System Theoretic Safety Analysis of the Sewol-Ho Ferry Accident in South Korea

Citation: Kwon, Yisug, and Nancy Leveson. "System Theoretic Safety Analysis of the Sewol-Ho Ferry Accident in South Korea." INCOSE International Symposium 27, no. 1 (July 2017): 461–476.

As Published: https://doi.org/10.1002/j.2334-5837.2017.00372.x

Publisher: Wiley-Blackwell

Persistent URL: http://hdl.handle.net/1721.1/116713

Version: Author's final manuscript: final author's manuscript post peer review, without publisher's formatting or copy editing

27th Annual INCOSE International Symposium (IS 2017)
Adelaide, Australia, July 15-20, 2017

System Theoretic Safety Analysis of the Sewol-Ho Ferry Accident in South Korea

Yisug Kwon
Fellow, System Design and Management
Massachusetts Institute of Technology
1-860-214-7771
Yisug.Kwon@gmail,com

Nancy Leveson
Professor, Aeronautics and Astronautics
Massachusetts Institute of Technology
1-617-258-0505
Leveson@ mit.edu

Abstract. This paper is to (1) show the application of CAST, Causal Analysis based on STAMP (Systems Theoretic Accident Model and Processes) accident analysis tool to investigate the Sewol-Ho Ferry Accident at the entire maritime transportation sociotechnological system level and to provide the system level safety improvements to the system safety control structure; (2) show that CAST is an accident analysis tool to effectively and holistically analyze the entire maritime transportation sociotechnological system level disaster; and (3) show that CAST can provide preventive solutions in a holistic view of top-down system safety engineering.

Introduction

Two investigation reports of the Sewol-Ho accident published by the Korea Maritime Safety Tribunal (KMST) and the Board of Audit and Inspection of Korea (BAI), which provide the information for the understanding of how and why the accident occurred and the improvements of the maritime transportation system safety, conclude with the causes of the hazard, "Capsizing of the ferry" and the improvements, both of them derived by using a simple linear causality model that a chain of failure events causes an accident. Heinrich's Domino Model was one of the first general accident models based on Chain of Events and was very influential in shifting the emphasis in safety to human error. The events were assumed to be caused by an operator or worker error. The Swiss Cheese Model is another chain of events based causality model which includes more than operator error, but operator error remained the last event in the chain. These Chain of Events models are likely appealing because of their simplicity, which allows for the model to be easily conveyed and comprehended. The models are, however, too simplistic to capture the complex sociotechnical relationships.

Because the two investigation reports were completed after the fact, it is very likely that the problems of hindsight bias could not be overcome in some of their findings and recommendations. Hindsight bias allows oversimplifying the causality, overestimating the likelihood of the outcome, overrating the role of rule, misjudging the prominence of data presented to people at the time, and matching outcome with the actions (Dekker, 2007). Avoiding hindsight bias requires changing our emphasis in analyzing the role of humans in accidents from what they did wrong to why it made sense for them to act the way they did.

Systems with organized complexity are too complex for complete analysis and too organized for statistics. Many of the complex sociotechnical systems including the maritime transportation system fit into this type of system. Systems theory was developed for this type of system. The systems approach focuses on systems taken as a whole, not on the parts taken separately. It assumes that some properties of systems can be treated adequately only in their entirety, taking into account all facets relating the social to the technical aspects. Because safety is an emergent property, it is not possible to take a single system component, like a single human action, in isolation and assess its safety. In addition, a general model of organized complex systems can be expressed in terms of a hierarchy of levels of an organization where each level imposes constraints on the activity of the level beneath it, that is, constraints at a higher level allow or control lower-level behavior. Control processes operate between levels to control the processes at lower levels in the hierarchy.

For the better understanding of the causes of accidents and improving ways to prevent the accidents, Dr. Leveson suggests an approach using systems theory and systems thinking, which is known as Systems-Theoretic Accident Model and Processes (STAMP).

STAMP (Systems-Theoretic Accident Model and Processes)

STAMP is a new causality model which is based on Systems Theory, changing the emphasis in system safety from preventing failures to enforcing behavioral safety constraints. A unique concept in STAMP compared to that of traditional causality models such as Chain of Events is to use a constraint, not an event. The foundation of three main concepts of STAMP – safety constraints, hierarchical control structures and process models enabling the component relationships to be represented and incorporated into the system analysis – is that of Systems Theory which rests on two pairs of ideas; emergence and hierarchy, and communication and control. Safety as an emergent property in Systems Theory becomes a control problem where the goal of the control is to enforce the safety constraints. Therefore, accidents result from inadequate control or enforcement of safety-related constraints on the development, design, and operation of the systems.

Safety Constraints

The most basic concept in STAMP is to use a constraint, not an event. When necessary safety constraints are not enforced, the inadequate control may allow unsafe control actions or accidents to occur. In the hierarchical control diagram, each level of the hierarchy serves to constrain the level below. To maintain safety by the controls, the safety constraints need to be first identified to enforce and then to design effective controls to enforce them.

Hierarchical Safety Control Structure

Figure 1 depicts a typical sociotechnical hierarchical safety control structure which includes many structure levels. There are two basic hierarchical control structures with interactions between them, one for system development on the left and the other for system operation on the right. Effective communication channels are also needed between the hierarchical levels of each safety control structure; a downward reference channel provides the information as a control action that is necessary to impose safety constraints on the level below; an upward measuring channel provides feedback of how effectively the safety constraints are being satisfied. Feedback from the upward measuring channel is critical in any open system to provide adaptive control.

Process Models

Process models are an important part of control theory on which STAMP accident model is based. A controller needs either a human mental model or a software or hardware model of the process being controlled to control the process effectively. Whether the process model is embedded in the control logic of an automated controller or the mental model maintained by a human controller, it must contain the same type of information: The required relationship among the system variables as the control laws, the current state as the current values of the system variables, and the ways the process can change the state. The process model is used to determine what control actions are needed, and it is updated through various forms of feedback.

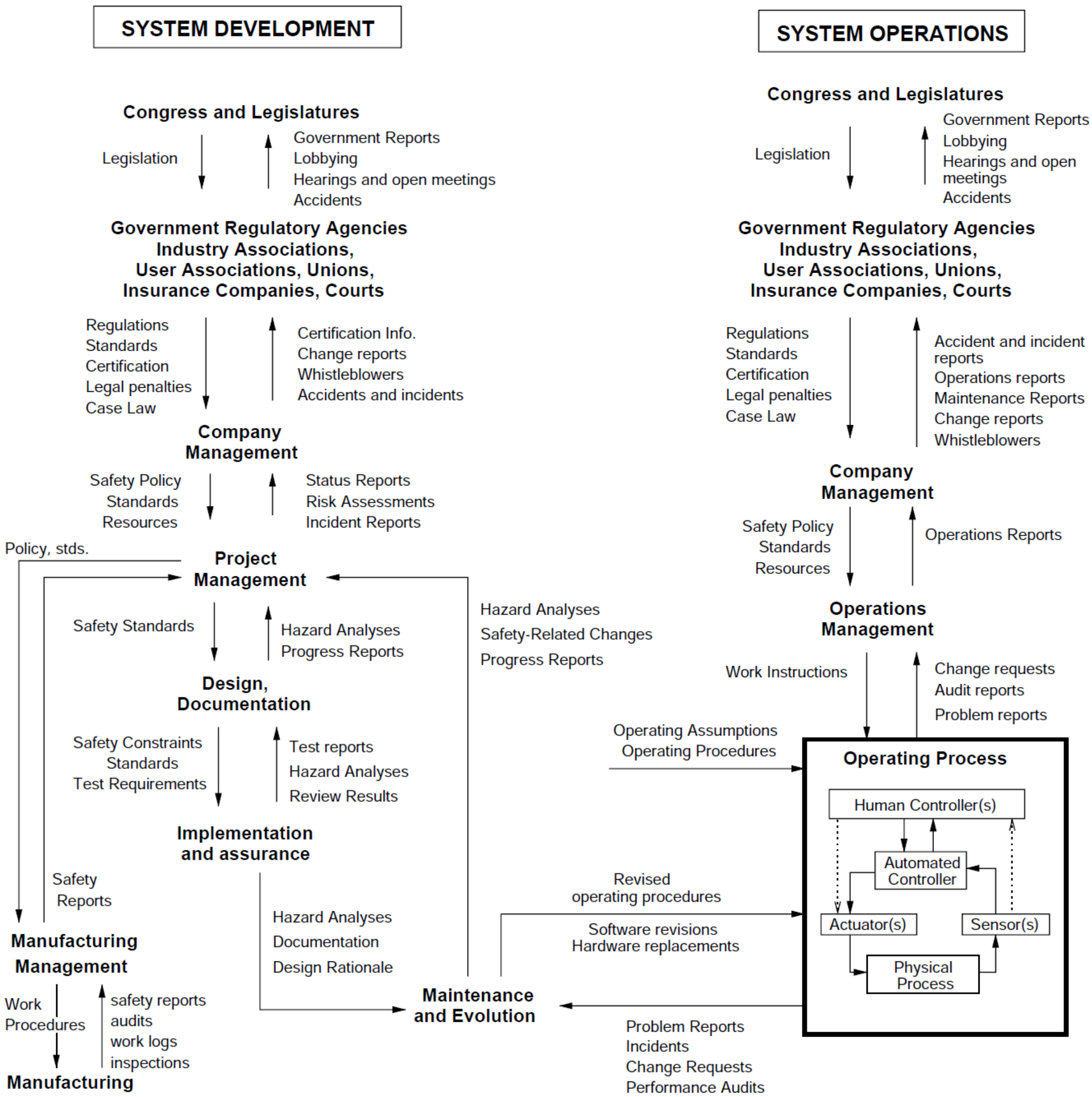

Figure 1. A typical sociotechnical hierarchical safety control structure (Leveson, 2011)

Causal Analysis based on STAMP or CAST

Accident investigation should start with the assumption that most people have good intentions and do not purposely cause accidents. Also, it is often assumed that if an outcome is good, then the process leading up to it must have been good too, i.e., that people did a good job. The inverse is true too: it is often concluded that people may not have done a good job when the outcome is bad (Dekker, 2007).

Using CAST, understanding the causes of the accident and identifying necessary system improvement opportunities can be enabled even if only the information presented in an existing accident report is used. CAST can provide a framework or process to assist in understanding the entire accident process and identifying the most important systemic causal factors involved. Using CAST in the accident analysis also provides the ability to identify the symptoms and all the causal factors of the entire sociotechnical system design, including the weaknesses in the existing safety control structure and the systemic causes. To minimize hindsight bias, getting away from assigning blame to people and instead shifting the focus to why the accident occurred and how to prevent similar losses in the future, CAST focuses on determining why people behaved the way they did, given the information they had at the time. By analyzing the accident in CAST, the dynamic process that led to the loss is documented by showing the sociotechnical safety control structure for the system involved and the safety constraints that were violated at each level of this control structure and why. The nine steps of the CAST demonstrated in this thesis are the following (Leveson, 2011):

1. Identify the system(s) and hazard(s) involved in the loss.
2. Identify the system safety constraints and system requirements associated with that hazard.
3. Document the safety control structure in place to control the hazard and enforce the safety constraints. This structure includes the roles and responsibilities of each component in the structure as well as the controls provided or created to execute their responsibilities and the relevant feedback provided to them to help them do this.
4. Determine the proximate events leading to the loss.
5. Analyze the loss at the physical system level. Determine why the physical controls in place were ineffective in preventing the hazard by identifying the contribution of each of the following to the events:
   - Safety Requirements and Constraints violated
   - Physical and operational control flaws
   - Physical failures
   - Dysfunctional Interactions due to control algorithm flaws and incorrect process or interface models, and communication and coordination flaws due to reference channel flaws, inadequate coordination or communication among multiple controllers, and feedback flaws
   - Environmental and behavior-shaping factors and unhandled disturbances
6. Moving up the levels of the safety control structure, determine how and why each successive higher level allowed or contributed to the inadequate control at the current level. For each system safety constraint, either the responsibility for enforcing it was never assigned to a component in the safety control structure or a component or components did not exercise adequate control to ensure that their assigned safety constraints were enforced in the components below them. Any human decisions or flawed control actions need to be understood in terms of:
   - The information available to the decision maker as well as any required information that was not available
   - The behavior-shaping mechanisms (the context and environment in which the human is working, impacting greatly human behavior)
   - The value structures underlying the decision (any positive or negative forces that can influence behavior)
   - Any flaws in the process models of those making the decisions and why those flaws existed.
7. Examine overall communication and coordination contributors to the loss.
8. Determine the dynamics and changes in the system and the safety control structure relating to the loss and any weakening of the safety control structure over time.
9. Generate recommendations.

Traditional Root Cause Analysis

Korea Maritime Safety Tribunal (KMST)

A special investigation team at the Korea Maritime Safety Tribunal (KMST) conducted an independent analysis of the Sewol-Ho accident. The following results were provided to establish a representation of outcomes achieved using the root cause analysis methodology (KMST, 2014). The KMST identified contributing factors and root causes and provided the recommendations as follows.

Contributing factors

- There existed higher priority on cost, productivity, profit, and schedule at Chonghaejin Marine Company (CM).
- Operation officers at Korea Shipping Association (KSA) did not inspect the overloading and improperly lashing of the cargo containers and vehicles.
- The crew of the ferry in charge of supervising the loading and lashing of cargo and the personnel of the loading and lashing companies were not provided training and instructions in using proper methods.
- No one followed the new requirements of ballast water and cargo load after the ferry's modifications.

Root causes

- Unreasonably sharp turn to starboard caused the capsizing.
- The overloading and improperly secured cargo caused the deterioration of the restoring force of the ferry.
- The Sewol-Ho did not satisfy the required ship stability requirements after the modifications.
- The severe listing deteriorated the stability of cargo containers, which were improperly secured, and everything started to tip over.

Recommendations

- Introduce enforced safety training: Companies must provide the required safety training and drills to the crew and the crew must follow the requirements for ballast water and cargo; Operation officers at the Korea Shipping Association should have clear checklists, responsibilities, and roles.
- Provide training on proper methods for loading and lashing of cargo and vehicles to the crew of the ferry and the personnel of the loading and lashing service companies.
- Install a weigh station on the quay to measure the total loads on the ferry.
- Include the minimum ballast water needed for the safe travel in the Operation Management Regulations Document (OMR).
- Reinforce the KR's safety inspection process including an update of the ship inspection checklist.
- Apply loading and lashing Codes required for far sea ferries or carrier to the near sea ferries or carriers.

Board of Audit and Inspection of Korea (BAI)

The Board of Audit and Inspection of Korea (BAI) conducted an independent analysis of the Sewol-Ho accident. The following results were provided to establish a representation of outcomes achieved using the root cause analysis methodology (BAI, 2014). The BAI identified the following contributing factors and root causes. In this study, all disciplinary punishments, indictments and prosecutions requested by the BAI, which were related to human errors and mistakes, are excluded in this section and not considered as the recommendations.

Contributing factors

- There were inappropriate operations of the Sewol-Ho ferry by CM to maximize profits over passengers' safety.
  - CM made extensive modifications.
  - The KR approved the modifications without reviewing the plan drawings for lashing vehicles.
  - The KSA poorly inspected the overloading and improper lashing conditions before the ferry's departure.
  - The operation officer at the KSA approved the departure after checking only that the load line was satisfied.

Root causes

- Unreasonably sharp turn to starboard caused the ferry's capsizing.
- The severe listing deteriorated the stability of cargo containers.

Recommendations: None

CAST ANALYSIS

This CAST analysis will show that the factors involved in the accident are not the result of human error as indicated by the BAI and the KMST but are related to systemic factors in the safety control structure. The recommendations generated from this analysis are compared to those made by the KMST to determine any systemic issues that were not considered.

CAST Step 1: Identify the System(s) and Hazard(s) Involved in the Loss

The Sewol-Ho accident was involved in two relevant processes being controlled as a system:

- Process 1: Safe operations of the ferry
- Process 2: Rescue operations of people on the distressed ferry

At this study, only the process of safe operations of the ferry is considered. The system hazard related to the Sewol-Ho accident is the following:

- Hazard: Capsizing of the ferry

CAST Step 2: Identify the System Safety Constraints and Requirements with the hazards

Accordingly, the system-level constraint to the system hazard related to the Sewol-Ho accident is the following:

- Constraint: The ferry must not capsize.

CAST Step 3: Document the Safety Control Structure in place to control the hazard and enforce the safety constraints

A high level system safety control structure is created to capture the primary controllers, the control actions and feedback. As shown in Fig. 2, the system safety control structure is highly simplified and idealized in order to capture a generalized Maritime Transportation System. The CAST analysis has been carried out with a system boundary (pink area) defined for the process to include the following:

- The Sewol-Ho Operations, CM, Korea Shipping Association, and Loading and Lashing Service Companies acting upon the ferry as the controlled process.

The high level Sewol-Ho Operations, ROK Coast Guard, Korea Shipping Association, and CM Company include a number of lower level controllers as shown in the subsequent control diagrams of the process. Each component in the high level control diagram depicted in Fig. 2 has the responsibilities in enforcing the necessary system level safety constraint of "The ferry must not capsize." The arrows connecting the elements indicate control actions, controlled variables, measured variables, and feedback. The bi-directional arrows indicate control actions in black letters to down direction and feedback in blue letters to up direction.

CAST Step 4: Determine the proximate events leading to the loss

Through the investigation reports and documents compiled by the BAI, the KMST and the Court, the following chronology can be established for the Sewol-Ho accident. Events and the event times documented by the BAI were referred in this study if any discrepancies among the reports and documents were found.

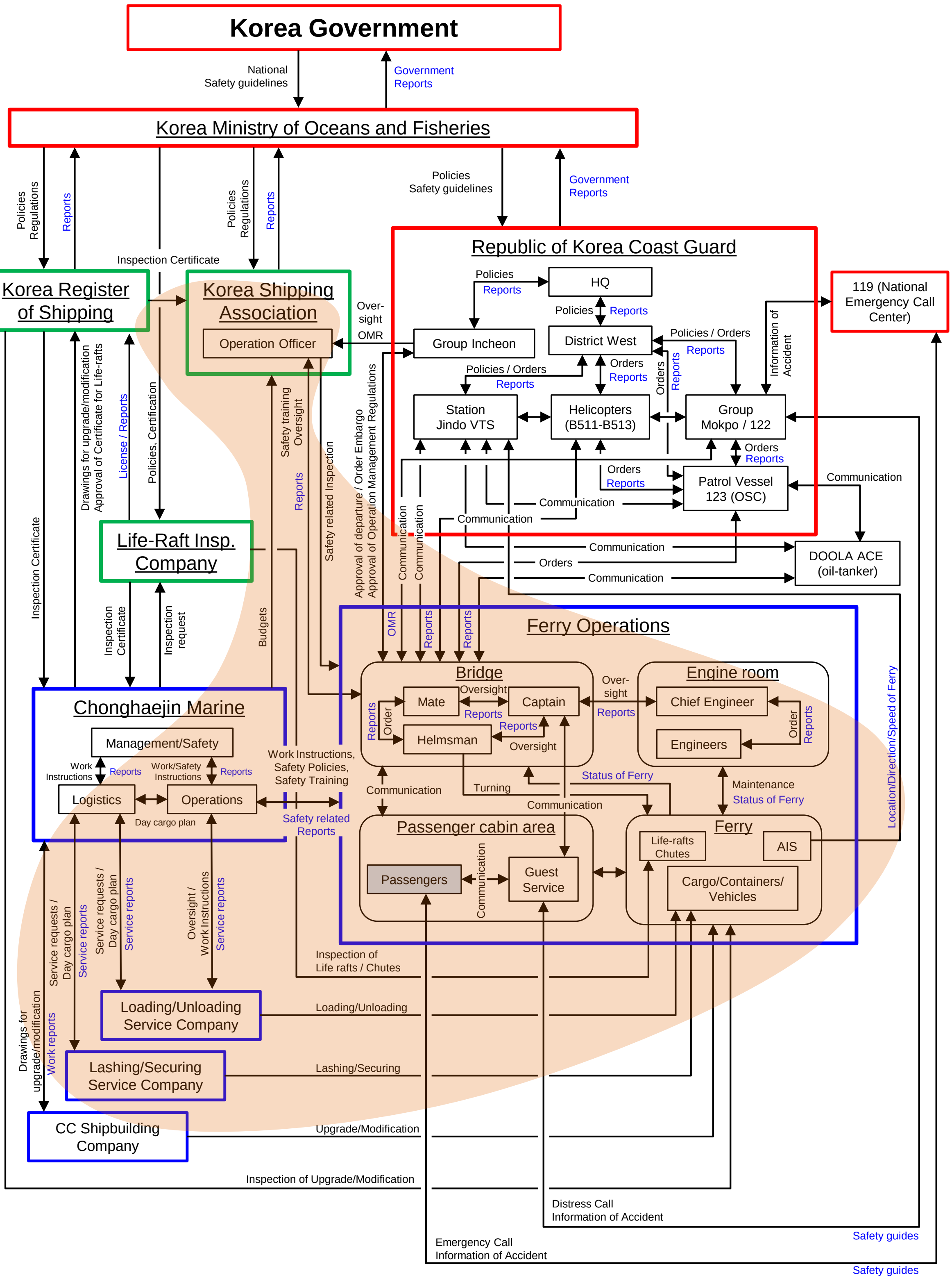

Figure 2. System Safety Control Structure of generalized Maritime Transportation System

April 15, 2014

1830: The Sewol-Ho's departure was delayed for two and a half hours due to a thick fog.

2045: More vehicles arrived, were loaded and were improperly secured.

2100: As an officer at the KSA approved the departure with the inspection of the load line only, the Sewol-Ho with 476 passengers on board departed Incheon en route to Jeju Island.

2130 (around): The Sewol-Ho called the operation officer at the KSA and provided fictitious information about the number of passengers and vehicles and the weight of cargo.

2145 (around): The operation officer at the KSA filed the paperwork with the information.

April 16, 2014

0700: The Sewol-Ho was passing near Jindo-Island located on the southern coast of South Korea. Winds were from a southwesterly direction at 2 to 3 knots. Seas ranged from 1 to 2 feet. Air temperatures were near 59° F or 15° C. Visibility was above 20 nautical miles.

0730: The third mate Park and Helmsman Cho began their scheduled 4-hour shifts.

0840: The Sewol-Ho traveling at about 18 knots entered the Maenggol Channel where is located 11 miles away from Jindo Island. It is a shortcut through the islets of the South coast of South Korea.

0847 (around): Helmsman Cho was steering the ferry at 135 degrees.

0848: The third mate who was monitoring the radar and radio on the bridge, gave two orders to the helmsman to turn the ferry; first to 140 degrees, and then to 145 degrees. The helmsman heard the mate's orders and made the first turn of five degrees to starboard. Once the ferry was heading at 140 degrees, the helmsman, then, steered it to 145 degrees, but the ferry was listing sharply to port. How the helmsman made the second turn is still in question.

0849: The ferry herself listed 20 degrees into the water, causing cargo to fall to one side of the ferry. The ferry turned about 45 degrees to starboard and then, rotated 22 degrees on the spot for about 20 seconds. Water to flow into the ferry through the bow and stern doors.

0850: The ferry was listing 30 degrees to port. The Chief engineer Park stopped the engines. The Captain ordered the second mate to turn on the anti-heeling pumps to return the ferry to its upright position, but the pumps were not working.

0916: The ferry was listing 45 degrees to port.

1007: The ferry was listing 69 degrees to port.

1031: The bow of the ferry was submerged.

1257: The Sewol-Ho sank completely.

Figure 3 shows a graphical summary of the events causing the ferry's capsizing. Indications of elements in the graphics are the following: Round-rectangular pink line boxes: Trigger events, Rectangular pink line boxes: Events in chain, and Rectangular orange box: End event.

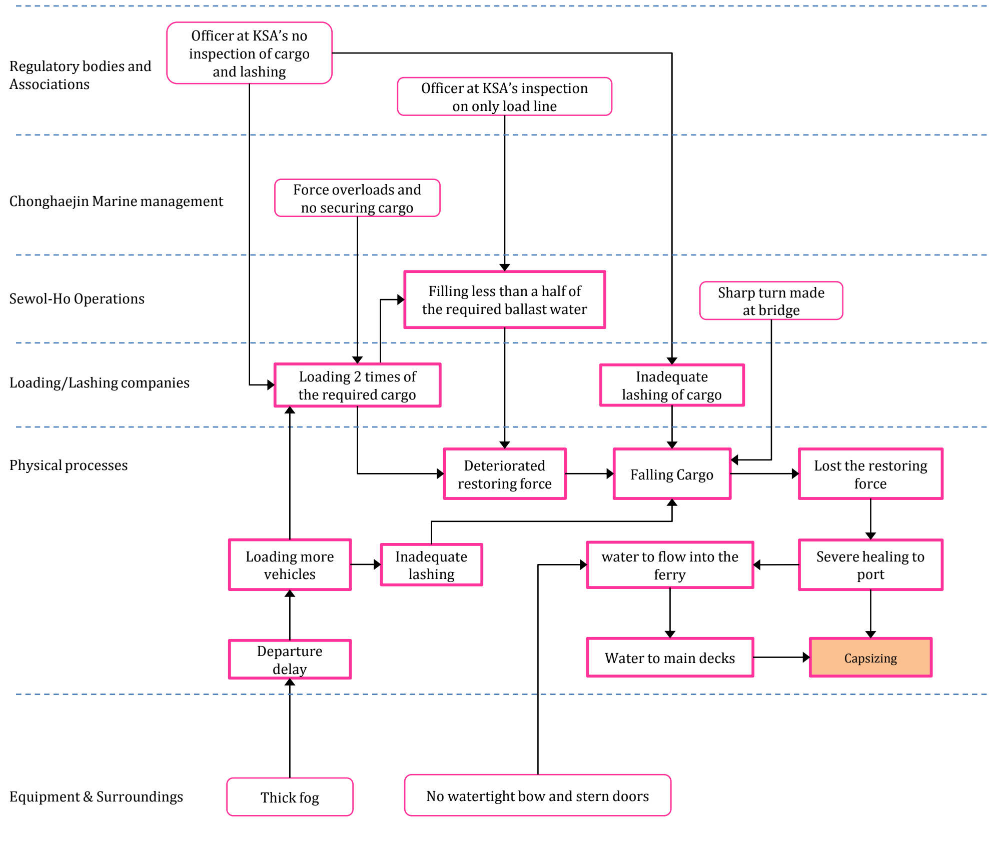

Figure 3. Graphical Summary of the events causing the ferry's capsizing

CAST Step 5: Analyze the Loss at the Physical System Level

There were some specific physical failures identified in the accident (KMST, 2014 and Oh, 2015). In order to determine why the physical controls in place were ineffective in preventing the accident, the contribution of each of the following in the physical needs to be identifed based upon CAST methodology.

- Safety Requirements and Constraints Violated
- Failures and Inadequate Controls
- Physical Contextual Factors

Emergency and Safety Equipment involved in Safe operations of the ferry: Partial list

- Ballast: To maintain stability of the ferry, the ferry fills the ballast tanks with water.
- Lashing bands: Securing vehicles.
- Lashing bars, turnbuckles, twist locks and bridge fittings: Securing cargo containers.
- Watertight bow and stern doors

Safety Requirements and Constraints violated

- Load 987 tons or less as the total weight of both cargo and vehicles.
- Load 88, 60 and 247 as the maximum number of passenger cars, trucks and 10 feet cargo containers respectively, as approved by the KR.
- Load ballast water at least 1,703 tons, as approved by the KR.
- Prevent water from flowing into the ferry.
- Secure vehicles lashed by using lashing bands.
- Secure cargo container lashed, fitted by using lashing bands.
- Prevent the ferry from capsizing using anti-heeling pumps when the ferry is listed.

Failures and Inadequate Controls

- No quantitative methods or tools for assessing the total weight of both cargo and vehicles on the ferry.
- No quantitative methods or tools for assessing ballast water in the ferry.
- Inadequate watertight bow and stern doors against water getting into the ferry.
- Inadequate emergency system: Anti-heeling pumps to return the ferry to its upright position did not work.

Contextual Factors

- Lashing bands, lashing bars, turnbuckles, twist locks and bridge fittings were not enough to carry out proper lashing cargo containers and vehicles.
- New or foreign brand vehicles recently sold in South Korea, which had different types and locations of hooks, could not be secured as defined in the Sewol-Ho's Operation Management Regulations Document and as approved by the KR.
- Lashing points on floors were practically unavailable to secure vehicles.
- Vehicles arrived at the port 10 minutes before the departure were allowed to be loaded.
- Loading cargo and vehicles was completed just before the departure.
- The bow and stern doors' rubber sealing parts were damaged.
- The only quantitative measurement for assessing the total weight of both cargo and vehicles was the load line.

CAST Step 6: Moving up the Levels of the Safety Control Structure, Determine How and Why each Successive Higher Level Allowed or Contributed to the Inadequate Control at the Current Level

To better understand what safety constraints were violated at the physical system level and why they were not controlled at the physical system level, the higher levels of the safety control structure need to be examined to explore the possible contributions to the inadequate controls. To get the information about true goals and motives and how and why the first and higher levels allowed or contributed to the inadequate control at the current level, the details described in this section are based upon the accident related people's testimonies made at the court in several months. All illegal control actions with the intentions are excluded in the analyses, which were addressed in the KMST and BAI's RCA analyses. In the process, the following controllers need to be included in the CAST analysis (in this paper, only Captain as the controller is shown in Table 1):

- Sewol-Ho Operations: Captain, regular captain, first mate, third mate, helmsman
- Chonghaejin Marine Company: Associate manager in Logistics team, president, safety director
- Loading Service Company (Woo-Ryun Trans. Co.): Foreman as an on-site manager
- Lashing Service Company (Won-Kwang Co.): Union members at Incheon port
- Korea Shipping Association (KSA): Operation officer, manager
- Korea Register of Shipping (KR): Inspector
- Republic of Korea Coast Guard (ROKCG) Group Incheon: Officer as reviewers
- Korea Ministry of Oceans and Fisheries (KMOF): The Minister of KMOF

Table 1: The roles of Captain in the accident

	Sewol-Ho Operations (Captain)
Safety Related Responsibilities	• Follow and practice rules of safe operations per the OMR • Check total loads per the OMR • Check ballast water per the OMR • Check bow and stern doors closed and watertight per the OMR • Check cargo containers are all 10ft size ones per the OMR • Check each passenger car is secured by four nylon lashing bands per the OMR • Check minimum distance between vehicles is 2ft per the OMR • Check each truck is secured by ten nylon lashing bands per the OMR. • Check containers are secured by lashing bars, turnbuckles, and corner fittings per the OMR • Check stacked cargo containers are secured by lashing bars, turnbuckles, twist locks and bridge fittings per the OMR • Submit "Ferry safety inspection chart: before-departure" to a KSA Operation Office
Context in which Decisions made	• Poor morale • Inadequate training • The ferry's restoring force was very low due to the modifications. • The captain was a part-time. • Ballast water had been used to meet the load line. • The captain's safety-related reports and feedback had been ignored by the Logistics team and management.
Unsafe Decisions and Control Actions	• Did not follow the OMR. • The captain overlooked overload, less ballast and improper lashing. • The captain did not report safety-related issues to safety team and management. • Command to stop overload and less ballast not provided. • Command to stop improper lashing cargo containers and vehicles not provided. • The captain overlooked "Ferry safety inspection chart: before-departure" report process. • Insufficient controls to correct "no safety related feedback" of the first mate. • Insufficient controls to correct "overlook" by the Logistics team. • Insufficient controls to correct "overlook" by the loading and lashing companies. • Insufficient controls to correct the first mate reduced ballast. • Insufficient controls to correct "maintenance process to fix not-watertight bow and stern doors" by the first mate.
Process Model Flaws	• Believed the ferry was safe. • Believed steering with small angle could avoid unsafe situations.

CAST Step 7: Examine Communication and coordination Contributors

Figure 4 depicts the actual state of Safety Control Structure for the process of "Safe operations of the ferry." The red dot lines in Fig. 4 highlight control actions, controlled variables, measured variables, and control feedback that were either missing or incomplete in the actual Safety Control Structure.

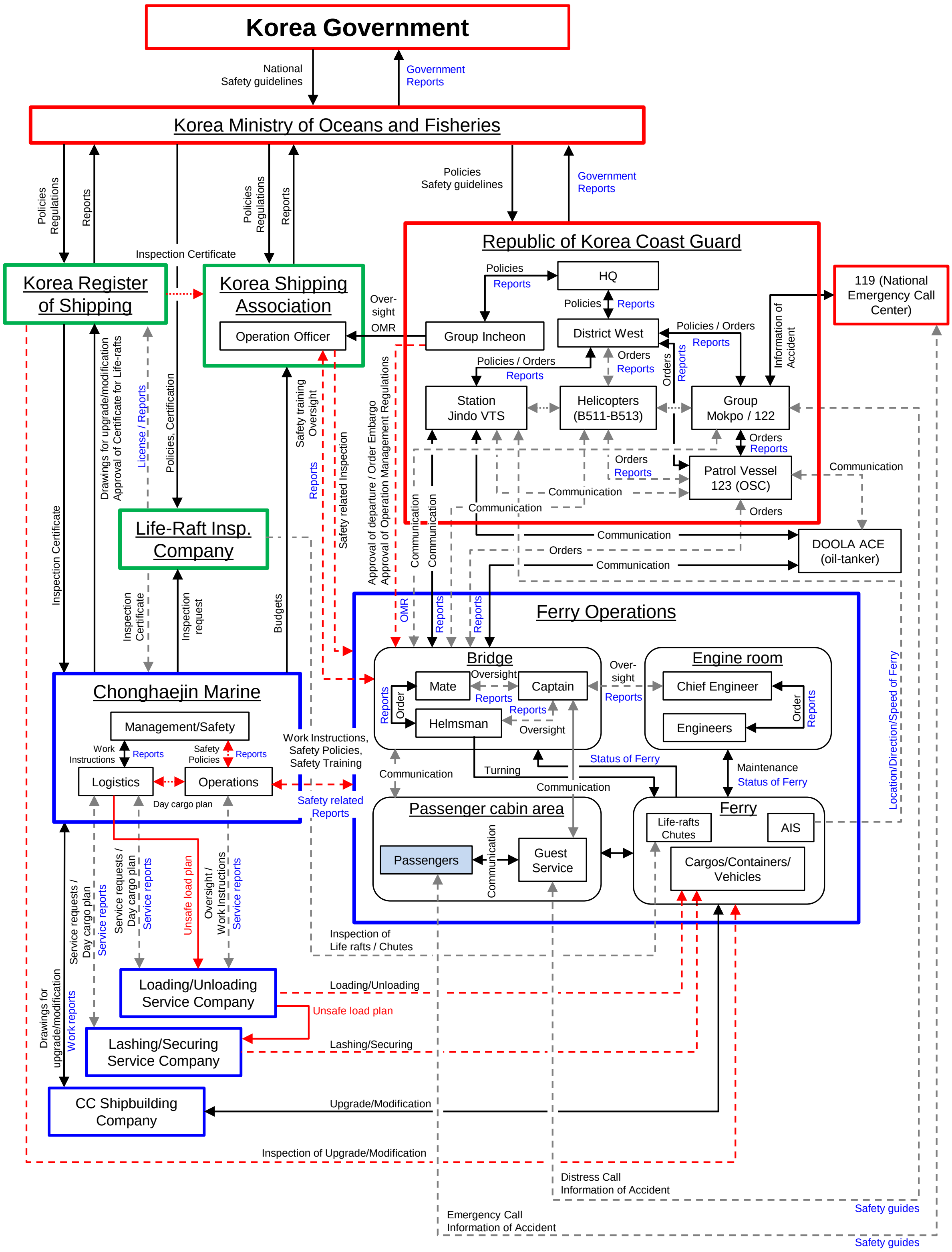

Figure 4. Actual state of Safety Control Structure for the process of "Safe operations of the ferry"

And the red line arrows in Fig. 4 highlight the bypassed or unsafe control actions. They should be corrected to prevent the bypassed or unsafe control actions from occurring in future. The bi-directional arrows indicate control actions in black letters to down direction and feedback in blue letters to up direction.

The inadequate decisions and control actions made by the controllers involved in the Sewol-Ho accident were essentially rooted in communication and coordination problems as highlighted in CAST Steps 5 and 6. There was evidence of communication failures in two processes between the KSA and the KR as well as between the Sewol-Ho Operations and the Service companies. Dysfunctional interactions and communication between the KSA and the KR as depicted in Fig. 4 resulted in the inappropriate comprehensive level of the operation officer at the KSA about the Sewol-Ho's required ballast water. CM Logistics neither communicated nor coordinated with the lashing service company at all but instead, the loading service company had communicated with the lashing service company, which means that even the day cargo plan made by CM had never been shared with the lashing service company.

CAST Step 8: Determine the dynamics and changes in the system and the safety control structure relating to the loss and any weakening of the safety control structure over time.

The accident resulted from a migration of the system toward reduced safety margins over time. With the ferry's modifications of adding more cabins, the management believed that carrying more passengers would increase profit but it turned out the opposite due to the fewer passengers than expected and due to the modification cost. The financial problem led the management to cut the safety margins: overloading cargo and vehicles, improperly securing cargo containers and vehicles and filling less ballast water. The management maintained their mental model about cargo weight and ballast with the "before-modification ones." Without updating the mental model, the management pressured the Captain and crewmembers to operate the ferry in a state of higher risk.

The Korea Register of Shipping contributed to the accident through the erosion of the safety controls. Without having any history of severe accidents, the ferry was deemed safe, and the inspector allowed CM to modify the ferry by reducing to less than a half of the previous cargo weight and four times more ballast water than previously. Therefore, the ferry moved toward a state where an accident would occur with small disturbances.

CAST Step 9: Generate Recommendations

There is a system level safety constraint defined in CAST Step 2: "the ferry must not capsize." The gaps and flaws of the safety control structure at the time of the Sewol-Ho accident, which are identified in CAST Steps 5 through 8, should be addressed to satisfy the system level safety constraint of the system. The necessary lower level safety constraints to avoid the unsafe control actions of the controllers should be provided to help prevent similar accidents from occurring in the future. The following recommendations are generated to provide the necessary safety constraints, which are divided into the following levels.

Physical equipment

- Provide quantitative methods or tools for assessing total weight of both cargo and vehicles on the ferry to the Operations and the KSA operation officer.
- Consider quantitative methods or tools for assessing ballast water in the ferry to the KSA operation officer.
- Upgrade protection means against water getting into the ferry through bow and stern doors.
- Anti-heeling pumps should work properly at any time and return the ferry to its upright position when necessary.

Sewol-Ho Operations and cargo loading and lashing services

- Review and enforce safety policy rules in the OMR.
  - Enforce detection and prevention of overload, less ballast, and improper lashing.
  - Enforce loading only 10 feet size cargo containers on the designated decks.
  - Enforce complying with the process of loading and lashing: loading a cargo container or vehicle, lashing and securing it, and repeating the steps.
  - Enforce a review process to operations and maintenance (day, month and quarter).
  - Periodically evaluate Operations and personnel of the loading and lashing services companies about knowledge of restoring force, ballast water, maximum load limit, load line, and loading and lashing of cargo, as defined in the OMR.
- Review and enforce a report process of "Ferry safety inspection chart: before-departure" to Operations.
  - Enforce submitting the chart after filling with actual data.
  - Enforce adding a checkpoint for reviewing ballast water.
- Enforce maintenance schedules.
  - Enforce maintaining bow and stern doors to prevent water from getting into the ferry.
- Create a process for reviewing and updating the OMR.
  - Add suitable means, methods, and maps for adequate lashing of cargo containers and vehicles to the OMR.
- Regularize and improve safety communication (information and feedback) channels.
  - Review and enforce effective communication channels for disseminating safety information.
  - Improve feedback loops between Operations and the management.
  - Improve feedback loops between Operations and personnel of the loading and lashing services companies.
  - Improve feedback loops between Logistics team and personnel of the loading and lashing services companies.
- Provide a day cargo plan to Operations, the KSA and the loading and lashing service companies 24 hours in advance.

<u>Chonghaejin Marine Company</u>

- Establish and reinforce organizational safety policy and culture.
  - Improve morale in the company.
  - Maintain leadership and commitment to safety as the highest priority.
  - Enforce safety integrated into the organizational culture.
  - Encourage Operations and contractors to contribute to safety-related decision making.
  - Maintain minimum arrival time of vehicles and cargo to be loaded before departure.
- Enhance a review process of the OMR before submitting to ROKCG.
  - Enhance the OMR to provide suitable means, methods, and maps for adequate loading and lashing of cargo containers and vehicles.
  - Upgrade lashing points to secure new or foreign brand vehicles, and update the maps in the OMR.
  - Enhance the OMR to provide the information about ballast water.
- Create and provide safety information training to the management and Logistics team.
  - Provide a complete understanding of restoring force, ballast water, maximum load limit and load line.
- Enhance a process to detect and correct "no feedback on safety-related reports."
  - Review and enhance a process to correct dysfunctional communications between Operations and Logistics about overloading related issues.
- Review and enhance a maintenance process to safety-related equipment and safety devices.
  - Enhance a maintenance process to fix "no watertight bow and stern doors."

Korea Shipping Association

- Enforce a review process of "Ferry safety inspection chart: before-departure."
  - Provide quantitative methods and means for assessing ballast water, and total weight of both cargo and vehicles. Information about ballast water should be in the OMR.
  - Allow appropriate time to physically check and examine safety-related equipment and watertight bow and stern doors.
  - Allow appropriate time to physically check and examine a number of passengers and total weight of both cargo and vehicles before departure.
  - Allow appropriate time to physically check and examine how cargo and vehicles are secured before departure, which should be lashed based on the OMR.
- Provide periodic training and evaluations to operation officers to test knowledge of restoring force, ballast water, maximum load limit, load line, and loading and lashing of cargo.
- Regularize and improve safety communication (information and feedback) channels.
  - Review and enforce effective communication channels for disseminating safety information.
  - Improve feedback loops between operation officers and the supervisor.
  - Improve feedback loops between operation officers and the ferry's Operations.
  - Improve feedback loops between the KSA and the management of CM.
- Consider and provide operation officers to have a full authority to order voyage cancellation when any unsafe situation is found, although Korea Shipping Association was an association of marine transportation business companies.
- Consider establishing a process for reviewing the ferry's inspection certificate and critical data.
  - Receive an inspection certificate and critical technical data including load limits and ballast directly from the KR, and review the OMR with the KR's approved data.

Korea Register of Shipping

- Review and enhance processes for approving the ferry's inspection certificate.
  - Enforce a physical inspection process for lashing of various vehicles including new Korean and European vehicles and stacked containers.
  - Enforce a review process for inspecting drawings with actual structures.
  - Consider introducing safety leading indicators with cargo load and ballast water before-and-after deterioration rate and the trend in order to prevent similar accidents from occurring.
- Improve safety related communication channel to the KSA and ROKCG.
  - Provide load limit, type of cargo containers, ballast and lashing methods directly to the KSA and ROKCG.

ROKCG Group Incheon

- Review and enhance a process for approving the OMR.
  - Receive technical data including critical load limits and ballast directly from the KR and review the OMR with the KR's approved data.
  - Physically review the applicability of lashing of vehicles and cargo containers.

Korea Ministry of Oceans and Fisheries

- Enforce maritime transportation regulatory system to ensure that regulators carry out their responsibilities adequately.
  - Enforce a process for overseeing and feeding back the KSA about conducting maritime transport safety measures.
  - Enforce a process for overseeing and feeding back the KR about conducting inspection certificate of the ferry.

CAST Summary

As started with the assumption that most people have good intentions and do not purposely cause accidents, the CAST analysis enhances understanding of why the accident occurred and how to prevent future occurrences. Therefore, it was possible to find a number of contextual or systemic causal factors. The CAST analysis provides a powerful tool to investigate the accident at the entire complex sociotechnological system level and therefore, provide awareness of the system level safety constraints and the necessary safety constraints enforced by controllers in the higher and lower structure levels. The CAST also provides the safety control structure in a hierarchical framework as the perspective foundation to identify the unsafe control actions, the lack of feedback and the incorrect mental models of the human controllers which occurred in the related context at the time. The following are the systemic causal factors and the recommendations identified by the CAST; Multi-Controllers in overlap areas - none of the five controllers (Captain and the first mate, KSA, Loading/Lashing companies' On-site managers) inspected the overloading quantitatively and improperly lashing of the cargo containers and vehicles; none of the two controllers (the Logistics and Safety Director) enforced safety policy rules in the OMR. Dynamics and changes in the system over time - the Sewol-Ho's OMR did not consider that new or foreign brand vehicles recently sold in South Korea had different types and locations of hooks; Appropriate control actions were provided but not followed - the KMOF relied on voluntary compliance with regulations, policies and guidelines, the KR, the KSA, and Chonghaejin Marine.

References

Chonghaejin Marine (2014), *The Operation Management Regulations Document*, Chonghaejin Marine Company, Incheon, South Korea.

Dekker, S. (2007), Just Culture: Balancing Safety and Accountability, London: Ashgate.

Leplat, J. (1987), Some observations on error analysis. In *New Technology and Human Error*, ed. Jens Rasmussen, Keith Duncan, and Jacques Leplat, pp. 311 – 316, New York, John Wiley & Sons.

Leveson, Nancy G. (2015), "A systems approach to risk management through leading safety indicators," Reliability Engineering & System Safety, Volume 136, pp. 17-34, Elsevier, Amsterdam, Netherlands.

Leveson, Nancy G. (2013), "The drawbacks in using the term 'system of systems'," Biomedical Instrumentation and Technology, March/April, pp. 115-118, Arlington, VA.

Leveson, Nancy G. (2011), Engineering a Safer World: Systems Thinking Applied to Safety, The MIT Press, Cambridge, MA.

Rasmussen J., Svedung I. (2000), *Proactive Risk Management in a Dynamic Society*, Swedish Rescue Services Agency, Karlstad, Sweden.

Rasmussen, J. (1997), "Risk management in a dynamic society: A modeling problem." *Safety Science*, 27 (2/3), pp. 183-213.

Rasmussen, J. (1990), "Mental models and the control of action in complex environments. In Mental Models and Human – Computer Interaction," ed. D. Ackermann and M. J. Tauber, pp. 41 – 69, Amsterdam, North-Holland.

Oh, Jun-Ho (2015), Document the Sewol-Ho: sinking – voyage – rescue – crew, documentation of trials on the Sewol-Ho for 150 days, Mizibooks, Seoul, South Korea.

The Board of Audit and Inspection of Korea (BAI) (2014), "The Special Audit Report: Investigation of the Search and Rescue Program at The Sewol-Ho Accident and Safety management and oversight on Coastal Class Ferries," The Board of Audit and Inspection of Korea, South Korea. http://www.bai.go.kr.

The Korea Maritime Safety Tribunal (KMST) (2014), "The Special Sewol-Ho Accident Investigation Report," The Korea Maritime Safety Tribunal, South Korea. https://www.kmst.go.kr.