Case study of major accident to demonstrate the possibility of prediction of conditions for accidents

Tiantian Zhu[a,*], Stein Haugen[a], Yiliu Liu[b], Kim Hyungju[b]
[a] Department of Marine Technology, Norwegian University of Science and Technology, Trondheim, Norway
[b] Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, Trondheim, Norway

Abstract
The purpose of this paper is to investigate the possibilities of predicting conditions of accident through a study of MV Sewol accident. A capsizing accident model is developed and relevant information is investigated and connected to the accident model to evaluate whether if those indications were available before the accident, making it possible to foresee that the accident would happen.

According to Turner's man-made disaster theory, there is an incubation period before an accident occurs. During this period, events accumulate and information spreads out to various places but stay unnoticed. This study is based on Turner's theory and has investigated relevant information, the information holders and the time when the information becomes available. Afterwards, the collected information is integrated into the developed accident model to see whether the accident could have been foreseen. Hence, this study will help in operational risk monitoring and support the concept of preventing accident by measuring, monitoring and controlling the conditions for accidents.

Keywords: Information availability, Accident prediction, MV Sewol

1. INTRODUCTION

It is of interest to study accident prediction or prediction of the conditions for accidents. This prediction provides time constraints in accident mitigation [1], up-to-date safety margins for operation and produces fault information for corrective or predictive maintenance and therefore forms the basis for risk management strategies. In this paper, an accident will be used as a case study to initiate the discussion about the feasibility of improving our ability to predict accidents and find out the future research focuses in real life context. The Korean RORO passenger ferry MV Sewol capsizing accident, which happened in 2014 and led to 304 people dying has been well investigated and is a suitable candidate for this study.

A single event or a single condition will usually not cause a severe accident but will be the effect of interaction of many conditions and events [2]. It would be difficult or impossible to see the outcome when only considering one condition or event due to the capability of human's brain and limits of information that we know and process. Also, it would be difficult or impossible to see all the pre-warnings and interpret them correctly in reality. This creates difficulties in foreseeing accidents. Another challenge is that there are many types of accidents that may happen in a real facility or area, and a large number of different scenarios may exist for each type of accident. This potentially large number may obfuscate people involved in the situation.

[*] Contact author at: Otto Nielsens veg 10, Marinteknisk senter D2.260, Trondheim 7491, Norway.
E-mail address: tiantiz@stud.ntnu.no

Turner's man-made disaster theory states that major accidents are not sudden cataclysmic events that occur without pre-warning, but concludes that there is an incubation period before the accident occurs. During this incubation period, *there is a chain of discrepant events, or several chains of discrepant events, that develop and accumulate unnoticed* [3]. The theory proposes that the development of an accident is not only a result of a physical failure, but also a failure of communicating and interpreting hazard signals and information. The signals and information for anticipating an accident either are totally unknown, or existed somewhere or was known by someone but not appreciated or disregarded for different reasons. Therefore, it is important to make the relevant but unnoticed or ignored information available as early as possible to proactively prevent accidents from occurring. Chernov and Sornette [4] also criticized the overseeing of risk information after studying many accident cases.

The incubation period of an accident may last for years [3]. Following Turner [5]'s research, Shaluf, Ahmadun, Mat Said, Mustapha and Sharif [6] and Aini and Fakhrul-Razi [7] have investigated the length of the incubation period of several disasters. These studies show that actually there is enough time to collect and integrate those unnoticed or ignored hazard signals, if we know what to monitor and how to monitor the information. Similarly, monitoring these signals could also tell us that the system is safe, and what we should do to maintain safety. Besides, even though these researches have demonstrated that there is an incubation period before the disaster occurs, we also need to know how long this incubation period is to effectively manage risk. This means that we have to know how exactly those events accumulate temporally, and how and when the system state changes during the whole period. Some accident models may implicitly explain the causal-effect relationships during this period, even though not in a temporal perspective.

To understand how we can prevent accidents, risk analysis is usually applied. This is done by predicting the probability of an accident. To determine the occurrence probability of a major accident, a causality model of the major accident is required due to the scarcity of historical accident data. There are two main requirements for this prediction, a capable accident model and available input data. A representative concept of this includes Quantitative Risk Analysis (QRA) and real-time risk monitoring. QRA provides long-term average risk[8] , while real-time risk monitoring provides the up-to-date state of major accident risk. Real-time risk monitoring has been studied across several industries including nuclear power plants, oil-and gas industry, aviation, road transportation, maritime transport, etc. Several methods have been developed to predict changes in risk level during operation. For instance, ORIM [9], BORA [10-12], Real-time risk analysis for safety system [13], HCL method [14], RISK_OMT project [15], SHIPP methodology (System hazard identification, prediction and prevention) [16, 17], Safety barometer [18], and MIRMAP [19].

There have been several studies that analyzed the causes of MV SEWOL accident and provided recommendations to prevent same or similar accidents in the future. Kim, Haugen and Utne [20] analyzed the MV SEWOL disaster from four perspectives to see the whole picture of the causation of this accident. Kim, Nazir and Øvergård [21] analyzed this accident by the Systems-Theoretic Accident Model and Processes (STAMP) model. Kee, Jun, Waterson and Haslam [22] and Lee, Moh, Tabibzadeh and Meshkati [23] studied the accident by applying Rasmussen's risk management framework and associated AcciMap method. These papers investigated the causes of this accident systematically and made recommendations for further accident prevention, and highlighted the importance of establishing safety information systems of a major accident, which integrate piecemeal information, to assist decision making and continuous risk monitoring. However, these previous studies did not pay much attention to the availability of valuable information with time. Some information may be available years before the accident, while other is available minutes or seconds before the accident. The strategy to utilize information and prevent accident can vary depending on the time when the information is available. Therefore, it is important to include "when information is available" into the accident prediction model.

The objectives of this paper are (1) to investigate the possibility of getting more information on accident prediction by looking into the availability of valuable information with time prior to the occurrence of the accident, and (2) to identify and integrate the pre-warnings and their availability in time through an accident prediction model to demonstrate if there were enough pre-warnings to say that this accident really was "waiting to happen" when it occurred.

The limitations of this study are mainly two. First, the accident information heavily relies on the public information and papers published analyzing accident causation. The information collected might be unjustified and incomplete for varies reasons. False or incomplete information may lead to incomplete analysis and conclusions in this paper. Secondly, the analysis is necessarily affected by hindsight bias.

The rest of this paper is structured as follows: Section 2 presents the method applied to do the work. Section 3 is case study. First, a capsizing model for the accident scenario is presented and the information collection process is described. Then, the collected important pre-warnings, the holders of the information and the time when it could have been available are presented. Afterwards, the pre-warning information is mapped into the capsizing model to illustrate how much about the conditions required to an accident was known before it occurred. The last section is discussion and conclusion.

2. RESEARCH METHOD

The research method applied for this study is qualitative. It followed the research path described in Figure 1. First, prediction of the conditions for accident as the research interest is specified. A literature study was conducted to identify earlier research within the field. The hypothesis that conditions of accident can be anticipated with both a capable accident model and data available was established, as a result of interaction of the proposed theories, existing problems, researches and advances in risk analysis and accident modelling, opinions and interests of authors. In the end, a recently occurred accident was used as a study case to verify the hypothesis.

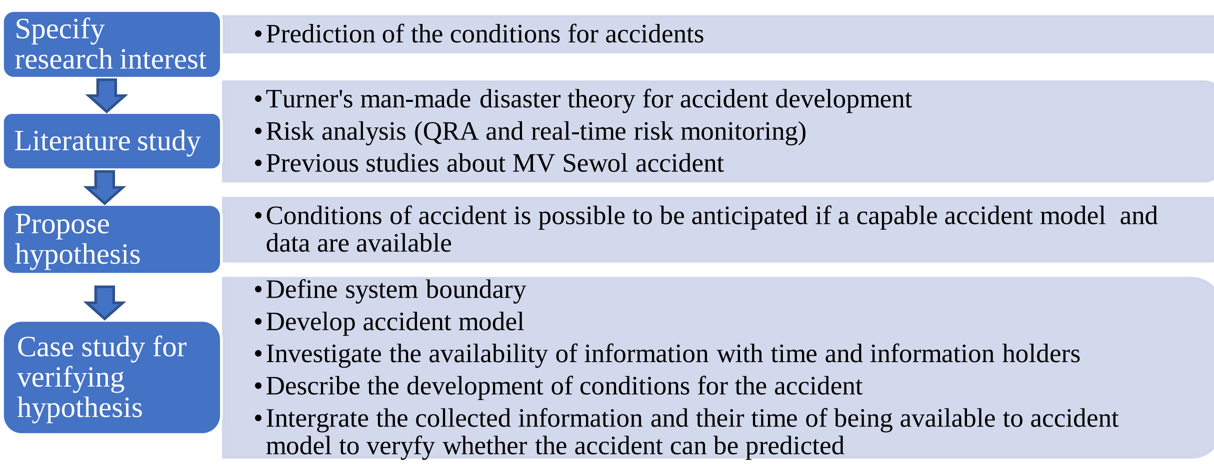

Figure 1 Research path

3. CASE STUDY OF MV SEWOL

3.1 System definition

With present day technology and complexity of systems, a major accident is not simply a failure of a single item but also a result from dysfunctional interactions among system components. A well-defined system with clear boundary is necessary for accident analysis and accident model development. According to the model described by Rasmussen and Svedung [24], a socio-technical system should include multiple levels from government to operators. Pressure from various levels can push the system towards increasingly hazardous states, and ultimately to an accident [25-27].

Following the scope of a socio-technical systems defined by Rasmussen [27], the defined system for this study includes the South Korean government, Coast guard, Federation of Shipping Association, Korean Register of Shipping (KR), the design company, Chonghaejin Marine Company, the crew of the ship, the MV Sewol ferry, and the passengers. Even though the crew are employed by Chonghaejin Marine Company, and MV Sewol ferry is owned by Chonghaejin Marine Company, they are separated from the company and considered as subsystems in the analysis. Chonghaejin Marine Company owned five ferries in total, and there were five main functional parts [28] within its organization. They were the CEO, safety manager, plan and management team, captains, passengers and logistic team. The safety manager was the maritime duty team leader who directly reported to the CEO and led the other three functional parts. The safety manager was in charge of every duty of ship operation and safety except the works that were duties of the captain. The Plan and management team was in charge of projects and relevant ship management issues in the company. The Logistics team was in charge of cargo loading and unloading, and responsible for (1) daily work related with cargo loading and unloading, (2) discussion with captain about dangerous cargos and relevant safety measure, and (3) HR management of workers on shore.

3.2 MV Sewol disaster

MV Sewol capsized on its route from Incheon to Jeju in South Korea on the morning of 16 April 2014. On the voyage, it carried 476 passengers and crew. Among them, 304 died in this accident. A sharp turn by the helmsman made the ship start to list. Reduced inherent stability due to modification, cargo overload and discharging of ballast water decreased the turning tolerance. Unsecured cargo shifted and made capsizing and sinking happen quickly. No evacuation order, and unavailability of rescue sources weakened the rescue action [20]. The capsizing is analyzed in this paper to verify the hypothesis of accident prediction.

3.3 Capsizing model

Capsizing of a ship is a situation that the vessel lists to one side and loses its ability to upright or regain its original position and make it dangerous. There are various causes leading to capsizing of a ship, which are concluded to two categories: loss of intact stability and ship damage. Loss of intact stability may due to shifting of the position of the center of gravity, external heeling forces and environmental hazards [29]. Ship damage may result from grounding, collision, fatigue in the structure.

For the capsizing scenario of MV Sewol, it occurred due to intact stability lost after the ferry made a sharp turn during navigating as a result of poor inherent intact stability and inappropriate operation. An accident model is developed for such a scenario or type of capsizing, as showed in Figure 2. The intact stability of a vessel is relevant to the design of the vessel, load and operation condition. During operation, the relative position of center of gravity and center of buoyancy, speed, rate of turning, and weather conditions (wind and waves) would impact the stability of vessel. The center of gravity depends on the lightweight and deadweight of the vessel, cargo load, ballast water, and the passengers' weight distribution and so on.

3.4 Information collection process

According to the defined system boundary, the information gathering process covers all those system components and the interactions between them. There are two routes in the information collection process. The first one is a process driven by the accident model. This means that we can follow each node in the accident model to see what happened with regards to each node. The second route is driven by available information sources. This needs to go through the main information sources to seek required data for the study. Main information sources include accident investigation report, academic studies, relevant people, videos, media reports, court records, etc.

Information sources used for this study include media report, published papers, accident investigation reports and court records, etc. Data regarding information available time and information holders were retrieved there. The availability of these documents provided convenience for this study. They also ensured the quality of retrieved data.

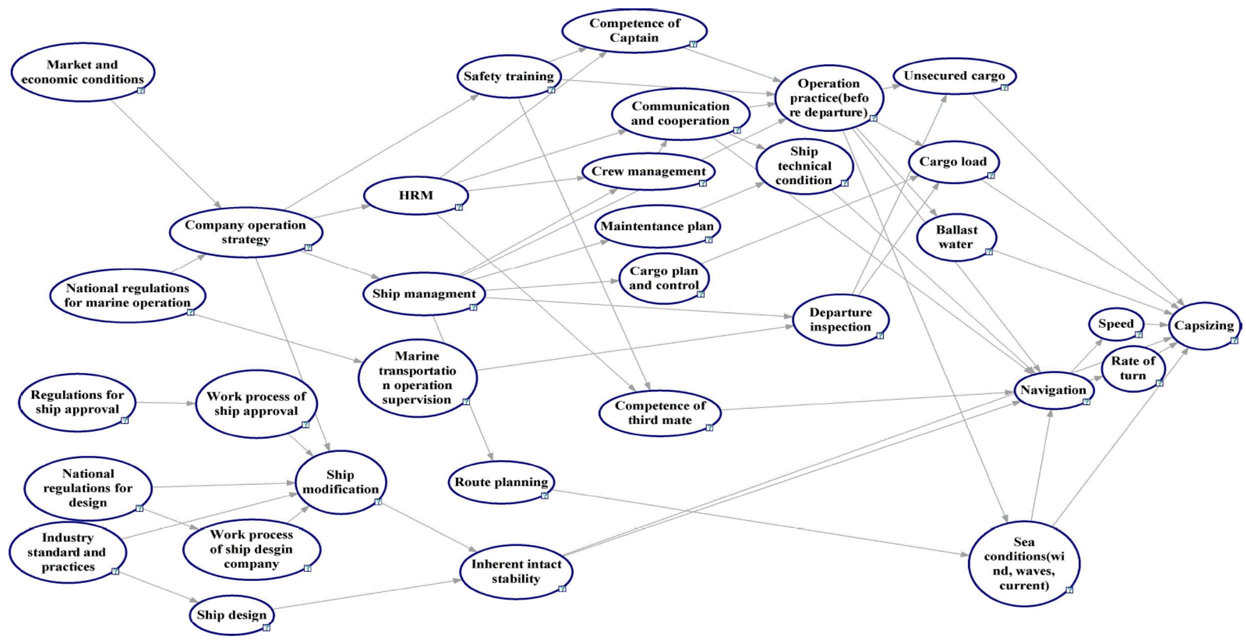

Figure 2 Capsizing accident model

3.5 Information and its availability with time

From several studies of the accident [20-23, 30] and accident investigation reports [28], the main causes of the capsizing includes the sharp turn, reduced inherent stability, overloaded cargo, unsecured cargo and discharged ballast water. When the investigations go deeper, it becomes clearer that information about these causes could have been identified and understood by different persons before the accident occurred. Table 1 to 6 describe the development of each accident condition. To avoid long tables, only key information is included. Therefore, the tables do not cover all facts that were identified for the accident, for example, the small budget for safety training and thus very little safety training that was provided to the crew.

Relevant information includes “who or where”, “when”, “subsequent effect” and “input to which node in the accident model”. The purpose of finding out who knew the information is not to find out who to blame in this accident. The primary goal is to find out whether the fact was truly known, unknown or veiled. The “when” data provide information about the time that the facts could have been retrieved and make a new prediction. This is a matter of whether we can make prediction early enough to prevent further accident progress. In addition, these columns provide a guide as to when and where to look for relevant pre-warnings for future information collection. The “subsequent effect” helps in clarifying the cause-effect relationships and relevance to the node in the accident model.

3.6 Description of the development of the conditions of the accident

Reduced inherent stability is one cause of the accident. Table 1 lists the events and conditions that led to the inherent stability issue of the ship. This goes back to the ship purchase. In the very beginning, the pursue of profits and market pressure led to the buying and modification of an old ship instead of buying a new one. This event initiated the development towards the accident and created a chance for adding weights and misevaluating the lightweight during the remodeling process. After the ship was in operation, imbalance of the ship was noticed and reported by the previous captain. However, no measure from company management was taken to solve this problem. A likely reason can be the conflicts between short-term economic interests and safety. Instead, a rule of less than 5-degree turning was set by the previous captain.

Table 1 key information about reduced inherent intact stability

No.	Key information	Information holder	Time of being available	Effects	Accident model
1	Priority to the pursuit of short-term profit	Ferry company, Crew members	When the ferry was purchased	Tendency to cut cost and buy an old ferry; No response to imbalance issue; Hire temporary crew	Company operation strategy
2	The 18-year-old ferry that was purchased when it should go out of commission soon	Ferry Company	When the ferry was purchased (October 2012)	Increased demand for maintenance, old machinery and technology in ferry. Less capacity than what the company wanted	Ship modification
3	The ferry company raised MV Sewol's average revenue per trip to get the authorization for the expansion.	Planning and Management Team	2012	Approval of Sewol's remodeling application	Ship modification
4	Ferry extension, added two more floors, increased light weight	Planning and Management Team	2012	Center of gravity became higher, and caused reduced stability	Ship modification
5	The remodeling design company underestimated the lightweight of the MV Sewol with 100 tons compared to its actual weight.			Wrong technical data of the ferry on which the final approval of the vessel was based	Work process of design company
6	Inclining test was conducted based on the documents with wrong data from the design company.			Fail to catch the stability issue of the ferry	Work process of design company
7	Rule was not followed when calculating intact stability of the ship	Design company	Early 2013	Increased the chance of making mistakes	Work process of design company
8	KR only used 1 day for the approval of MV Sewol, stability calculation was not verified	KR	Early 2013	Reduced the chance of catching the stability issue of the ferry	Work process of ship approval
9	KR failed to recognize the lightweight is underestimated and approved the vessel.			Fail to catch the stability issue of the ferry	Work process of ship approval
10	Limit of turning (less than 5 degrees)	Previous captain, crew members	Months after ferry being in operation	Safety margin reduced, therefore ferry operation was more critical.	Inherent intact stability

Table 2 lists the facts showing the development of overloading. Korean Register approved the ferry on the condition that the maximum cargo limit is 987 tons. However, this operation rule was not respected and violated. Furthermore, departure inspection from Korean Shipping Association did not work either due to the procedure and technique for overloading inspection.

Table 2 key information about overloading

No.	Key information	Information holder	Time of being available	Effects	Accident model
1	Ferry company ordered to load as much as possible to make more profit	Logistic team, safety manager from ferry company		Pushed the ferry to the overloaded condition	Ship management
2	MV Sewol’s paperwork for the Incheon Coast Guard says that it was allowed to carry the total weight of 3963 tons	Plan and management team, safety manager	Before the ferry started its operation	Incheon coast guard fail to catch MV Sewol's overload	Ship management
3	Use telescope for overloading inspection, which is not sufficient and can be bypassed	Marine inspector, Captain, Ferry Company	Common practice	Overloading inspection failure	Marine transportation operation supervision
4	Frequent overloading	Crew member, loading company and ferry owner, local governmental office	Months after ferry being in operation	Reduced stability and safety margin	Cargo plan and control
5	Overloaded (2142.7 tons of cargo loaded)	Crew member, loading company	Before departure	Changed the center of gravity	Departure preparation

Ballast water has an important influence on the restoring force of the ferry and keep the ship balanced if it is tilted. Discharging of ballast water was a countermeasure of preventing overloading being caught. Table 3 shows its development.

Table 3 key information about discharging of ballast water

No.	Key information	Information holder	Time of being available	Effects	Accident model
1	Marine Inspector uses telescope to check the load line on the hull from a distance for overloading inspection.	Marine inspector, the captain, logistics team	Common practice for inspection	Allow chance to cheat by discharging ballast water	Marine transportation operation supervision
2	Frequent overloading	Crew member, loading company and ferry owner, local governmental office	Months after ferry being in operation	Discharging ballast water to compensate the weight	Cargo plan and control
3	Discharged ballast water (761.2 tons carried in fact, requirement is 1703 tons when fully loaded)	The captain, crew members	Voyage preparation	Higher the center of gravity, reduced restoring force.	Ballast water

Table 4 illustrates its development. Unsecured cargo shifted after the ship listed and changed the center of gravity of the ship, and reduced the restoring force which could bring the ship back to upright position.

Table 4 key information about condition of unsecured cargo

No.	Key information	Information holder	Time of being available	Effects	Accident model
1	The ship didn't have proper system to store containers.	Logistics team, crew members, loading company	2012	Unsecure of cargo	Design
2	Unsafe cargo storage (unsecured cargo)	Crew member, loading company, logistics team	Voyage preparation	Cargo shift when ferry lists	Cargo security

The sharp turn was defined as a human error which was not intended. This sharp turn made the ship start to list and triggered the capsizing. It can be a reasonable guess that the poor navigation competence of the third mate and helmsman are indications. Table 5 describes the development of the sharp turn.

Table 5 key information about sharp turn

No.	Key information	Information holder	Time of being available	Effects	Accident model
1	Poor navigation competence of third mate	Captain, third mate	Six months before the voyage	Unsafe operation	Crew management
2	The ferry was delayed by about 2.5 hours due to thick fog at the departing port (Incheon port).	Marine inspector, crew members, passengers	Before departure	Third mate's shift to take the navigation task when ferry passed Maenggol Strait, which is the captain's shift if ferry was not delayed according to the time-schedule	Operation practice
3	Third mate and helmsman steered the ship when the ferry pass an accident-prone route	Captain, third mate, helmsman	Before the shift (or during departure according to the time-schedule of shift)	Unsafe operation, increased the chance of human error	Navigation

The presence of current when the ferry was passing Maenggol Strait added external force to the ship. This disturbance brought navigational difficulty to the ship and demanded good navigational skills to ensure safety. While it is not a surprise that ferry would experience this disturbance because the course is predefined. Table 6 shows the development of encounter of fast tide.

Table 6 key information about fast tide

No.	Key information	Information holder	Time of being available	Effects	Accident model
1	Maenggol Strait is an accident-prone route with treacherous currents(tide)	Ferry company, captain	Common knowledge	Safe operation	Route plan
2	Company's preferred course included a passage through the Maenggol Strait	Ferry company, captain, navigation officers	2013. When this course is approved by the government.	Encounter fast tide	Route plan
3	Fast tide in the Maenggol Strait (about 0.39m/s)	Captain, the third mate	Available with tide table	Added external force	Sea conditions

3.7 Accident prediction with assumption that information is available and integrated

With the information available and collected, the capsizing accident model described in Section 3.3 is updated as Figure 3 with time when the state of the node was available and severities of the nodes. The red nodes are in very severe state, which means that mostly it violated regulations or operational rules. The yellow nodes are in medium severe state, the green node is in an acceptable state that did not make a negative contribution to the accident, and the white nodes are no information available. The color for each node is based on judgment and relative comparison between different nodes. In addition, a conceptual capsizing probability with time is drawn at the bottom of the model to illustrate the prediction result with well-known probability. The result shows that from the ferry was purchased and modified, information started accumulating that could tell us that the risk was increasing. With time, marine inspections remained in name only, quality of crew members decreased, overloading became frequent, the chance of capsizing increased dramatically. While, the fluctuation in the operational phase in the capsizing probability is due to the variations in navigational behavior and loading conditions in the voyages.

During the incubation period, events occurred in different parts of the system. Problems existed in the modification process, approval of the ferry, the recruitment of crew members including the captain, ferry operation and navigation, and so on. All these accumulated and pushed the ferry towards capsizing. With the information available, conditions for accident prediction can be given at several time spans with disparate accuracy. As shown in the accident model, the information about loading conditions and ballast water were available before the departure during departure preparation period. And tide is a regular periodic natural phenomenon, which is quite predictable and can be found from tide tables. The precise real-time speed and turning rates are however more variable depending on the navigational behavior. With the information available, safety margin about turning rate and speed can be estimated for capsizing prevention. Accordingly, even without known turning rate and speed, the capsizing risk is quite high with the ferry's loading condition and reduced intact stability.

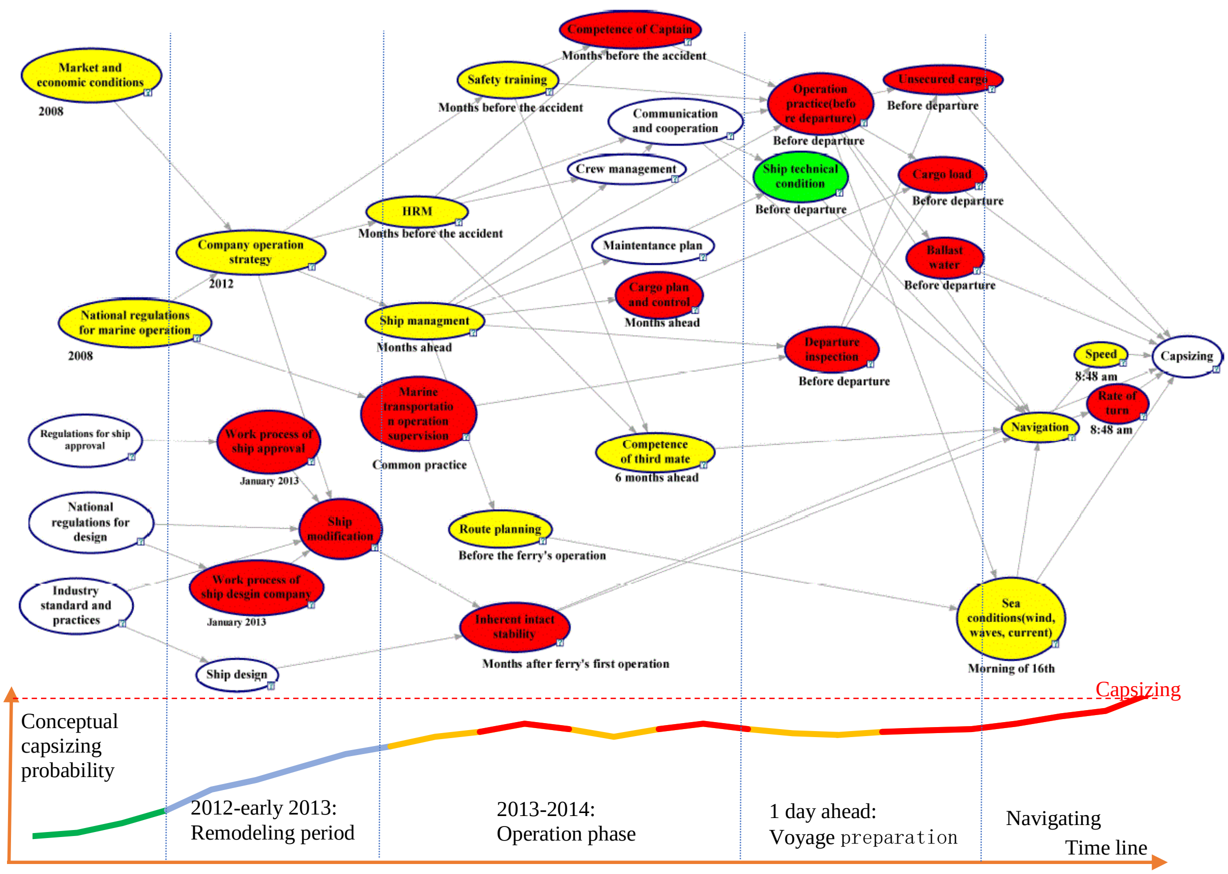

Figure 3 result of accident prediction from accident model with available information

4 RESULTS AND DISCUSSION

The development of the accident becomes clearer with an updated capsizing accident model. It gives an improved estimation of the situation. It becomes obvious that the occurrence of capsizing is not a surprise after information integrated and the critical signals highlighted. The result from the case study verified the hypothesis that the accident conditions can be identified before the accident occurs through the accident model and available data. Our belief that capsizing may occur has increased even though deterministic prediction regarding whether the capsizing would happen at a certain time cannot be made due to the uncertainties, indeterministic and imprecise property of the model. The developed capsizing model can be further improved and used for similar cases for future accident prediction

The time when information is available shows that 1) some indications were available a long time before the accident; 2) events happened at different times and involved different parties which contributed to the development of accident; and 3) the time dimension indicates when a prediction could be made and when the prediction can be updated when new information is obtained.

The different information holders show that the persons who are in charge of design and modification may not be the same who are responsible for the operation. The design issue which was found out during operation phase may not be reacted to in a proper way, especially if the design is approved even though there may be a mistake. Within the company, tasks are distributed across different departments or just different people. Each department or person generally has different goals and considerations according to their duties in the company. They push each other and cooperate at the same time. The safety margin might be exceeded without proper boundaries or limits [27]. The people in charge on the top should have the widest coverage of information, but they will normally not know all the details. Without those details, the overview is not possible to achieve.

This model could be expanded and further developed to cover more details. It is also possible to develop this qualitative model into a quantitative model. The developed accident model can assist safety managers in gathering data for risk monitors and accident prevention in practice. Methods for collecting data, which are required for the capsizing model, can be applied in modern ships. For example, information about cargo load, ballast water. Digitalization of those data is simple and achievable. Regarding data collection for accident prediction, a potential problem would be how to ensure that the data reported are reliable within a bureaucratic system without a good safety culture. It is challenging to let people see things if they want to and pretend to be blind. Another concern is that the information spread out among different people and stakeholders about different aspects, it is difficult to evaluate the criticality of it regarding risk or accident.

For the defined system in the accident analysis, it is relatively easy to identify the stakeholders and define the system boundary because the relevant parties were all identified during the accident investigation. For future accident prevention, it can be challenging to define the system boundary. A certain procedure could be developed and used to define the system boundary. For example, a procedure based on system functions.

The developed capsizing model only present one type of scenario of capsizing while several different scenarios may occur for capsizing and different types of accident may happen for ferry operation. This will lead to large numbers of possible accident models for one ferry, which make it difficult to accumulate and analyze them [31]. Therefore, it is important to identify the current situation and exclude out the impossible ones or rarely likely ones and focus on the possible ones in the future. To achieve this, information collection for situation identification or situation awareness will be required.

5 CONCLUSION

This paper has shown a potential way of accident condition prediction based on Turner's man-made disaster theory and demonstrated it through MV Sewol accident. A capsizing accident model was developed, pre-warning information availability with time and holder for MV Sewol accident were investigated to verify the prediction possibility. With the capsizing model proposed and collected information, it shows how events and conditions accumulate across several parties towards the occurrence of the accident. The integrated results show that the MV Sewol accident is not a surprise, and it could have been foreseen before it occurred from pre-warnings. The accident is possible to be predicted with the availability of a capable accident model and required input data. While in reality, decision makers have to rely on their limited knowledge and experience for safety related decisions.

The study shows that 1) a well-developed capsizing accident model and information availability is very useful for accident prediction and 2) verifies verified part of the truth that why we are not able to see that an accident is coming and why accident is usually treated as a surprise in reality. In addition, it provides hints in where and when to collect information for accident prediction and indicates that different strategies can be applied at different system components at varied time for accident prevention.

As for future research, three tasks can be proposed at least. 1) Study of a detailed capsizing model to improve the prediction quality. It will require a very good understanding of the system, including the chain of power and decisions, and the interaction between different components. Also, there should be an appropriate tool to represent the accident model both for visualization and calculation. 2) Study of a paradigm of continuous operation condition monitoring and accident prediction process. New information can be integrated into the accident model when it is available to identify the scenario and make a new prediction of the accident progression. This process will avoid the difficulties in accumulating and analyzing many accident scenarios. 3) Analyze the prediction of rescue failure with a similar approach.

Acknowledgements

The authors would like to thank the China Scholarship Council which provided the fund for this work and Norwegian University of Science and Technology for providing the workplace and academic environment.

References

[1] Dolganov, K.S. and A.V. Kapustin and A.E. Kisselev and D.Y. Tomashchik and S.V. Tsaun and T.A. Yudina, *Real-Time Calculation of the Accident at the Fukushima-1 NPP (Japan) Using the Sokrat Code.* Atomic Energy, 2013. **114**(3): p. 161-168.

[2] Saleh, J.H. and K.B. Marais and E. Bakolas and R.V. Cowlagi, *Highlights from the literature on accident causation and system safety: Review of major ideas, recent contributions, and challenges.* Reliability Engineering & System Safety, 2010. **95**(11): p. 1105-1116.

[3] Turner, B.A. and N.F. Pidgeon, *Man-made disasters*. Vol. 2. 1997: JSTOR.

[4] Chernov, D. and D. Sornette, *Man-made Catastrophes and Risk Information Concealment : Case Studies of Major Disasters and Human Fallibility*. 1st ed. 2016. ed. Man-Made Catastrophes and Risk Information Concealment 2016. 2016: Springer International Publishing : Imprint: Springer.

[5] Turner, B.A., *The development of disasters—a sequence model for the analysis of the origins of disasters.* The Sociological Review, 1976. **24**(4): p. 753-774.

[6] Shaluf, I.M. and F.-r. Ahmadun and A. Mat Said and S.a. Mustapha and R. Sharif, *Technological man-made disaster precondition phase model for major accidents.* Disaster Prevention and Management: An International Journal, 2002. **11**(5): p. 380-388.

[7] Aini, M.S. and A. Fakhrul-Razi, *Development of socio-technical disaster model.* Safety Science, 2010. **48**(10): p. 1286-1295.

[8] Yang, X. and S. Haugen, *Classification of risk to support decision-making in hazardous processes.* Safety Science, 2015. **80**: p. 115-126.

[9] Øien, K., *Risk indicators as a tool for risk control.* Reliability Engineering & System Safety, 2001. **74**(2): p. 129-145.

[10] Aven, T. and S. Sklet and J.E. Vinnem, *Barrier and operational risk analysis of hydrocarbon releases (BORA-Release): Part I. Method description.* Journal of Hazardous Materials, 2006. **137**(2): p. 681-691.

[11] Sklet, S. and J.E. Vinnem and T. Aven, *Barrier and operational risk analysis of hydrocarbon releases (BORA-Release). Part II: Results from a case study.* J Hazard Mater, 2006. **137**(2): p. 692-708.

[12] Aven, T. and S. Sklet and J.E. Vinnem, *Barrier and operational risk analysis of hydrocarbon releases (BORA-Release);Part I Method description*.

[13] Meel, A. and W.D. Seider, *Real-time risk analysis of safety systems.* Computers & Chemical Engineering, 2008. **32**(4–5): p. 827-840.

[14] Røed, W. and A. Mosleh and J.E. Vinnem and T. Aven, *On the use of the hybrid causal logic method in offshore risk analysis.* Reliability Engineering & System Safety, 2009. **94**(2): p. 445-455.

[15] Gran, B.A. and R. Bye and O.M. Nyheim and E.H. Okstad and J. Seljelid and S. Sklet and J. Vatn and J.E. Vinnem, *Evaluation of the Risk OMT model for maintenance work on major offshore process equipment.* Journal of Loss Prevention in the Process Industries, 2012. **25**(3): p. 582-593.

[16] Rathnayaka, S. and F. Khan and P. Amyotte, *SHIPP methodology: Predictive accident modeling approach. Part I: Methodology and model description.* Process safety and environmental protection, 2011. **89**(3): p. 151-164.

[17] Rathnayaka, S. and F. Khan and P. Amyotte, *SHIPP methodology: Predictive accident modeling approach. Part II. Validation with case study.* Process Safety and Environmental Protection, 2011. **89**(2): p. 75-88.

[18] Knegtering, B. and H. Pasman, *The safety barometer: How safe is my plant today? Is instantaneously measuring safety level utopia or realizable?* Journal of Loss Prevention in the Process Industries, 2013. **26**(4): p. 821-829.

[19] Haugen, S. and N.J. Edwin and J.E. Vinnem and O. Brautaset and O.M. Nyheim and T. Zhu and V.L. Tuft, *Activity-based risk analysis for process plant operations.* 2016.

[20] Kim, H. and S. Haugen and I.B. Utne, *Assessment of accident theories for major accidents focusing on the MV SEWOL disaster: Similarities, differences, and discussion for a combined approach.* Safety science, 2016. **82**: p. 410-420.

[21] Kim, T.-e. and S. Nazir and K.I. Øvergård, *A STAMP-based causal analysis of the Korean Sewol ferry accident.* Safety Science, 2016. **83**: p. 93-101.

[22] Kee, D. and G.T. Jun and P. Waterson and R. Haslam, *A systemic analysis of South Korea Sewol ferry accident – Striking a balance between learning and accountability.* Applied Ergonomics, 2017. **59**: p. 504-516.

[23] Lee, S. and Y.B. Moh and M. Tabibzadeh and N. Meshkati, *Applying the AcciMap methodology to investigate the tragic Sewol Ferry accident in South Korea.* Applied Ergonomics, 2017. **59**: p. 517-525.

[24] Rasmussen, J. and I. Svedung, *Proactive risk management in a dynamic society*. [Non-commercial ed.]. ed. 2000, Karlstad: Swedish Rescue Services Agency.

[25] Reason, J., *Managing the risks of organizational accidents*. 1997, Aldershot: Ashgate.

[26] Leveson, N., *A new accident model for engineering safer systems.* Safety Science, 2004. **42**(4): p. 237-270.

[27] Rasmussen, J., *Risk management in a dynamic society: a modelling problem.* Safety science, 1997. **27**(2): p. 183-213.

[28] KMST, *여객선 세월호 전복사고 특별조사 보고서 [Investigation report of the capsizing of the MV SEWOL] (in Korean)*. 2014, Korean Maritime Safety Tribunal (KMST): Seoul; South Korea.

[29] Kobylinski, L. *Capsizing scenarios and hazard identification*. in *Proceedings of the 8th international conference on stability of ships and ocean vehicles. Universidad Politecnica de Madrid, Madrid*. 2003.

[30] Cho, J.K. and S. Yoon, *A note on the marine policy of the ferry Sewol-ho disaster in Korea.* American Journal of Applied Sciences, 2015. **12**(3): p. 229-236.

[31] Gabbar, H.A., *Fault Semantic Networks for Accident Forecasting of LNG Plants*, in *Knowledge-Based and Intelligent Information and Engineering Systems: 14th International Conference, KES 2010, Cardiff, UK, September 8-10, 2010, Proceedings, Part II*, R. Setchi, et al., Editors. 2010, Springer Berlin Heidelberg: Berlin, Heidelberg. p. 427-437.