human crew. Therefore, if the wrong decisions could be predicted beforehand, accidents can be avoided. It can also be argued that accidents result from series of decisions made by the crew which seem to be correct at that particular instant when the decisions are made. However, when the decisions are cumulatively evaluated, the eminent accident is then observed. In these scenarios, an expert system of such kind may become very practicable in predicting an accident and thus avoiding possible consequences.

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