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CAUSAL ANALYSIS ON HERALD OF FREE ENTERPRISE'S DISASTER: A STAMP-BASED APPROACH

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Abstract

Existing event-based accident analysis methods have some limitations by taking into account the direct causal factors only; hence providing limited contributions on sustainable safety improvements of maritime system as a result of the increased complexity ofthis kind of socio-technical systems. In this paper, aSystem-Theoretic Accident Model and Processes (STAMP) approach to safety was used to provide insights into accident causality of Herald of Free Enterprise Disaster by analysing both direct and indirect factors involved. Some recommendations on fault tolerance mechanisms for addressing some of the identified issues were presented. The STAMP approach revealed other factors that immensely contributed to the failure that resulted in the accident. This approach is more desirable because it allows the root causes of the accident to be efficiently investigated.

Keywords: Socio-technical Systems, STAMP, Herald of Free Enterprise, Maritime safety.

Introduction

Safety and reliability are two distinct system properties. That is, safety does not imply nor require reliability and vice versa; in the sense that, a system can be safe and unreliable or reliable and unsafe. Sometimes, these two system properties are conflicting, which means, enhancing system reliability may decrease its safety and making a system safer may decrease its reliability. The assumption by some notable researchers (La Porte, 1996; Roberts, 1990; Rochlin *et al.*, 1987; Weick, 1987; Weick *etal.*, 1999) in this regard who posit that, highly reliable organizations will be safe is simply not true. This is because in complex systems, accidents often result from interaction among perfectly functioning components. However, in most cases accident occur because the system designers did not account for all interactions between the subsystems components.

According to Leveson (2011), besides thorough testing which was possible and used to eliminate system design errors before system use in the past, our designs were more intellectually manageable such that potential interactions among system components could be thoroughly planned, anticipated, understood, and guarded against. However, Modern high-tech systems no longer satisfy these properties and system design errors as well as organizational decision making are increasingly the cause of major accidents, even when all the components are found to be operating reliably.

In this paper, we present an accident causal analysis of the 1997 *Herald of free enterprise* ferry disaster(a ship that capsized on 6thMatch, 1987killing 188 passengers and crew) with the aim of understanding the reason why the accident occurred so as to identify areas that need improvement in order to prevent future occurrence using a system safety approach for accident investigation. A Systems-Theoretic Accident Model and Processes (STAMP) – an accident model based on systems theory proposed by Leveson (2011) to improve system safety in a number of complex socio-technical systems was applied. STAMP has the capability of helping to identify a broad set of systemic causal factors and to help improve as well as developing the safety control structure for the entire maritime transportation safety structure. The use of STAMP does not lead to identifying single causal factors or variables. Instead, it examines the entire socio-technical system design in order to identify the weaknesses in the existing safety control structure as well as changes that will not only eliminate symptoms, but potentially remove all the causal factors, including the systemic ones. The aim is to move away from the usual blame game and focus on why the accident occurred and how to prevent the occurrence of similar losses in the future instead.

The rest of this paper is organized as follows: In section two, we presented a review of related work; the methodology followed to achieve the stated aim was presented in section three, similarly, analysis and consideration of the overall system, result and fault tolerance mechanism was also discussed in this section. Finally, in section four we offer some concluding remarks.

Related Work

STAMP is an approach to accident modelling that adopts a systemic view which considers the performance of the system as a whole. According to Hollnagel (2004), in systemic models, accident arises when several causal factors (such as human, technical and environmental) exist coincidentally in a specific time and space. Systemic models view accidents as emergent phenomena, which occurs due to complex interactions between system components which may lead to degradation of system performance, or result in an accident. Accidents are treated as a result of flawed processes involving interactions among people, social and organizational structures, engineering activities, as well as physical and software system components. A system oriented approach based on a hierarchical socio-technical framework was adopted by Rasmussen (1997) for the modelling of the contextual factors involved in organisational, management and operational structures that create the preconditions for accidents. According to Leveson (2004), safety can be viewed as a control problem that can be managed by a control structure embedded in an adaptive socio-technical system. A systemic accident model for safety and accident analysis has been developed based on the principles of cognitive systems engineering: the Cognitive Reliability and Error Analysis Method (CREAM) which is based on the modelling of cognitive aspects of human performance for an assessment of the consequences of human error on the safety of a system (Hollnagel, 1998).Hollnagel (2006)developed Bridge Reliability and Error Analysis Method(BREAM) - aversion of CREAM for accident modelling for use in maritime accident analysis. The AcciMap accident analysis technique is based on Rasmussen's risk management framework (Rasmussen, 1997; Rasmussen & Svedung. 2000). Kim *et al.* (2015) proposed a STAMP-based causal analysis of the Korean Sewol ferry accident to stimulate a broader view of accident mechanisms that expands casual analysis beyond immediate physical failures to a systemic view.

Methodology

The methodology used in this research employs STAMP accident analysis to be undertaken in two stages, namely:

(i) Development of the Hierarchical Control Structure, which includes identification of the interactions between the system components, identification of the safety requirements and constraints.

(ii) Classification and Analysis of Flawed control (Constraint Failures), which includes the classification of causal factors followed by the reasons for flawed control and dysfunctional interactions. Table 1 shows causal Analysis based on STAMP (CAST) constructed using STAMP as a theoretical foundation.

Table 1:Causal analysis based on STAMP (CAST) Process (Adapted from Leveson, 2011)

Step No.	Steps Description
1	Identify the System(s) and Hazards involved in the accident
2	Identify system requirements and system safety constraints associated with that hazard (s)
3	Document safety control structure in place to control the hazard and enforce safety constraints.
4	Determine the proximate constraint events that leads to the accident
5	Analyse the accident at the physical system level
6	Moving up the levels of the safety control structure, determine how and why each successive higher level contributed to the inadequate control at the lower level
7	Analyse overall communications and coordination contributors to the accident
8	Determine if there were any changes to the system hierarchical safety control structure over time that migrated the system to a less safe position and contributed to the accident
9	Develop recommendations

Fault – Error – Failure Analysis

To analyse the fault that led to the disaster, we used some information from Sheen (1987) which revealed no fault with the machine itself, but human operators and the management of the company that run the ship. Therefore, the error that causes the failure was active human error which was then segmented into Fault, Error and Failure using STAMPas follows:

FAULT 1: *The Assistant Boatswain failed to close the bow doors*

This resulted in water entering the ship through the opened doors in very large quantity; thereby causing flooding of the car deck and causing instability of the ferry.

ERROR: *Water entered through the opened doors into the Car deck*

Consequently, the ferry capsized into the sea bed.

FAILURE: *Ferry Capsized*

Another factor which contributed to the failure was the fact that at Zeebrugge, ships can only be loaded from one deck. So the ferry was trimmed so as to load from the E deck. However, after the trimmed the water was not completely drain when the ferry left the port.

FAULT2: *The vessel was trimmed*

Similarly, the ship manoeuvre (control) also contributed to the failure. Since she was trimmed, the normal procedure for controlling the ferry was to initially minimise the speed to prevent water from entering the vessel until when water in the ballast tanks is completely drain before increasing the speed. However, the engine was set to accelerate to the maximum speed limit of knot 18 (33km/h) when the water wave was enough to engulf the bow doors.

FAULT3: *Normal Control procedure was not followed, hence, the ship accelerate rapidly*

ERROR: *Water rapidly flooded the car deck*

FAILURE: *Ferry Capsized*

Figure 1 depict the analysis of fault, error and failure.

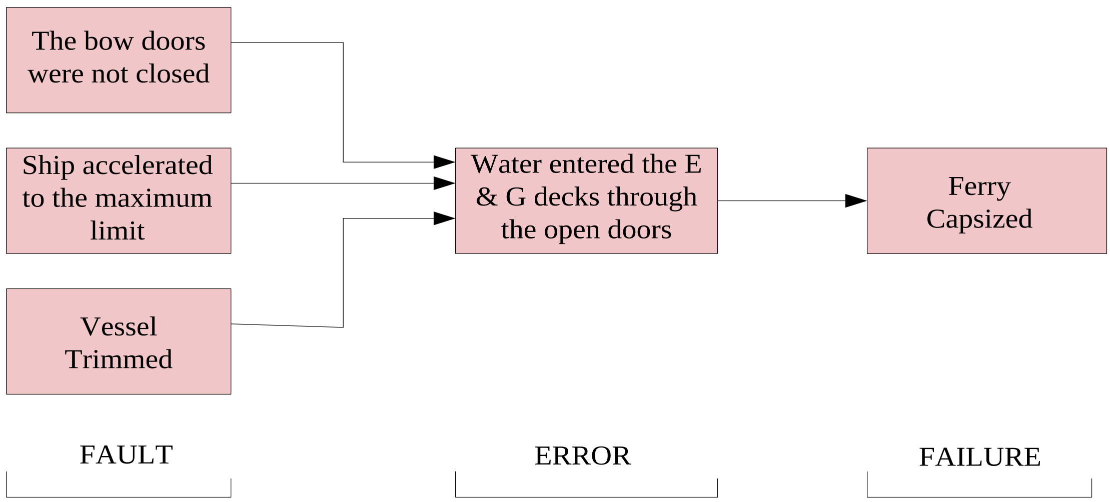

Figure 1: Fault – Error – Failure Analysis

3.2 Analysis and Consideration of the Overall System

In this section, the overall system issues of the *Herald of Free Enterprise* disaster are presented.

In General, the failure that leads to the disaster was caused by human errors as a result of lack of adequate management system, consciousness of individuals as well as ethical responsibilities on the part of both staff and management of the organization. In addition, the inherent instability of the ferry and other design flaws has also contributed to the system failure.

(i) Reliability: The Assistant Boatswain failed to close the bow doors because he was asleep. The Boatswain noticed that the bow doors were not close but he did not close them, and when asked during the investigations he said it was not part of his duty to close the bow doors or to ensure that there is anyone there to close them.

The chief officer who was also required to be at the bridge 15minutes before the sailing time and also responsible for ensuring that the doors are closed, said he thought that he saw the Assistant Boatswain going to close the doors before leaving to the bridge. He couldn’t recognise the Assistant Boatswain because both officers and the crew work on different shift systems and were changed regularly which contributed in their lack of knowing each other very well, as well as the equipment and procedure of the ships.

Furthermore, it seems there was communication gap between the Company Board of Directors and the Masters, in the sense that, they had a one way communication system. Example, they were of the view that the Captain was to assume that the doors were safely closed unless otherwise told. However, it was not categorically stated in the written procedures whose duty was it to tell him if the doors are not closed.

On the evening of the accident, the Captain did not follow the right procedure of controlling the ship. Similarly, the ferry was not divided into water tight compartments below the water line that could prevent water from spreading to other parts of the ship in an event of flooding.

(ii) Availability: The Assistant Boatswain was not at his duty post when the call to harbour was made. There was no any engineered means of error recovery; despite the fact that the position of the doors was not visible from the bridge, there was nothing to indicate to the captain or any senior officer at the bridge that the doors are open or closed and the ferry was not fitted with automatic draught gauges. Furthermore, there was only one suitable loading ramp at the berth of Zeebrugge.

(iii) Safety: Due to lack of second line of defence against error, a dangerous method was adopted; in which the captain worked on the assumption that not hearing anything from the Assistant Boatswain means the doors are closed and the ship is ready and hence on that evening sailed the ship with her doors opened. One of her sister ship has once sailed with her bow doors open as the management did not take any action.

Safety responsibilities were not clear due to poor safety culture of the company. Similarly, safety measures were not given priority due to the pressure to turn the ship as fast as possible purely for cost benefit without any regard for passengers' safety. Figure 2 shows the hazard, incident and accident chain.

Figure 2: Hazard – Incident – Accident Chain

The overall safety standard of the system was expected to have an integrity level 1 (10^{-5} to 10^{-4}) but due to the circumstances of the environment that couldn't be realised.

Fault Tolerance Mechanism

The procedure for ensuring that the doors were closed before sailing the ship was vague, hence not adequate. It solely rely on an exception, and there was ambiguity in the way the rules were given because it was stated that, the Captain should assume everything is normal at due time of sailing but it was not stated who was to inform him if something is wrong, and there was nothing to indicate to him that the doors are not closed.

The ferry (Herald) was usually equipped with life-saving apparatus that can be used in case of emergency but there was no time to deploy lifejacket or any assistive equipment because the failure was so sudden that both crew and passengers were caught unaware. Also the way the ship capsized on her side port made escape very difficult, and the emergency equipment couldn't be utilized because lockers were either underwater or on the ceiling.

Social, Organisational and Technical faults of the system

(i) Social (Ethical Considerations)

The Assistant Bosun who supposed to close the door but neglected his duty. His act was the direct cause of the failure, even though there were other faults that contributed directly or indirectly and lead to the disaster; what he did was unethical. Similarly, despite the ambiguity of the order, the Chief Officer should have made it his responsibility to check the Assistant Bosun to ensure that the doors were safely closed first, before proceeding to the bridge. Because, it easy to visualised the consequences of this action if something goes wrong.

The order given to the Master was ambiguous, because the absence of a report does not necessary mean that everything is ok, the order should have require the captain to request for a report on the situation of the door before sailing if not given to him. However, in the absence of that, the Captain should have made it his responsibility to enquire since he knows he cannot see from his position.

(ii) Organisational: There was ineffective means of communication between the captains (Masters) and the onshore higher level management. All requests by the Masters to improve safety measures like indicator light, banning overloading the ferries, suggestions for taking disciplinary actions against rule violators were consistently turn down by the onshore mangers.

(iii) Technical: Herald like RORO ferries used at that time around the world have some design flaws due to their inherent instability because she was designed in such a way that cars can drive in and out freely to facilitate loading and offloading, therefore was not divided into watertight compartments below the water line which can prevent water from spreading to her other part in case of flooding, and ship designed in this way could easily capsize when even a small amount of water enter its deck.

Causal analysis of the Hazard that led to the accident

(i) The Performance of the operator: The Assistant Bosun slept while he supposed to be at his duty, because the crews were subjected to physical and mental stress as a result of excessive working hours.

(ii) The working environment: The working environment was not favourable for the staffs. For example the chief officer was expected to be at two places at the same time.

(iii) Practices and procedures: The ferry was equipped with enough emergency equipment but they were not properly kept where they could be easily accessible. Safety plans were inadequate due to safety not properly taking into account during the ferry design.

(iv) Information and Communication: There was a very ineffective means of communication between the higher level management and the master. All requests by the Masters for safety improvements were disregarded by the management and Board of Directors. Orders were not clearly stated, and when an ambiguity occurs in a given order, the staffs usually process and interpret it based on their own perception.

(v) The Management Control: The senior management of the company had little maritime experience; that was probably why they view all the requests, suggestions from the Master to improve the safety standards of the ferries as unnecessary expenditure. Furthermore, the records shows that number of passengers at times exceeded the limit by hundreds especially during summer, draught level was falsified, and when the management was notified they didn't do anything to stop that. The management have failed to adequately direct, co-ordinate and define responsibilities and ensure that those who fail to carry out their duties and responsibilities are disciplined.

(vi) Engineering Integrity: There was nothing to indicate the position of the bow doors to those at the bridge. Likewise the RORO ferries were inherently instable due to their design flaws because the lower deck was not divided to prevent water from moving freely.

(vii) Site Plan and facilities: The vessels were of inadequate standards, as a result of the industry refusal to consider new ways of implementing improved standards of freeboard. The loading plan at Zeebrugge was inadequate, because there was only one suitable loading ramp which made it necessary to trim the ship in order to load her from deck E.

(viii) Managements and organisations: There was too much pressure from the management to sail the ship no matter the risk involve without any consideration or commitment to safety. The means of communication between the Directors of the company was inadequate.

(ix) The System Prevailing Conditions: There were deliberate violations of regulations, for instance on the same day bow doors were not closed, ship was overloaded and speeding. In addition as a result of the competitive nature of the market which was caused as result of privatization of the Sealink Ltd, UK; there was a lot of pressure to turn the ferries around as soon as possible.

(x) The external systems: Lack of support from the parent company to the senior staffs was also contributing factor to the failure of the ferry, the company was more interested in profit than safety of its staffs and passengers. Figure 3 shows root causes of the Hazard that led to the ferry's failure.

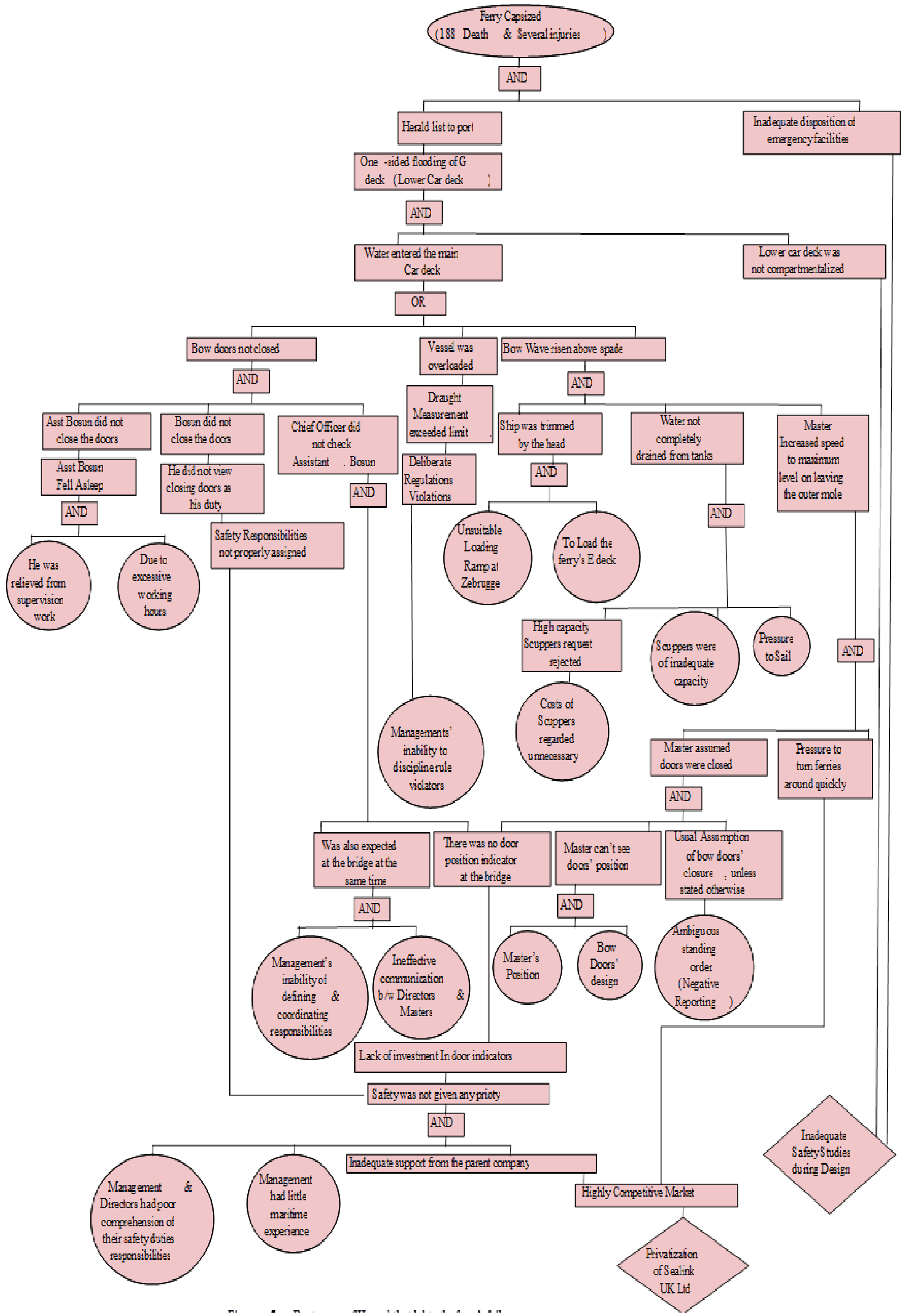

Figure 3: Root Causes of Hazard that led to the ferry's failure

Severity of the failure
The Herald disaster was the first worst-peace time disaster experienced in United Kingdom after the Titanic of 1912. The Ferry capsized to port at Sandbank killing 188 passengers and crew. Most of the people died as a result of hyperthermia due to the freezing cold of the sea water or due to injuries they sustained.

Recommendation of alternative adaptations to prevent the accident
(i) Failure Prevention
The ships should be fitted with door (open – close) light indicator that can be seen at the bridge which the Master, Chief Officer and other crew can check to know the position of the doors. Fault avoidance is shown in Figure 4.

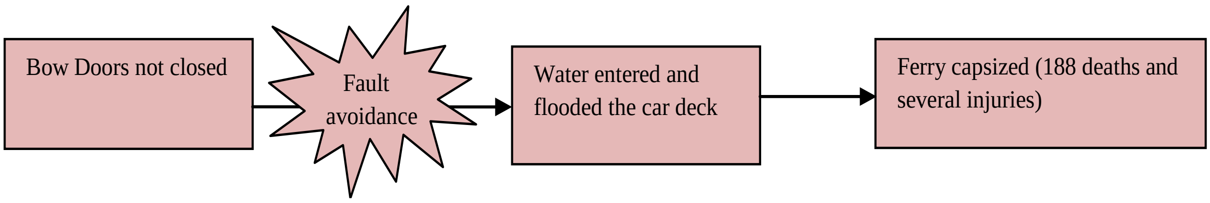

Figure 4: Fault Avoidance

To install cameras to the front of the ship and electronic sensors in the craft to automatically send information about the state of readiness for sailing of the ship from below to the Master and other senior officers at the bridge.
The Management should minimize issuing orders that are ambiguous, through checking the statements contain in the order for completeness and correctness of the message(s) and its consistency with other orders to be issue together or that have already been issued.
Management should avoid stressing their staffs, by reducing the period they have to work at a stretch, and increasing the resting period to avoid crew members falling asleep while on duty.
Automatic draught measurement system should be fitted to the ship to provide the Masters with the true draught measurement of the ferry, and details of all passengers should be recorded so that the harbour authority officials know those that are on board before sailing. Management should ensure that the ferries are not overloaded.

(ii) Failure Removal
The chief officer should check on the Assistant Bosun and make sure he closes the doors before proceeding to his station.
The Master should enquire about the state of readiness of the ship from both chief officer (who is in charge of loading) and the Assistant Bosun and be sure he obtains a report before taking the ship to the sea.
All staff should be train for safety awareness, safety responsibilities and how to act quickly in safety critical situations irrespective of whose duty it is.
International Maritime Organization should regulate ships from leaving ports until the watertight doors closure is verified. Adequate facilities at all docking stations should be install to enable loading all ships regardless of their type without the need of trimming. Fault removal is shown in Figure 5.

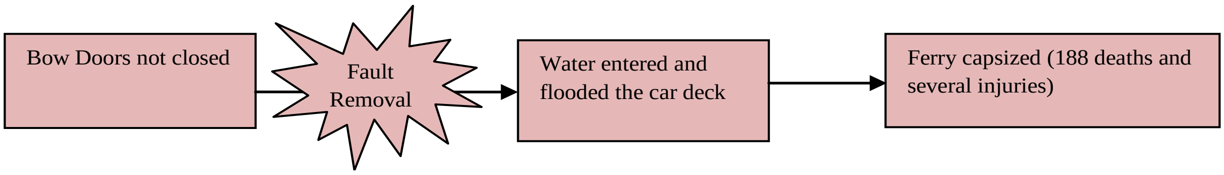

Figure 5: Fault Removal

(iii) Fault Tolerance

The following fault tolerance mechanisms could help in preventing the severity of the accident.

The personnel should seek for clarification of orders issued to them in order to reduce misinterpretation cause by misunderstanding of the meaning of a message given to them.

The Bosun as the last person to leave the door area should close the door or report to the master / chief officer that the doors are not close.Similarly, emergency equipment should be kept in an unobtrusive but easy to access place.

To design ships in a way that is possible to take the passengers to a safe section of the ship that has not been damage, and the vessel should have inbuilt buoyancy to stay afloat by itself sometime without capsizing in an emergency.

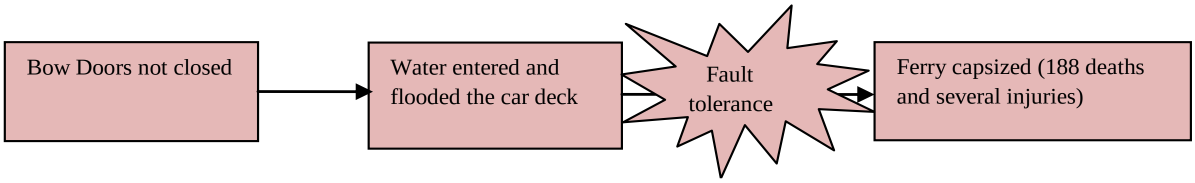

Figure 6: Fault Tolerance

Possible adverse effect of the recommended adaptations

Having the Chief officer to check with the Bosun ensure doors are closed, and cameras and sensors for checking position is redundancy and all have cost (financial) implication on the company.

Adequate safety study, consideration and designing buoyant ships involve huge commitment of resources (Qualified staffs, time & money) on the part of the designers.

Similarly provision of adequate loading ramp at all ports involves incurring additional cost.

Conclusion

STAMP-based casual analysis method was used to explore and construct the cause of *Herald of free Enterprise* system accident using systematic approach to uncoverdecisions made at various levels of the system that led to the disasterand consequently the huge death toll. This approach revealed that despite the fact that human error was one of thecauses of the accident, there were other factors which immensely contributed to the failure such as design issue, and management problems. Fault Tolerance Mechanism that could make the system more dependable was also discussed.

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