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

by

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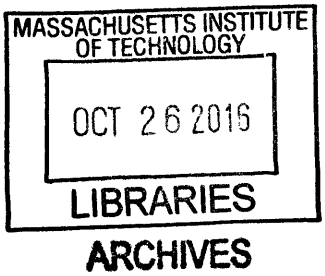

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ABSTRACT

The disaster of the Sewol-Ho, which took place on April 16, 2014, was one of the worst maritime disasters in South Korea in decades, and rescuing only 172 of a total 476 people triggered thorough accident investigations. As the results of the investigations performed by the Korea Maritime Safety Tribunal and the Board of Audit and Inspection of Korea, 399 people were blamed for the accident and arrested, 154 of them were put in jail, many safety policies and manuals were found inadequate, new safeguards against the kinds of accidents were implemented, and Korean high and low governments' structures which were related to the accident were reorganized: disbanding the 61-year-old Republic of Korea Coast Guard and establishing a new Ministry responsible for Korean public safety. The accident investigation reports, however, were limited in revealing the most important systemic causal mechanisms leading to a more complete understanding of the reason why the accident occurred, and therefore, appear to be inadequate in designing and obtaining sociotechnical system level safety because they did not apply system engineering tools in the investigations.

The Systems-Theoretic Accident Model and Processes (STAMP), created by Dr. Nancy Leveson, is an accident model based on systems theory. It has been applied to improve system safety in a number of complex sociotechnical systems. STAMP has the capability to help identify a broader set of systemic causal factors and develop and improve the safety control structure for the entire maritime transportation safety structure.

This thesis applies the Causal Analysis based on Systems Theory (CAST) accident analysis tool created by Dr. Leveson to the accident and provides the application and findings of CAST. The CAST analysis demonstrated that a complete set of systemic causal factors was identified by the systems theory approach, which was much broader than those of the Korea Maritime Safety Tribunal and the Board of Audit and Inspection of Korea. The powerful and effective tool to reveal the systemic causal mechanism led to the identification of the systemic causal factors and system improvements of the safety control system.

Thesis Supervisor: Nancy G. Leveson
Title: Professor of Aeronautics and Astronautics and Engineering Systems

Acknowledgements

"If I speak in the tongues of men and of angels, but I do not have love, I am a noisy gong or a clanging cymbal (1Co 13:1). Love is patient, love is kind, it is not envious. Love does not brag, it is not puffed up. It is not rude, it is not self-serving, it is not easily angered or resentful. It is not glad about injustice, but rejoices in the truth. It bears all things, believes all things, hopes all things, endures all things (1Co 13:4-7).
I would first like to thank God for the great opportunity to learn.

I would like to thank Dr. Leveson, as my thesis supervisor, for contributing to my understanding of STAMP and guiding me along the way. At her class, ESD355 Engineering of software, in the fall, 2013, Dr. Leveson claimed that Safety is a system property. It must always be analyzed top-down and for the system as a whole. When putting two or more existing components ("systems") together, the emergent properties must be analyzed for the integrated system. Calling that larger system a "System of systems" may be misleading by implying that emergent properties can be treated differently than any other system or different system engineering techniques can be used (Leveson, 2013). This claim challenged me to know more about system engineering and STAMP, and start my thesis research.

I would like to thank the MIT SDM program, including the faculty, staff, and cohort. Special thanks to Pat Hale who welcomed me to the 1-year SDM Certificate program and later, this SDM Master program, and has been a great supporter along the way.

To my sponsor company and its great people, I would like to thank you, especially Dan, Randy, and Jinho for supporting me to get through this SDM program.

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I would like to express my deepest sympathy to the families for the losses in the accident.

Table of Contents

List of Acronyms

AIS	Auto Identification System
AMSS	Advanced Maritime Surveillance System
BAI	Board of Audit and Inspection of Korea
CAST	Causal Analysis based on STAMP
EDRE	Emergency Deployment Readiness Exercise
FM	Frequency Modulation
KMOF	Korea Ministry of Oceans and Fisheries
KMST	Korea Maritime Safety Tribunal
KR	Korea Register of Shipping
KSA	Korea Shipping Association
OMR	Operation Management Regulations Document
OSC	On Scene Commander
PFDs	Personal floatation devices
ROKCG	Republic of Korea Coast Guard
ROP	Rescue Operations of Passengers
SAR	Search and Rescue
SSB	Single-SideBand modulation
STAMP	System-Theoretic Accident Model and Processes
TRS	Trunked Radio System
VHF	Very High Frequency
VTS	Vessel Traffic Service

Chapter 1: Introduction

Motivation

Passengers expect joyful, peaceful and safe sea travels to the destinations when they ride cruise ships, ferries or any transportation means at sea waters. They want the maritime transportation system to be safe. Similar to the crewmembers, Chonghaejin Marine Company, Republic of Korea or South Korea Coast Guard (ROKCG), Korea Register of Shipping (KR), Korea Shipping Association (KSA), and Regulators do not set out to provide passengers unsafe travel. Also, the safety of maritime transportation industry is also relatively well controlled and maintained compared to land transportation ones. For most Koreans, passengers riding on ships assumed that the sea travels they take resulted in neither harm nor serious accidents until the Sewol-Ho accident occurred, 295 died and nine people remained missing.

Since the Sewol-Ho accident, mass media in South Korea has focused on finding people to blame for the accident for several months. Due to the emphasis on the blame sought by Korean prosecutors and Board of Audit and Inspection of Korea (BAI), 399 people involved had been arrested, and 154 among them were put in jail (May 5, 2015).

Since the time of the accident, some individuals and organizations have attempted to find the causes and improve the safety of the maritime transportation system. For example, Korea Maritime Safety Tribunal (KMST) published the accident investigation report which presented safety problems of the maritime transportation system and called for government and industry-wide changes. Around the same time, the BAI also published the audit report, which presented faults of people, ordered the related organizations to charge them and enforced regulations and rules to prevent people from committing the faults in the future. Even with the efforts, Koreans are sure that the safety of the maritime transportation system remains inadequate.

The efforts made mostly at the lower levels of the organizations involved in the accident may achieve little success in part because the modern maritime transportation system is a

complex and sociotechnical system in which the bottom-up decentralized decision making can lead and has led to major accidents. Each local decision may be "correct" in the limited context in which it was made but leads to an accident when the independent decisions and organizational behaviors interact in dysfunctional ways (Leveson, 2011, pp. 14). The decentralized decisions, like all safety-critical decisions, must be made in the context of system-level information and from a total systems perspective to be effective in reducing accidents (Leveson, 2011, pp. 44). As a complex system, it is inherently difficult to improve in part because of the number of components, as well as the degree of coupling among those components. The coupling between system elements increases the difficulty in predicting emergent properties such as system safety (Leveson, 2011, pp. 64). The root cause analysis investigation approach without the consideration of system safety as an emergent property has remained, however, standard across the safety investigation organizations including the KMST.

Systems including the maritime transportation system are not static. Rather than accidents being a chance occurrence of multiple independent events, accidents tend to involve the effects of a systematic migration of organizational behavior toward an accident under the influence of pressure toward cost-effectiveness in an aggressive, competitive environment. (Rasmussen and Svedung, 2000, pp. 14). Therefore, any approach to enhancing safety that includes the social system and humans must account for adaptation (Leveson, 2011, pp. 51).

Accident investigations are vital to the efforts to improve the safety of the system as the investigators strive to understand why an accident occurred and to identify the areas that need to be improved to prevent accidents from occurring in the future. While the KMST accident investigation report outlined recommendations needed to improve the safety of maritime transportation system, it did not include systemic causal factors to understand why the accident occurred and to identify the areas need to be improved to prevent future accidents.

This thesis intends to understand why the accident occurred and to identify the areas that need to be improved to prevent future accidents by using a system safety approach for accident investigation, the Causal Accident based on STAMP (CAST) accident analysis tool, developed by Dr. Nancy Leveson. CAST is a tool based on the Systems-Theoretic Accident Model and Processes (STAMP), a model created using system theory (Leveson, 2011). The use of CAST does not lead to identifying single causal factors or variables. Instead, CAST provides the ability to examine the entire sociotechnical system design to identify the weaknesses in the existing safety control structure and to identify changes that will not simply eliminate symptoms but potentially all the causal factors, including the systemic ones. One goal of CAST is to ***get away from assigning blame*** and instead to ***shift the focus to why*** the accident occurred and how to prevent similar losses in the future. To accomplish this goal, it is necessary to ***minimize hindsight bias*** by determining why people behaved the way they did, given the information they had at the time (Leveson, 2011, pp. 349).

Objective

The objective of this thesis is (1) to 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) to show that CAST is an accident analysis tool to effectively and holistically analyze the entire maritime transportation sociotechnological system level disaster; and (3) to show that CAST can provide preventive solutions in a holistic view of top-down system safety engineering.

Overview

Chapter 2 provides an overview of STAMP and Causal Analysis based on STAMP (CAST) which is used as the research methodology for this thesis.

Chapter 3 conducts a review of the Sewol-Ho accident documents made at the courtrooms, which were compiled by Oh, Jun-Ho (Oh, 2015).

Chapters 4 and 5 present the findings of the Root Cause Analyses conducted by the Korea Maritime Safety Tribunal and the Board of Audit and Inspection of Korea respectively.

Chapters 6 analyzes the Sewol-Ho accident at the maritime transportation system level using the CAST and also provides the recommendations and CAST summary.

Chapters 7 discusses the comparison of KMST and BAI Root Cause Analyses and CAST.

Chapter 2: Literature review

Firstly, this thesis reviews 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. These two reports conclude with the causes of the two hazards, "Capsizing of the ferry" and "Not rescuing all people in the distressed 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 developed in 1931 as 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. Heinrich's model explains accidents as a series of events or "Dominos." In this model, an event, usually a failure, occurs, which then leads to another, which leads to another, cascading eventually to the accident under investigation. The events were assumed to be caused by an operator or worker error. James Reason developed another chain of events based causality model, the Swiss Cheese Model, which includes more than operator error. However, operator error remained the last event in the chain. The Swiss Cheese Model maintained the core elements of the Domino Model. These Chain of Events models are likely appealing because of their simplicity, which allows for the model to be easily conveyed and comprehended. There is comfort in believing that finding and addressing the root causes can prevent accidents. However, the models are too simplistic to capture the complex sociotechnical relationships because the events represented by falling dominos are treated as independent. The problem is the oversimplification implicit in using a chain of events to understand why this accident occurred (Leveson, 2011, pp. 15 - 25). Unsafe interactions may be controlled through processes such as maintenance processes and operations, or through social controls. The social controls can be organizational management, governmental, and regulatory structures, cultural, policy, or individual interest, which cannot efficiently be treated by the models. In general, accidents

related to human and social interactions often occur rather than those caused by the failure of individual components.

Because the two investigation reports of the Sewol-Ho accident were completed after the fact, and because they did not appear to follow any accident model process in their investigations, it is very likely that the problems of hindsight bias could not be overcome in some of their findings and recommendations. It would have been much easier for them to simplify the accident and look for the root causes. 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, pp. 65 - 73). 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 (Leveson, 2011, pp. 39).

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. A component that is perfectly safe in one system or one environment may not be when used in another system or environment. In systems theory, safety as an emergent property arises from the interactions among the system components.

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 or lack of 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. These control processes enforce the

constraints for which the control process is responsible (Leveson, 2011, pp. 61 - 64). The two reports from the KMST and the BAI, however, did not appear to consider safety as an emergent property and to view the maritime transportation system as a hierarchical control structure for safety.

For the better understanding of the causes of accidents and improving ways to prevent the accidents, Dr. Leveson suggests in her book: *Engineering a Safer World (2011): Systems Thinking Applied to Safety,* ***an approach using systems theory and systems thinking***, which is known as Systems-Theoretic Accident Model and Processes (STAMP). As mentioned earlier, the traditional ways like Chain of Events models, of looking at accidents and safety are not capable of handling the complex sociotechnical systems and fail to address systemic issues behind many accidents. This thesis also reviews STAMP, and the Causal Analysis based on STAMP (CAST) accident analysis tool.

STAMP (Systems-Theoretic Accident Model and Processes)

Event-based or Chain of Events models work best for accidents in which one or several components fail, leading to a system failure or hazard. The accident models and explanations involving only chains of failure events, however, miss complex couplings and interactions among failure events and easily omit entirely accidents involving no component failure at all. The models developed basically to explain physical phenomena are inadequate to explain accidents involving organizational and social factors and human decisions errors in highly adaptive, tightly-coupled, interactively complex sociotechnical systems (Leveson, 2011, pp. 58).

In the book, *Engineering a Safer World: Systems Thinking Applied to Safety,* Dr. Leveson questions basic but important assumptions about the cause of accidents and ***how to prevent accidents of complex sociotechnical systems,*** and suggests the new assumptions need to be substituted or added. The new assumptions as shown in Table 1 provide the foundation for a new view of accident causation. Dr. Leveson also sets the following goals stemming from the assumptions whether a new causality model to be developed does satisfy them (Leveson, 2011, pp. 57 - 60).

- Expand accident analysis by forcing consideration of factors other than component failures and human errors.
- Provide a more scientific way to model accidents that produces a better and less subjective understanding of why the accident occurred and how to prevent future ones.
- Include system design errors and dysfunctional system interactions.
- Allow for and encourage new types of hazard analysis and risk assessments that go beyond component failures and can deal with the complex role software and humans are assuming in high-tech systems.
- Shift the emphasis in the role of humans in accidents from errors (deviations from normative behavior) to focus on the mechanisms and factors that shape human behavior (i.e., the performance-shaping mechanisms and context in which human actions take place and decisions are made).
- Encourage a shift in the emphasis in accident analysis from "cause" - which has a limiting, blame orientation - to understanding accidents in terms of reasons, that is, why the events and errors occurred.
- Examine the processes involved in accidents and not simply events and conditions.
- Allow for and encourage multiple viewpoints and multiple interpretations when appropriate.
- Assist in defining operational metrics and analyzing performance data.

To satisfy the goals, Dr. Leveson develops a new causality model which is based on Systems Theory, Systems-Theoretic Accident Model and Processes (STAMP), changing the emphasis in system safety from preventing failures to enforcing behavioral safety constraints. In addition, 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, rather than a reliability 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. The control problem then becomes one of controls where the goal is to control the behavior of the system - especially complex sociotechnical system which has dysfunctional interactions among the system components - by enforcing the safety constraints in its design and operation. In this STAMP framework, understanding why an accident occurred requires determining why the control was ineffective, and preventing future accidents also ***requires shifting from a focus on preventing failures to the broader goal of designing and implementing controls that will enforce the necessary constraints*** (Leveson, 2011, pp. 75 - 102).

STAMP begins with the definition of the accident and system hazards involved in the investigation. In STAMP, an accident is defined as "an undesired and unplanned event that results in (at least) a specified level of loss" (Leveson, 2011, pp. 181). The system hazards are defined as "A system state or set of conditions that, together with a particular set of worst-case environmental conditions, will lead to an accident (loss)." (Leveson, 2011, pp. 184). The three main concepts of safety constraints, hierarchical control structures, and process models are core foundations in STAMP (Leveson, 2011, pp. 76).

Table 1 The basis for a new foundation for safety engineering (Leveson, 2011, pp. 57)

Traditional Assumption	New Assumption
Safety is increased by increasing system or component reliability. If components do not fail, then accidents will not occur.	High reliability is neither necessary nor sufficient for safety.
Accidents are caused by chains of directly related events. We can understand accidents and assess risk by looking at the chain of events leading to the loss.	Accidents are complex processes involving the entire sociotechnical system. Traditional event-chain models cannot describe this process adequately.
Probabilistic risk analysis based on event chains is the best way to assess and communicate safety and risk information.	Risk and safety may be best understood and communicated in ways other than probabilistic risk analysis.
Most accidents are caused by operator error. Rewarding safe behavior and punishing unsafe behavior will eliminate or reduce accidents significantly.	Operator behavior is a product of the environment in which it occurs. To reduce operator "error" we must change the environment in which the operator works.
Highly reliable software is safe.	Highly reliable software is not necessarily safe. Increasing software reliability or reducing implementation errors will have little impact on safety.
Major accidents occur from the chance simultaneous occurrence of random events.	Systems will tend to migrate toward states of higher risk. Such migration is predictable and can be prevented by appropriate system design or detected during operations using leading indicators of increasing risk.
Assigning blame is necessary to learn from and prevent accidents or incidents.	Blame is the enemy of safety. Focus should be on understanding how the system behavior as a whole contributed to the loss and not on who or what to blame for it.

- **Safety Constraints**

The most basic concept in STAMP is to use a constraint, not an event. In STAMP, the basics of control engineering are adopted to allow for a systems approach to understanding safety as an emergent system property, and when necessary safety constraints are not enforced, this 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. In system design and operation, the safety constraints will be broken down and sub-constraints allocated to the components of the design and the lower operation level (Leveson, 2011, pp. 76 - 80).

- **Hierarchical Safety Control Structure**

Figure 1 shows a standard control diagram to understand how the system interacts with the control elements. The safety control model is a functional control diagram rather than a physical component diagram, and therefore, the causes of unsafe control are based on lack of control rather than physical parameter deviations. Four elements in the safety control model, Controller, Actuators, Controlled Process and Sensors provide the basic feedback loop. In the control structure diagram, the four elements are displayed as labeled boxes. The arrows connecting the elements indicate control actions, controlled variables, measured variables, and feedback. In this diagram, Controller is a system element that has the ability to issue a control action. The Controller runs the control algorithm and sends a control action to the Actuator (s). The Actuator then sends the controlled variables to the Controlled Process to change the state of the Controlled Process. The Sensor (s) monitors the state of the Controlled Process and sends the measured variables back to the Controller. The Controller then compares the state with the desired state or set point and determines the next control action (Leveson, 2011, pp. 66). The control diagram helps understand why an accident occurred and identify what changes are needed to prevent an accident from occurring. The control diagram also provides a communication tool during and after the investigation.

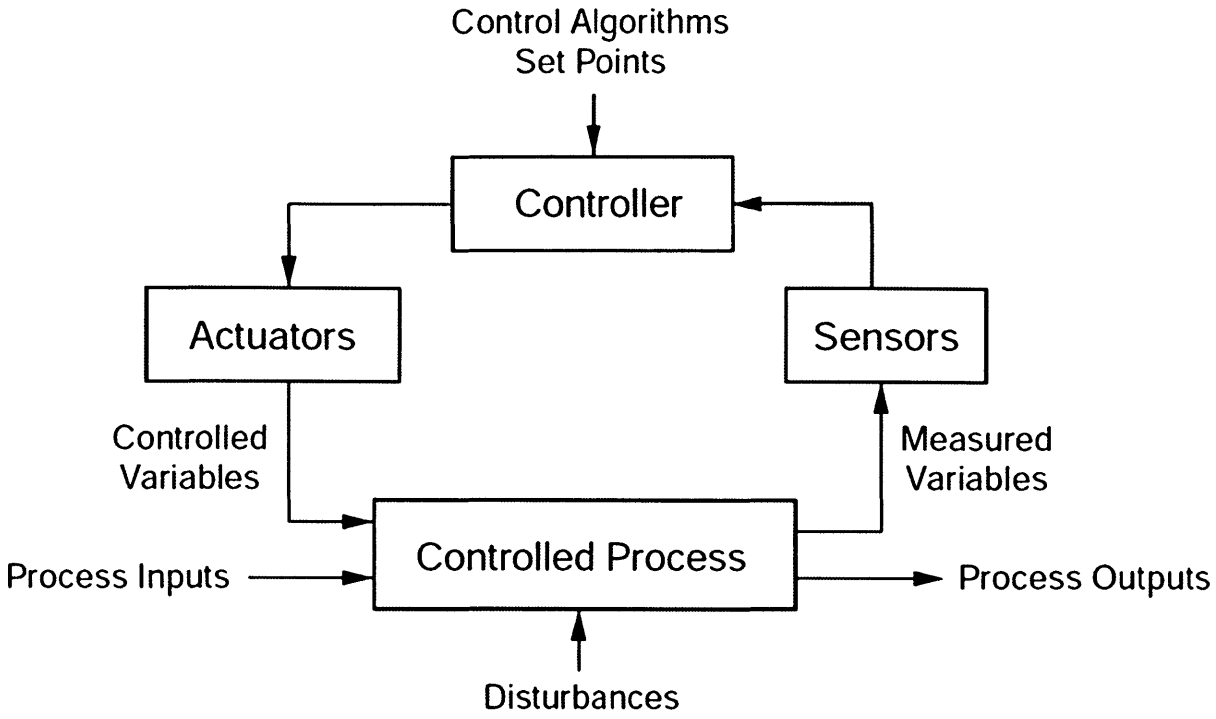


Figure 1 A standard control diagram (Leveson, 2011, pp. 66)

Using the safety control model, one or more of the following must have occurred if there is an accident (Leveson, 2011, pp. 92):

1. The Safety Constraints were not enforced by the Controller.
   a. The control actions necessary to enforce the associated safety constraint at each level of the sociotechnical control structure for the system were not provided.
   b. The necessary control actions were provided but at the wrong time (too early or too late) or stopped too soon.
   c. Unsafe control actions were provided that caused a violation of the safety constraints.
2. Appropriate control actions were provided but not followed by the Actuator (s).

As described with the inadequate control actions (1-b), time lags may affect the flow of control actions and feedback and may impact the effectiveness of the control structure in enforcing the safety constraints. Therefore, time lags at the lowest levels may require the use of feedforward control to overcome the lack of feedback or may require temporary controls on behavior.

The classification of causal factors in accidents can be divided into four categories (Leveson, 2011, pp. 92 - 100):

1. Controller Operation to include control inputs and other relevant external information sources, the control algorithms, and the process model:
   a. The control inputs provided by the higher level and required for safe behavior may be missing or wrong.
   b. Human control algorithms are affected by initial training, by the manuals/guidelines, and by feedback and experimentation over time. Moreover, when time delays in feedback are not adequately considered in the control algorithm, accidents can result.
   c. Particularly component interaction accidents often result from inconsistencies between the human mental (process) model and the actual process state.
2. Behavior of Actuators and Controlled Processes:
   a. Accidents occur when the commands are not implemented due to flaws in the transmission, actuator failures, or inadequate inputs, such as power, from other system components for the execution of the control actions provided.
   b. There may be external disturbances that are not handled by the controller.
3. Communication and Coordination among controllers and decision makers:
   a. When there are multiple controllers (human and/or automated), control actions may be inadequately coordinated. Communication flaws play an important role here.
   b. The greater the distance, the more difficult the communication, and thus the greater the uncertainty and risk to occur accidents.
   c. Often there is more than one controller in an operation. This situation can lead to conflicts in communication and coordination within the overlapped areas of the controlled process.
4. Context and Environment: Behavior-shaping mechanisms - human behavior is greatly impacted by the context and environment in which the human is working.

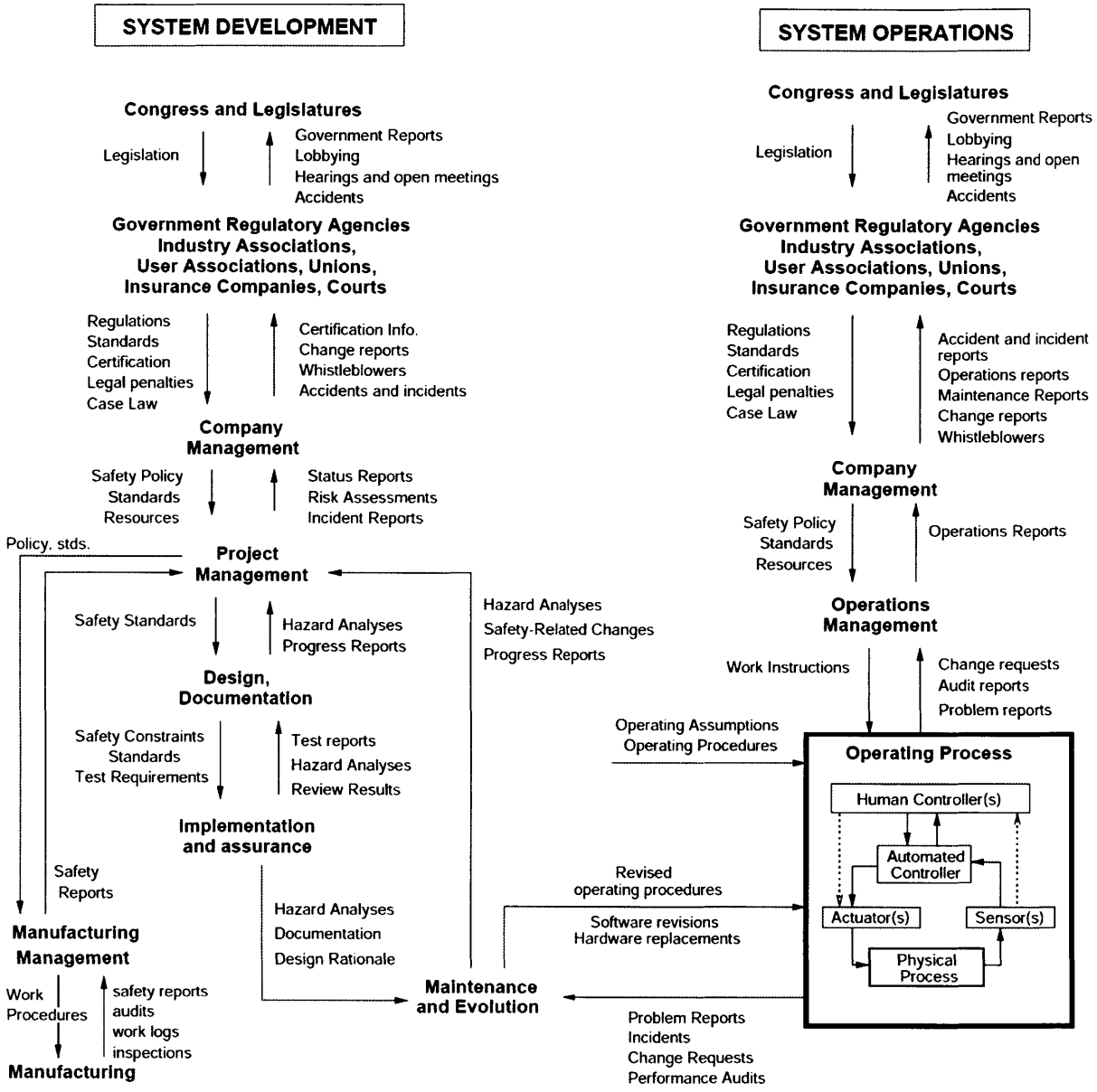


Figure 2 A typical sociotechnical hierarchical safety control structure (Leveson, 2011, pp. 82)

Figure 2 shows a typical sociotechnical hierarchical safety control structure which includes many structure levels, which is common in a regulated air transportation system in the United States. 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.*** The Controller uses the feedback to adopt future control actions to achieve more easily its goals. Government, general industry groups and courts at the top levels need the same effective communication channels to impose safety constraints on the level below and to provide feedback to the level above as Congress and state legislatures. Safety control structures may be very complex so abstracting and concentrating on parts of the overall structure may be useful in understanding and communicating about the controls. Only subsets of the overall structure may be relevant and need to be considered in detail, and the rest can be treated as the inputs to or the environment of the substructure (Leveson, 2011, pp. 87).

Control at each level may be enforced in a very prescriptive command and control structure, or it may be loosely implemented as performance objectives with many degrees of freedom in how the objectives are met. Recent trends from management by oversight to management by insight reflect differing levels of feedback control that are exerted over the lower levels and change from prescriptive management control to management by objectives, where the objectives are interpreted and satisfied according to the local context. Management insight, however, does not mean abdication of safety-related responsibility. The poor transition from oversight to insight may be a factor in accidents. *Attempts to delegate decisions and to manage by objectives require an explicit formulation of the value criteria to be used and an effective means for communicating the values down through society and organizations.* The impact of specific decisions at each level on the objectives and values passed down need to be adequately and formally evaluated. Feedback is required to measure how successfully the functions are being carried out. The only requirement is that responsibility for safety is distributed in an appropriate way throughout the sociotechnical system. *If companies or industries are unwilling or incapable of carrying out their public safety responsibilities, then government has to step in to achieve the overall public safety*

goals. A much better solution is, however, for company management to take responsibility as it has direct control over the system design and manufacturing and over operations (Leveson, 2011, pp. 80 - 87).

- **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. Human controllers or operators require mental models to provide safe control actions. Accidents in complex systems, particularly those related to human controllers, often result from inconsistencies between the mental model of the process used by the controller and the actual process state. The inconsistency contributes to the controller providing inadequate control. These mental models of the controlled system become incorrect due to missing or inadequate feedback and communication channels. The effectiveness of the safety control structure in preventing accidents is greatly dependent on the accuracy of the information about the state of the controlled system each controller has. Process models are required not only at the lower physical levels of the hierarchical control structure but also at all levels. They are also used during operations and system development activities. Process models play an important role in understanding why accidents occur and why humans provide inadequate control over safety-critical systems and in designing safer systems (Leveson, 2011, pp. 87 - 89).

Causal Analysis based on STAMP or CAST

Using Causal Analysis based on STAMP or 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, pp. 349 - 352):

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.

The first three steps are the same ones which form the basis of all the STAMP-based techniques described in STAMP.

Chapter 3: Summary of the Sewol-Ho Accident (Oh, 2015)

Chonghaejin Marine Company purchased the ferry for US $9.8 million in 2012, when it was 18 years old. The ferry was built in 1994 by Hayashikane Dockyard who had operated her in Japan for 18 years without a single accident. The ferry was named Ferry Naminoue during the time of operation. The ferry was 481 feet long and 72 feet. After the purchase, Chonghaejin Marine made extensive modifications by adding cabins to the third, fourth, and fifth decks to accommodate additional 117 passengers. The modifications led to increasing in weight by 239 tons, decreasing the KR's authorized cargo capacity by half to 987 tons, and increasing the KR's required 1,703 tons of water to serve as ballast to provide balance, which was four times more than the previous ballast requirement, 370 tons. From October 2012 to February 2013, the ferry was subject to a 5-month testing period by the KR. The KR then approved the modifications made and provided to Chonghaejin Marine the inspection certificate. Chonghaejin Marine named the ferry as Sewol-Ho. When the Sewol-Ho began operating on March 15, 2013, the ferry became the fourth ship operated by Chonghaejin Marine, and the second to be placed on its route from Incheon to Jeju Island. The Sewol-Ho known as Car Ferry, Motor Vessel (MV) or Roll-On/Roll-Off (RORO or ro-ro) Ship made three round trips per week departing Incheon en route to Jeju Island, each 250 mile-voyage taking 13.5 hours. Incheon is located in northwestern South Korea, bordering Seoul and Gyeonggi Province to the east, and Jeju Island is located in a southern part of South Korea, off the Korean Peninsula. The ferry had made the round trip a total of 241 times before the day of the accident.

On April 15, 2015, the Sewol-Ho was scheduled to leave Incheon seaport at 1830, South Korea Standard Time. The Sewol-Ho was, however, delayed for two and a half hours due to a thick fog but eventually departed around 2100. The Sewol-Ho was carrying 476 passengers who were about a half of the legal capacity of 921 while it was carrying only 761 tons of ballast water which was less than a half of the required 1,703 tons. 325 of the passengers were Danwon High School students on a field trip. It was found that the Sewol-Ho was carrying 124 cars, 56 trucks, and 1,157 tons of cargo, which was more than twice

the legal limit and they were improperly secured. The Sewol-Ho was commanded by a Captain, Lee, Joon-Seok, who was a substitute captain as a replacement for the regular Captain. The Captain had, however, over 40 years of experience at sea, and had commanded the ferry many times before. The Captain was working with 33 crewmembers for the journey, and 19 of them were part-time workers.

In the morning on April 16, 2014, the weather during the voyage of the Sewol-Ho, based on actual weather observations at the accident site, is summarized as follows: Winds were generally 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. The water temperatures in the area were measured to be around 54 °F or 12 °C which could cause hypothermia in 90 minutes. At 0730, the third mate, Park, Han-Gyeol, began her scheduled 4-hour shift on the bridge. The mate had one year of experience in steering ships and an additional five months of experience on the Sewol-Ho. The mate had no previous experience of steering the Sewol-Ho through the Maenggol Channel from Incheon to Jeju Island, while she had dozens of experiences from Jeju Island to Incheon. Helmsman, Cho, Joon-Ki, who had six months of experience on the Sewol-Ho was under the mate's command at the time. The Captain left the bridge at 0808 and did not return for the next 30 minutes. By law, the Captain was not required to stay on the bridge all the time. The Captain returned to the bridge at 0837 and left again at 0841. Around 0848, the Sewol-Ho traveling at about 18 knots entered the Maenggol Channel, which is notorious for its strong underwater currents and is 3.7 miles long and 2.8 miles wide, located 11 miles away from Jindo Island and a shortcut through the islets of the South coast of South Korea.

While the Sewol-Ho passed the Maenggol Channel, breakfast was being served in the cafeteria; some of the passengers were eating breakfast, but most of them were staying in their cabins. Right before 0848, Helmsman Cho was directing the ferry at 135 degrees. At 0848, the 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 fast undercurrents of the Maenggol Channel required that the turns must be smaller than five degrees. The mate had previously received instructions from the regular Captain that turns

should be made five degrees or less because the Sewol-Ho's restoring force was known to be very low. The helmsman heard the mate's orders and made the first turn of five degrees to starboard. Once the ferry was directing to 140 degrees, the helmsman, then, steered it to 145 degrees. At this moment, how the helmsman made the second turn is still in question. There are two possible scenarios: 1) The police-prosecution joint investigation team concluded that the helmsman had attempted the second turn to 145 degrees, but he turned the ferry to 155 degrees from 140 degrees when he was flustered and perceived the turn as being inadequate. 2) The helmsman claimed at the Gwangju District Court on October 11, 2014, that he turned the ferry to the other direction after hearing the mate's order for a restoration of balance, "turn in the opposite direction." Based on what the Captain testified at the Gwangju District Court (09/02/2014) that he later saw the helm indicator fixed at 155 degrees, the helmsman could have turned the ferry to 155 degrees. While he tried to turn the ferry to port to restore it on his own judgment, he heard the mate's order to turn it to the opposite direction and did so. As the result of either scenario, the second turn made a turn of 10 degrees in one second as a sharp turn. Consequently, the ferry lost balance and listed 20 degrees into the water on 0849, causing cargo to fall to one side of the ferry.

The overall effect of the turning was that the ferry turned about 45 degrees to starboard and then, rotated 22 degrees on the spot for about 20 seconds. The cargo containers falling to one side caused the ferry to lose the restoring force and allowed the ferry to take on water through the bow and stern doors. On 0850, the ferry was listing 30 degrees to port. Around this time, the Chief engineer, Park, Ki-Ho stopped the engines on his own judgment. The Captain who was in his cabin immediately went to the bridge and ordered the second mate, Kim, Young-Ho to turn on the anti-heeling pumps to return the ferry to its upright position, but the pumps were not working. The Captain ordered the Chief engineer to stop the engines, which were in dead slow ahead condition, and the Chief engineer stopped them. On 0852, the Chief engineer ordered, on his own judgment, evacuation of the engine room through a call to the assistant engineer.

After a short period, all of the ferry's mates and helmsmen arrived on the bridge. On 0854, the Captain ordered the Chief engineer to go the engine room but did not provide clear

action items, perhaps checking the generator to run the anti-heeling pumps. On the way down to the engine room, the Chief engineer met his engineers staying in the aisle of their cabins on the third deck and stayed there with them because the ferry's list prevented him from going to the engine room and the generator. From that time until rescued by the Patrol Vessel-123, they had worn their lifejackets and waited in their cabins as the Guest Services Desk had announced the passengers to put on lifejackets and stay put. They assumed that the bridge made the announcement based on what they had learned from their safety training. The crewmembers at the Guest Services Desk had the roles and responsibilities of guiding the evacuation of passengers.

At 0852, Choi, Duk-Ha, a Danwon high school student aboard the ferry made the first emergency call on 119, the Korea National Emergency Service Call Number, and reported that the Sewol-Ho was capsizing. The student's call was connected to the ROKCG (Republic of Korea Coast Guard) Group Mokpo at 0854.

At 0857, the Incident Command Room at the Group Mokpo ordered the ROKCG Patrol Vessel-123 100 tons to depart to the scene, which was the closest ROKCG Search-and-Rescue SAR unit to the ferry, and also ordered Helicopters B511, B512 and B513 to depart to the scene. While approaching the scene around 0858, the Patrol Vessel-123 made two calls to contact the Sewol-Ho on VHF FM channel 16 as requested by the Group Mokpo but was unsuccessful. Therefore, the Patrol Vessel-123 focused on a cooperation plan with nearby ships because they were told that there were many passengers on the ferry. This focus on a cooperation plan prevented the Patrol Vessel-123 from communicating with Helicopters and the Sewol-Ho. Moreover, the primary rescue operation of the Patrol Vessel-123 was to rescue people in the water, so the members focused on the routine rescue operation without having any further discussion on different scenarios.

At 0916, the Commander of Patrol Vessel-123 was appointed as the On-Scene-Commander (OSC) by the District West. At 0917, the Patrol Vessel-123 replied to the Group Mokpo to notify them that there were no responses from the ferry with respect to the calls. At 0925, the Group Mokpo notified on TRS that there were about 450 passengers on the ferry and it

was listing 50 degrees to port. After that time, the Patrol Vessel-123 knew the information on TRS but Helicopters did not know it due to not listening to TRS.

As the Sewol-Ho began capsizing, the ferry's PA system started announcing the passengers to stay put. A communications officer, Kang, Hae-Seong at the Guest Services Desk made the announcements based on his own judgment, without reviewing the Operation Management Regulations Document and without getting permission from the Captain or the Chief communications officer. At the court, he testified (07/23/2014) that he made the announcements because, he thought, passengers' moving might cause the list to be worse. Another crewmember at the Guest Services Desk, Park, Ji-Young called the bridge several times on her hand-held two-way radio transceiver to ask what to do and whether an evacuation had to be announced, but received no answers from the bridge. The announcements of "passengers to stay put" began broadcasting on 0852 and continued until water began flooding passenger compartments and cabins, about 0952. Other crewmembers at the Guest Services Desk corroborated with this order of instructing passengers to stay put. Later, the Captain also ordered passengers to stay put.

At 0855, the Sewol-Ho's the first mate, Kang, Won-Sik who was on the bridge made the first distress call to the Station Jeju-VTS (Vessel Traffic Service under KMOF) on VHF FM channel 12, after switching from VHF FM channel 67 which was set for ROKCG Station Jindo-VTS, reporting that the ferry was capsizing and in danger. He thought that the ferry was near Jeju Island at that time because he forgot the two and a half hours of departure delay. The ferry was, however, near Jindo Island. The Station Jeju-VTS told the first mate to order the passengers to put on personal floatation devices (PFDs) and more clothing. The Captain ordered the second mate, Kim, Young-Ho to announce that the passengers put on lifejackets and more clothing. At 0857, as requested, the second mate on the bridge tried to make the announcements to passengers, by pressing the side button of the hand-held microphone, but it was not working. He had to press two additional buttons, emergency and alarm ones to make the emergency announcements to all areas in the ferry. From that moment, all crewmembers including the Captain on the bridge assumed that all broadcasting systems on the bridge were out of order, and therefore, no one tried them

again, and all communication to crewmembers at the Guest Services Desk was made only with hand-held two-way radio transceivers. An emergency alarming sound system was on the bridge, by pressing the emergency alarm button which was located under the desk, and a telephone to announce emergency calls from the bridge to all areas in the ferry was there too, by pressing a number, 'zero.' There was another emergency alarm lever at the outside rail of the bridge. Neither had been used from the bridge for the announcements of the evacuation. At 0858, the Station Jeju-VTS called the ROKCG Group Jeju. At 0902, the ROKCG Group Jeju called the Group Mokpo and knew that the Patrol Vessel-123 was already dispatched. On 0906, the Station Jindo-VTS, which was the closest ROKCG VTS unit to the ferry, was notified about the capsizing of the ferry through the notification by the Group Mokpo. In the meantime, communications watchstanders at the Station Jindo-VTS, who were monitoring data from the ferry's Auto Identification System (AIS), did not know the abnormal turn of the Sewol-Ho until notified by the Group Mokpo.

At 0904, the communications officer at the Guest Services Desk made a distress call on 122, the Korea National Maritime Distress Service Call Number, and notified the Group Mokpo that the ferry was capsizing and the order of "the passengers to stay put in their cabins" was announced to passengers by the Guest Services Desk. The Group Mokpo allowed him to keep maintaining the announcement of the order but did not share with other ROKCG units about this authorization of "passengers stay put in the cabins."

At 0907, the first mate on the bridge of the ferry began communicating with the Station Jindo-VTS on VHF FM channel 67. For the next two minutes, the Station Jindo-VTS alerted two other ships that the Sewol-Ho was capsizing, with the DOOLA ACE confirming that it had visual contact with the Sewol-Ho. The first mate notified the Station Jindo-VTS that the ferry was capsizing and the broadcasting system on the bridge did not work, and requested the help of the ROK Coast Guard. At 0914, another Helmsman, Park, Kyung-Nam after the first mate left to call Chonghaejin Marine, notified the Jindo VTS that passengers could not move and the evacuation was impossible due to the ferry's list. Meanwhile, as stated, the roles of Helmsmen in the Operation Management Regulations Document and practiced at the drills, two Helmsmen, Cho, Joon-Ki and Oh, Yong-Seok went to starboard side in order

to drop liferafts, without receiving any orders from the Captain or the first mate, but the effort to reach the liferafts was unsuccessful due to the list of 40 degrees. On 0917, the first mate called the Incheon branch of Chonghaejin Marine to report the capsizing. The Incheon branch had five phone calls with the first mate over the next 35 minutes.

On 0921, an apprentice first mate, Shin, Jeong-Hoon on the bridge of the ferry switched VHF FM channel 16 to channel 67 on his own judgment and reported to the Station Jindo-VTS that the ferry has listed more than 50 degrees to port. At 0923, the Station Jindo-VTS notified the apprentice first mate that the Patrol Vessel-123 would arrive at the ferry in 15 minutes and ordered the bridge to announce to the passengers to put on personal flotation devices by using all possible broadcasting means. When the second mate notified the Station Jindo-VTS on VHF FM channel 67 that the broadcasting equipment was out of order, the Station Jindo-VTS told the second mate to order the passengers personally to put on PFDs and more clothing. The second mate did not, however, follow the order.

On 0925, when the Station Jindo-VTS was asked by Helmsman Park about the abandonment or evacuation, the Station Jindo-VTS responded for the Captain to decide as soon as possible whether to evacuate the ferry, stating that the Station Jindo-VTS did not have enough information to make the evacuation decision. When Helmsman Park asked about the rescue, the Station Jindo-VTS replied that the Patrol Vessel-123 was due to arrive in 10 minutes and an ROKCG Helicopter in a minute. The Captain then replied that there were too many passengers to be rescued by the Helicopter and the Vessel.

At 0927, the Captain ordered the second mate to announce to the passengers to evacuate. On the hand-held two-way radio transceiver, the second mate ordered the Guest Services Desk to announce the evacuation but did not check whether the crewmembers at the Guest Services Desk heard and announced the order. At that time, only Yang, Dae-Hong and Park, Ji-Young had their hand-held two-way radio transceivers. The second mate notified the Station Jindo-VTS on VHF FM channel 67 of the ordering of the evacuation. The announcements made in the ferry's PA system were, however, not broadcasted and heard on the bridge. Survivors testified at the court (07/29/2014) that the ferry's PA system

repeatedly ordered passengers not to move. Helmsman Park and the second mate also tried to contact the Patrol Vessel-123 on VHF FM channel 16 at 0926 and 0928 respectively, but they received no answer. At 0933, after confirming that nearby ships and fishing boats had volunteered to help with the rescue operations, the Station Jindo-VTS told nearby ships to drop lifeboats for the passengers. On 0937, the second mate notified the Station Jindo-VTS that the ferry was listing 60-70 degrees to port and the evacuation was ordered to passengers, telling them to move to the port side. This was the last communication between the Station Jindo-VTS and the ferry.

Having no communication with the Station Jindo-VTS, the Patrol Vessel-123 and the Group Mokpo and not listening to TRS in order to concentrate on flight control, Helicopter B511 of the Group Mokpo arrived on scene at 0927, without knowing how many people were on the ferry and how to save them. As performed routinely before, the Pilot, Yang, Hee-Cheol started sending two rescuers to the fifth deck of the ferry. Two rescuers lifted only several passengers staying on the fifth deck because they had no information about the "many passengers staying put in the cabins." Helicopter B513 of the ROKCG Group Jeju and Helicopter B511 of the Group Mokpo arrived on scene at 0932 and 0945 respectively, and both of them started rescuing people on the decks. Two helicopters' pilots were not aware of the information about "passengers staying put in the cabins" either, for the same reason as that of Helicopter B511.

On 0930, the Patrol Vessel-123 arrived on scene as the first rescue ship to the ferry and reported to ROKCG HQ about the status of the ferry, i.e. that no passengers were on the decks of the ferry or were in the water. The Patrol Vessel-123 was not aware of the communication made between the ferry and the Station Jindo-VTS because the two parties had communicated on VHF FM channel 67 while the Patrol Vessel-123 was communicating with others on VHF FM channel 16 and SSB. On 0938, the Patrol Commander dispatched a rubber boat to the ferry, and the boat rescued the ferry's engineers including the Chief engineer who stayed on the third deck of the ferry. After rescuing the crewmembers, a member of the Patrol Vessel-123, Lee, Hyung-Rae, went up the ferry to drop the liferafts and dropped two liferafts, one activated immediately and the other activated after a while.

After the drops, he just came back to the boat, without letting passengers know about the evacuation. At that time, Helmsman Park with the first mate's help tried to reach liferafts on the port side to drop them but was unsuccessful in doing so due to the list. As the Patrol Vessel-123 was alongside the bridge of the ferry around 0944, the first mate and Helmsman Park who were trying to drop liferafts slipped to the wing bridge due to the severe list. The Patrol Vessel-123, therefore, rescued two of them first and all crew who stayed on the bridge. At 0947, the ROKCG District West ordered the Patrol Vessel-123 to send the members to climb and enter the ferry. A member of the Patrol Vessel-123, Park, Sang-Wook went into the bridge, found no one was there and simply came back without doing anything. At 0956, the Commander of the Group Mokpo made his first order from the ROKCG Cutter-3009 for the Patrol Vessel-123 to announce "abandon the ferry" using its loudhailer and guide passengers to evacuate. However, the Patrol Vessel-123 did not follow the order.

At 0950, the third deck exit was submerged. At 0952, the fourth deck exit was submerged, and the inside of the ferry was dark due to a power outage. At 0953, the broadcasting system at the Guest Services Desk was submerged and was not working. The communications officer started shouting to passengers to evacuate, and then passengers started going to port and jumping into the water. The Chief communications officer, Yang, Dae-Hong, the communications officer, two crewmembers at the Guest Services Desk, Ahn, Hyeon-Young and Park, Ji-Young, the high school teachers and some adult passengers had helped students escape from the submerging cabins. At 1010, the list was about 77 degrees to port, and the fifth deck exit was submerged. At 1012, all port side exits of the ferry were submerged due to the list. At 1017, the list was about 107 degrees to port. About 150 to 160 passengers had jumped into the water in the last 20 minutes.

About 1118, the bow and stern of the ferry were submerged, leaving a section of the hull about 6 feet in high and 100 feet long showing above the water. The Sewol-Ho took two and a half hours to capsize completely.

Chapter 4: Korea Maritime Safety Tribunal (KMST) Root Cause Analysis

A special investigation team at the Korea Maritime Safety Tribunal (KMST) conducted an independent analysis of the Sewol-Ho accident using the KMST's Root Cause Analysis process. The following results were provided to establish a representation of outcomes achieved using the root cause analysis methodology (KMST, 2014).

After reviewing the details of the Sewol-Ho accident, the KMST team identified the following contributing factors and root causes and provided the following specific recommendations.

Contributing Factors to the capsizing of the ferry:

- There existed higher priority on cost, productivity, profit, and schedule at Chonghaejin Marine Company.
  - The company forced the crew of the ferry and the personnel of the loading and lashing service companies to make the overload and improperly secure the cargo containers and vehicles.
  - 4 lashing bands for a passenger vehicle, 10 for a truck and 8 to 10 lashing chains for a cargo container should be used.
- 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.
  - The map of loading and lashing cargo and vehicles was posted on the station wall, but no one reviewed and followed it.
  - They did not know proper methods for loading and lashing of cargo containers and vehicles.

- No one followed the new requirements of ballast water and cargo load after the ferry's modifications.
  - The crew of the ferry, operation officers at Korea Shipping Association (KSA), and the personnel of the loading and lashing companies did not pay attention to the requirements.
  - Only the load line, which was determined by ballast water and cargo, was inspected by operation officers at the KSA as the only safety requirement.

Contributing Factors to not rescuing all people from the distressed ferry:

- Neither safety training nor evacuation drills were provided to the crew of the ferry.
  - The budget for the safety training, according to a crew member at the company, was US $2, which was used to buy a piece of certificate paper.
- Personal floatation devices (PFDs) were stored at cabins, not at evacuation points and therefore, passengers had to go to their cabins and stay there.
- Liferafts did not work.
  - Liferafts were improperly certified by the company, without any physical inspection.
- Communications watchstanders at Station Jindo-VTS did not know about the sharp turn.
  - Communications watchstanders were busy in guiding other ships in the region.

Root Causes of the capsizing of the ferry:

- Unreasonably sharp turn to starboard caused the capsizing.
- The sharp turn, due to inappropriate steering by the helmsman, caused the cargo to slip to port and caused the ferry to list and become eventually unmanageable and unrecoverable.
- 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.
  - To satisfy the required ship stability, at least 1,703 tons of ballast water and at most 987 tons of freight should be required.
  - However, 761 tons of ballast water and 2,143 tons of cargo were carried.
  - After using gasoline and water, the ship stability at the accident moment was worse than that at the departure.
- The severe listing deteriorated the stability of cargo containers, which were improperly secured, and everything started to tip over.
  - Inadequately lashing the cargo containers caused all the cargo containers to displace.
- The ferry was capsized due to the unrecoverable list to port side.
  - The listing was aggravated as the water entered the decks.

Root Causes of not rescuing all people from the distressed ferry:

- The crew abandoned the sharply listing ferry without providing any safety means and ways to the passengers.
  - The crew did not make any rescue actions other than making distress calls to ROKCG and ordering passengers to put on personal floatation devices (PFDs).
  - The crew on the bridge and engine room of the ferry were rescued before passengers.
- The ROKCG Patrol Vessel-123 did not effectively rescue passengers who stayed on the ferry.
  - Partially they had not taken practical safety training and did not have effective Search and Rescue Operation systems.
  - They received the information about the passengers staying in their cabins too late.

Recommendations related to the capsizing of the ferry:

- 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.
- Allow the day cargo plan to be accessible to the crew of the ferry and the personnel of the loading and lashing service companies 24 hours in advance. The loading and lashing of cargo and vehicles has to be finished earlier than the departure and therefore, enough time be given to the crew of the ferry and the KSA operation officers for safety inspection.
- 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 OMR. It should be reviewed by the crew of the ferry and KSA operation officers.
- Reinforce the KR's safety inspection process including an update of the ship inspection checklist.
    - The KR has to check lashing devices, which should be in the KR ship inspection checklist.
- Apply loading and lashing Codes required for far sea ferries or carrier to the near sea ferries or carriers (completed).

Recommendations related to not rescuing all people from the distressed ferry:

- Provide the crew of the ferry the proper education and training for the rescue operations of the passengers.
    - The training should include the control of passengers safely and coordinating crewmembers to help the rescue procedures in an emergency situation.

- The training should include the same levels of special education and training required of officers for oil tankers or LNG carriers in operations.
- The training should include the same levels required of officers of far sea ships in special training for rescuing many passengers in emergency situations.

- Enforce license qualification of officers for ferries that carry many passengers.
  - Currently, three mates including a captain who has the second mate license are required for near sea ferries of 3,000 tons or bigger while four mates including a captain who has the first mate license are required for far sea ships of 1,600 tons or bigger.
- Store Personal floatation devices (PFDs) at evacuation points (completed).

Chapter 5: Board of Audit and Inspection of Korea (BAI) Root Cause Analysis

The Board of Audit and Inspection of Korea (BAI) conducted an independent analysis of the Sewol-Ho accident for 30 days, May 14 through June 20, 2014. The following results were provided to establish a representation of outcomes achieved using the root cause analysis methodology (BAI, 2014).

After reviewing the details of the Sewol-Ho accident, 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 to the capsizing of the ferry:

- There were inappropriate operations of the Sewol-Ho ferry by Chonghaejin Marine to maximize profits over passengers' safety.
  - Chonghaejin Marine made extensive modifications by adding cabins to the third, fourth, and fifth decks to accommodate additional 117 passengers. These modifications led to an increase in the passenger capacity from 804 to 921 and an increase in weight by 239 tons. The KR, therefore, decreased the authorized cargo capacity by half to 987 tons and increased the ballast water four times to 1,703 tons to provide adequate restoring force. Chonghaejin Marine, however, carried only 761 tons of ballast water and 2,143 tons of cargo and others.
  - The KR certificated the ferry's operation with fictitious documents and data provided by Chonghaejin Marine and the contracted companies. The calculation of the ferry' stability was done with an adjusted cargo container's unit weight from 5.65 tons to 3 tons.
  - The KR approved the modifications without reviewing the plan drawings for lashing vehicles. It was found from the investigation that 58 out of a total 66 vehicles could not be lashed and secured properly.

- The KSA poorly inspected the overloading and improper lashing conditions before the ferry's departure. The operation officer did not count the number of passengers, vehicles and cargo containers nor inspect whether vehicles and cargo containers were loaded and secured as shown in the map of loading and lashing cargo containers and vehicles, which was on the station wall on the ferry.
  - It was beyond the officer's capacity to determine whether the ferry was carrying too much cargo because what the officer did was to check whether the load line was submerged. The load line, which was a marking line on the outside of the ferry, indicated whether the ferry was overloaded. However, checking the load line did not show whether the ferry met the requirements of cargo and ballast water that the KR's inspection certificate mandated the Sewol-Ho Operations to follow.
- The operation officer at the KSA approved the departure after checking only that the load line was satisfied, and after the ferry's departure, filed the paperwork with the information on passengers, cargo and vehicles provided by the crew of the ferry, which were all fictitious.
- The Sewol-Ho had been routinely overloaded because the crew did not share the actual load data with the KSA officers.
- In September 1999 and July 2007, Korean Maritime Law added an exemption of the necessary safety training for crew who have 1 year or longer of crew experience while previously crew should take the training every five years, resulting in the crew of the Sewol-Ho being exempted from training for a minimum of 7 to a maximum of 19 years.
  - For the last five years, only 33 out of 489 captains and mates for near-sea ferries in Korea took the training again.
- Chonghaejin Marine created the Sewol-Ho's Operation Management Regulations Document by describing all requirements required by Korean Maritime Law except for the two important factors of "ballast water" and "total load" (Chonghaejin Marine, 2014).

- No penalty was applied to the company by law when the company and the crew were found that they violated the requirements in the Operation Management Regulations Document (in 1983, Korean Maritime Law was changed to eliminate the penalty on violating the Operation Management Regulations Document).

Contributing Factors to not rescuing all people from the distressed ferry:

- Communications watchstanders at the Station Jindo-VTS did not know about the sharp turn for the first 20 minutes.
- Only one watchstander was on duty while there should be two. Later they were notified about the accident by the ROKCG Group Mokpo.
- The ROKCG District West did not notify the ROKCG SAR units (Group Mokpo, Patrol Vessel-123 and Helicopters B511, B512 and B513) that "Passengers were staying in their cabins." Helicopters B511, B512 and B513, therefore, only rescued people who were on the decks of the ferry.
- The Group Mokpo's commander, who was on ROKCG Cutter-3009 3,000 tons to carry out another mission on the previous day, did not go to the scene when the ROKCG Helicopter B512 was dispatched from the Cutter, but instead, stayed on board and issued orders from the Cutter.
- When the ROKCG District West was asked about whether an "evacuation" decision should be made, i.e., ordering passengers to evacuate the ferry or stay on the ferry and wait for the ROKCG units' rescue operations, the District West replied to the Station Jindo-VTS "the ferry captain has to determine the order based on the situation."
- The ROKCG HQ ordered the Group Mokpo to contact the Sewol-Ho directly, but the Group Mokpo did not follow that order.
- The District West did not order the Patrol Vessel-123 to contact the Sewol-Ho when the District West found the Patrol Vessel-123 had not made any contact with the Sewol-Ho, and the District West did not directly contact the Sewol-Ho either.

- The District West and Group Mokpo did not order the Patrol Vessel-123 and Helicopter 511 to report the current status and to board the ferry when they arrived on scene, and therefore, the Patrol Vessel-123 and Helicopter 511 did not make any report to the District West and Group Mokpo.
- The Patrol Vessel-123 was appointed as the On-Scene-Commander (OSC) but did not communicate with the ferry while it was approaching the ferry. They called the ferry three times, but the ferry did not answer the calls. Later, they did not answer two calls made by the ferry.
- The Patrol Vessel-123 rescued the crew including the Captain before passengers, without checking their identities and therefore, lost means to communicate with the crew at the Customer Services Desk, who were helping the passengers (the crew had cell phones and two-way radios that could talk to the crewmember at the Guest Services Desk).
- The District West and its five groups had planned and carried out 61% of the annual training standards.
    - The ROKCG HQ did not participate in critical training such as SAR operations to a passenger ferry's capsizing situation but had to do so because the HQ was the top of the command lines.
    - 7 of 44 SAR personnel at the District West and its five Groups were disqualified by having less than three years of SAR experiences (the qualification is three years or more).
    - The regular training had been exercised informally.

Root Causes of the capsizing of the ferry:

- Unreasonably sharp turn to starboard caused the ferry's capsizing.
- The sharp turn to starboard due to inappropriate steering made by a helmsman caused the severe degree of listing.
- The sharp turn due to inappropriate steering made by the helmsman caused the cargo to slip to port and caused the ferry to list.

- The severe listing deteriorated the stability of cargo containers, which were inappropriately secured, and everything started to tip over.

Root Causes of not rescuing all people from the distressed ferry:

- The communications officer at the Station Jindo-VTS did not notify the SAR members at ROKCG units (Group Mokpo, Patrol Vessel-123 and Helicopters B511, B512 and B513) of the command to the passengers to stay put in their cabins.
- When the commander of the Patrol Vessel-123 found the information that passengers stayed inside the ferry, he did not try to announce an "evacuation," report the status to the ROKCG District West and Group Mokpo, or order the members and Helicopters 511 and 512 to enter the ferry.
- The Patrol Vessel-123 did not rescue effectively the passengers who stayed on the ferry.

Recommendations related to the capsizing of the ferry:

- Reinforce the required safety training for crew of ferries after revisiting (or reviewing) the mitigated Korean Maritime Law.
    - For the last five years, only 33 out of 489 captains and mates for near-sea ferries in Korea took the training again.

Recommendations related to not rescuing all people from the distressed ferry:

- N/A due to blaming people for the accident

Chapter 6: CAST ANALYSIS

Most professionals do not come to work to do a bad job at all. Their actions make sense given their pressures and goals at the time. Their actions are produced by and within a complex sociotechnological system and are part and parcel of a normal workday. Professionals come to work to do a job, to do a good job. They do not have the motive to kill or cause damage (Dekker, 2007, pp. 116-117). Accident investigation should, therefore, 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, pp.65). It is always possible to identify a better decision in retrospect to prevent the bad outcome from occurring, which is called hindsight bias. The two Sewol-Ho accident investigation reports from the KMST and especially, the BAI concluded with the use of the words "should have" and "could have," which are typical results of hindsight bias, oversimplifying causality, overestimating people's ability, overrating the role of rule "violations," misjudging the prominence, and matching outcome with the actions. It may have been, however, difficult or impossible to identify if the decision was flawed at the time it had to be made. To overcome hindsight bias in the investigation, it is useful ***to examine exactly the contextual factors and mental model flaws*** people had at the time of each decision in the sequence of events.

The investigation, therefore, should focus on understanding why a person or persons did the wrong thing in that particular situation. In particular, what were the contextual factors and flaws in the safety control structure which influenced the human behavior? Often, a human controller had an inaccurate mental model of the state of the process and, given that mental model, did what appeared to be the right thing at the situation but turned out to be bad or wrong on the actual state. To prevent the errors from occurring in future, the investigation report should provide the redesign of ***the system or safety control structure***, after understanding the contextual factors and inaccurate mental models in the safety

control structure, so that the human controller has better information on which to make decisions (Leveson, 2011, pp. 372-373).

To investigate and then, analyze the Sewol-Ho accident, CAST analysis is applied, which is described in Chapter 2. 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.

Details, when necessary, were inferred based on the reports of the BAI (BAI, 2014) and the KMST (KMST, 2014) and documents of trials (Oh, 2015).

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

The Sewol-Ho Operations controls the operation and the passenger safety, and when the ferry is in distress, the Sewol-Ho Operations and the Republic of Korea Coast Guard shall provide the rescue operations for rescuing people in the distressed ferry.

The system hazards related to the Sewol-Ho accident are the following:

- Hazard 1: Capsizing of the ferry
- Hazard 2: Not rescuing all people in the distressed ferry

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

Accordingly, the system-level constraints to the system hazards related to the Sewol-Ho accident are the following:

- Constraint 1: The ferry must not capsize.
- Constraint 2: All people must be rescued when the ferry is in distress.

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. 3, the system safety control structure is highly simplified and idealized in order to capture a generalized Maritime Transportation System.

As indicated in the high level safety control structure shown in Fig. 4 and 5, the CAST analysis has been carried out separately with each system boundary defined for the two processes to include the following:

- The Sewol-Ho Operations, Chonghaejin Marine Company, Korea Shipping Association, and Loading and Lashing Service Companies acting upon the ferry as the controlled process as shown in Fig. 4 (pink area).
- The Sewol-Ho Operations, Chonghaejin Marine Company, and ROK Coast Guard acting upon the passengers as the controlled process as shown in Fig. 5 (green area).

The high level Sewol-Ho Operations, ROK Coast Guard, Korea Shipping Association, and Chonghaejin Marine Company include a number of lower level controllers as shown in the subsequent control diagrams of the two processes, "Safe operations of the ferry" and "Rescue operations of people on the distressed ferry."

Each component in the high level control diagram shown in Fig. 3 has the responsibilities in enforcing the necessary system level safety constraints, "The ferry must not capsize" and "All people must be rescued when the ferry is in distress." 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.

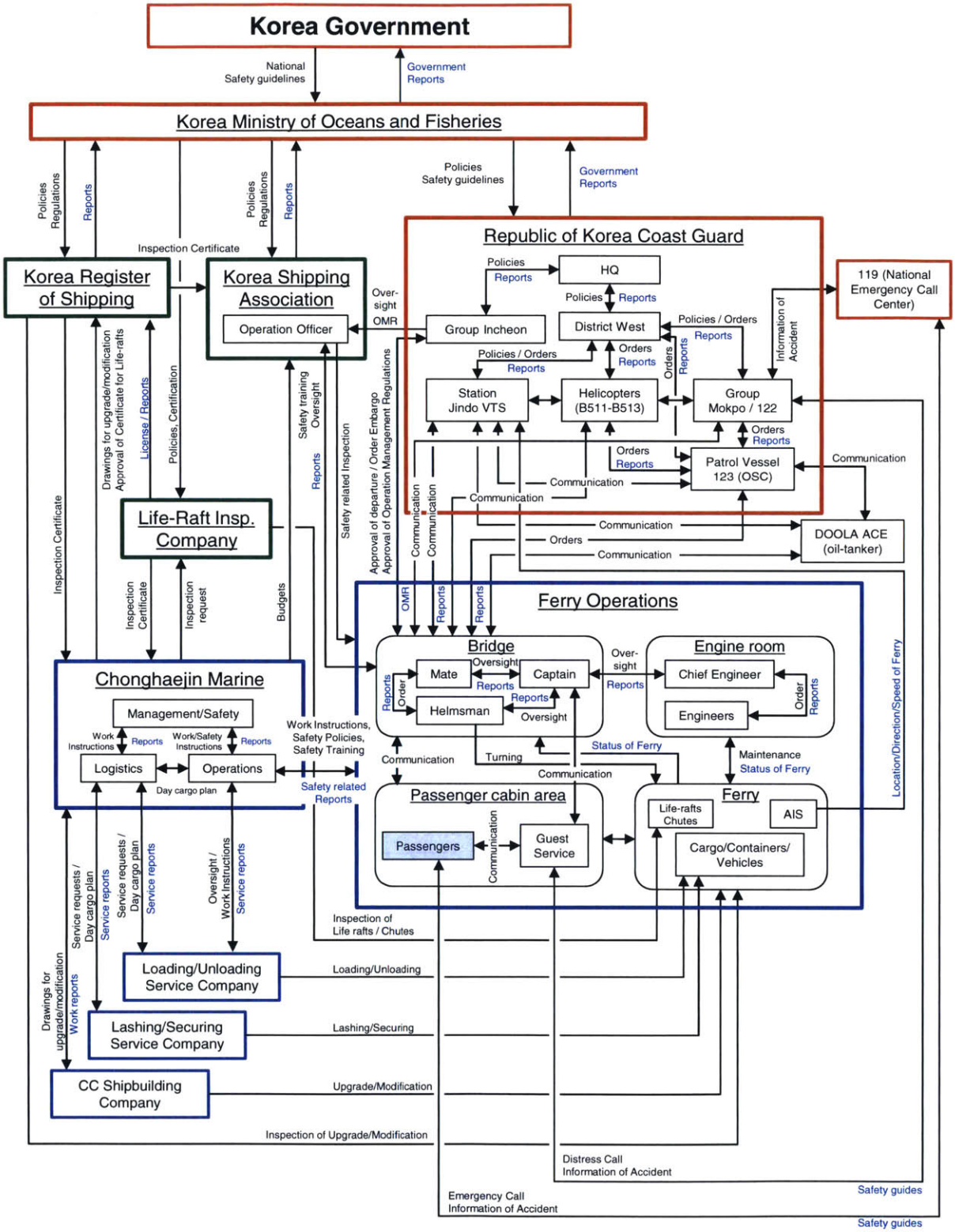


Figure 3 System Safety Control Structure of generalized Maritime Transportation System

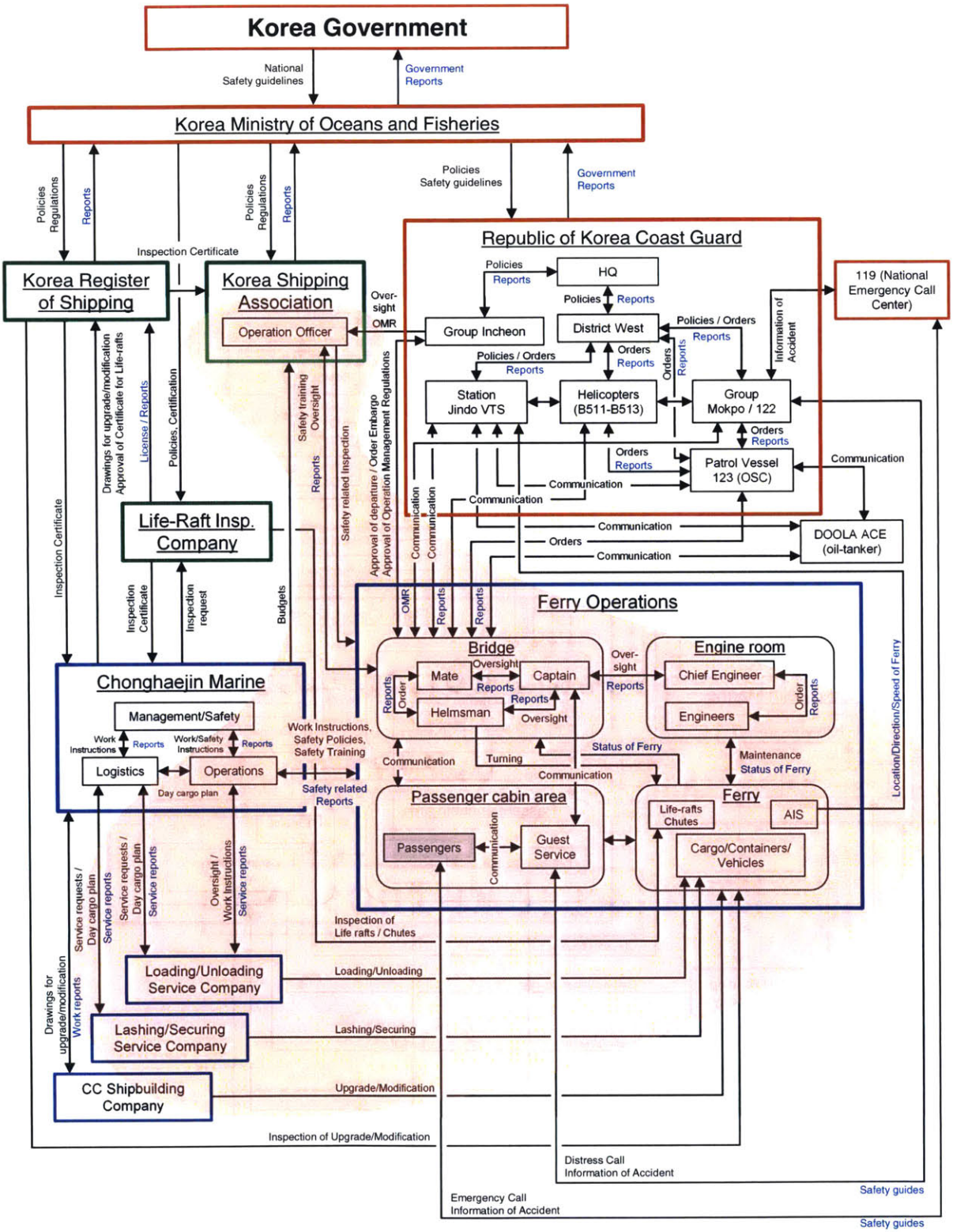


Figure 4 System Boundary for Process 1 of "Safe operations of the ferry" (pink)

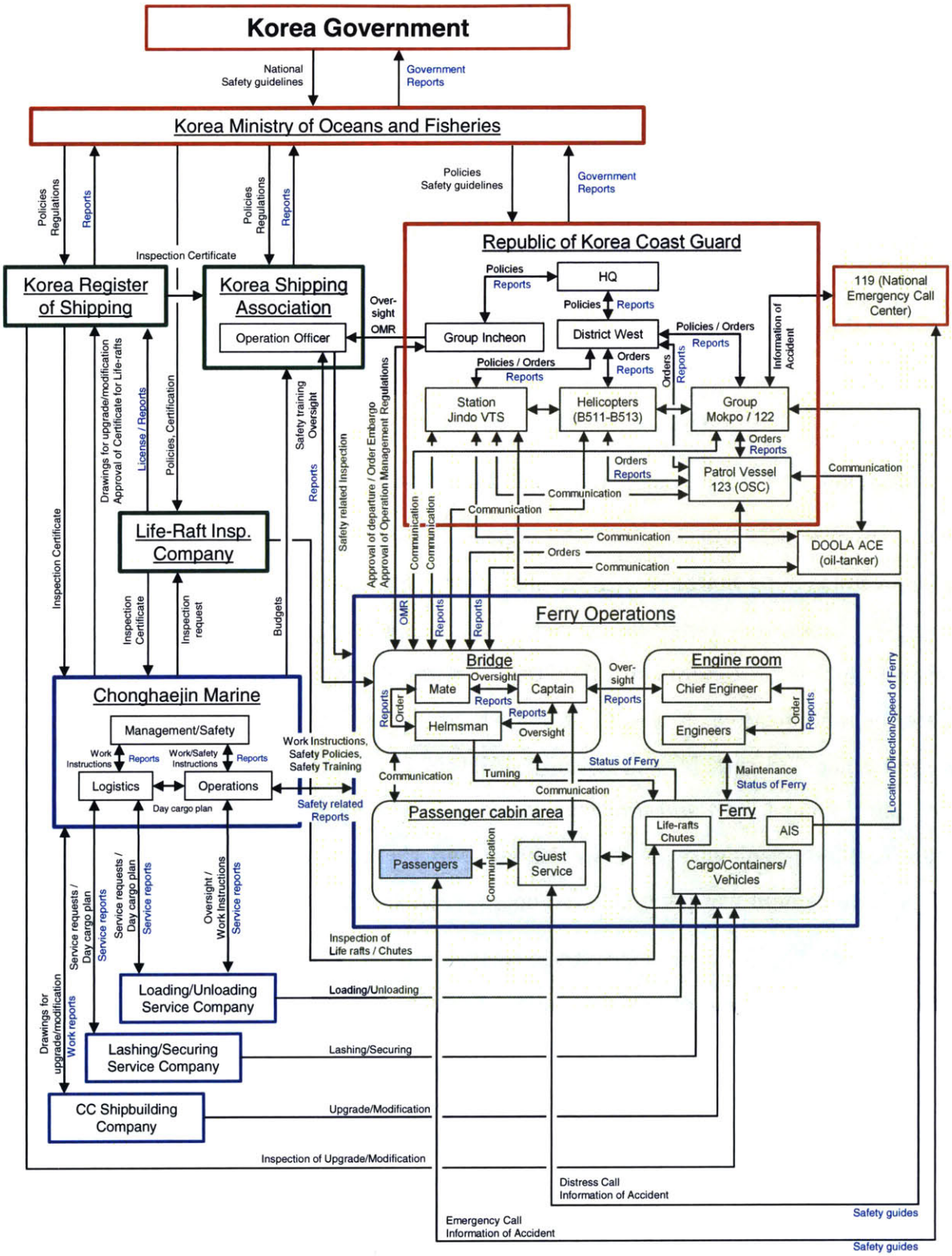


Figure 5 System Boundary for Process 2 of "Rescue operations of people on the distressed ferry" (blue)

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.

- **Process 1: Safe operations of the ferry**

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 operation officer at the KSA approved the departure, without the inspection of cargo and the lashing but only with the inspection of the load line, the Sewol-Ho with 476 passengers on board departed Incheon en route to Jeju Island. 325 of the passengers were Danwon High School students on a field trip. It was carrying only 761 tons of ballast water (before the modifications, it was 370 tons) which are less than a half of the required 1,703 tons, and it had 124 cars, 56 trucks, and 1,157 tons of cargo which were loaded, two times more than the legal limit and improperly secured. The Sewol-Ho was commanded by the Captain Lee, Joon-Seok with 33 crewmembers and 19 of them were part-time workers. No safety announcement was given to passengers when or after it departed.

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 filled and filed the paperwork with the incorrect information.

April 16, 2014

0700: The Sewol-Ho was passing near Jindo-Island located on the southern coast of South Korea. Winds were generally 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. The water temperatures in the area were measured to be around 54° F or 12° C.

0730: The third mate, Park, Han-Gyeol and Helmsman, Cho, Joon-Ki began her scheduled 4-hour shift on the bridge.

0840: The Sewol-Ho traveling at about 18 knots entered the Maenggol Channel, which is notorious for its strong underwater currents and is 3.7 miles long and 2.8 miles wide, 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. At this moment, how the helmsman made the second turn is still in question. There are two possible scenarios: 1) The police-prosecution joint investigation team concluded that the helmsman had attempted the second turn to 145 degrees, but he turned the ferry to 155 degrees from 140 degrees when he was flustered and perceived the turn as being inadequate. 2) The helmsman stated at the Gwangju District Court on October 11, 2014, that he turned the ferry to the other direction after hearing the mate's order for a restoration of balance, "turn in the opposite direction." Reviewing this situation carefully, it can be concluded that he turned to starboard at the end when heard "the opposite direction" while he was turning to port to manage the sharp turn. In either case, the second turn of 10 degrees in one second was a sharp turn.

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. The cargo falling to one side caused the ferry to lose its restoring force and allowed 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, Ki-Ho stopped the engines. The Captain who was in his cabin immediately went to the bridge and 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.

0934: The ferry was listing 53 degrees to port.

0944: The ferry was listing 57 degrees to port.

0950: The third deck exit was submerged.

0954: The ferry was listing 64 degrees to port. The fourth deck exit was submerged.

1007: The ferry was listing 69 degrees to port.

1010: The ferry was listing about 77 degrees to port, and the fifth deck exit was submerged.

1012: All port side exits of the ferry were submerged due to the list.

1017: The ferry was listing about 108 degrees to port.

1031: The bow of the ferry was submerged, leaving a section of the hull about 6 feet in high and 100 feet long showing above the water.

1257: The Sewol-Ho sank completely.

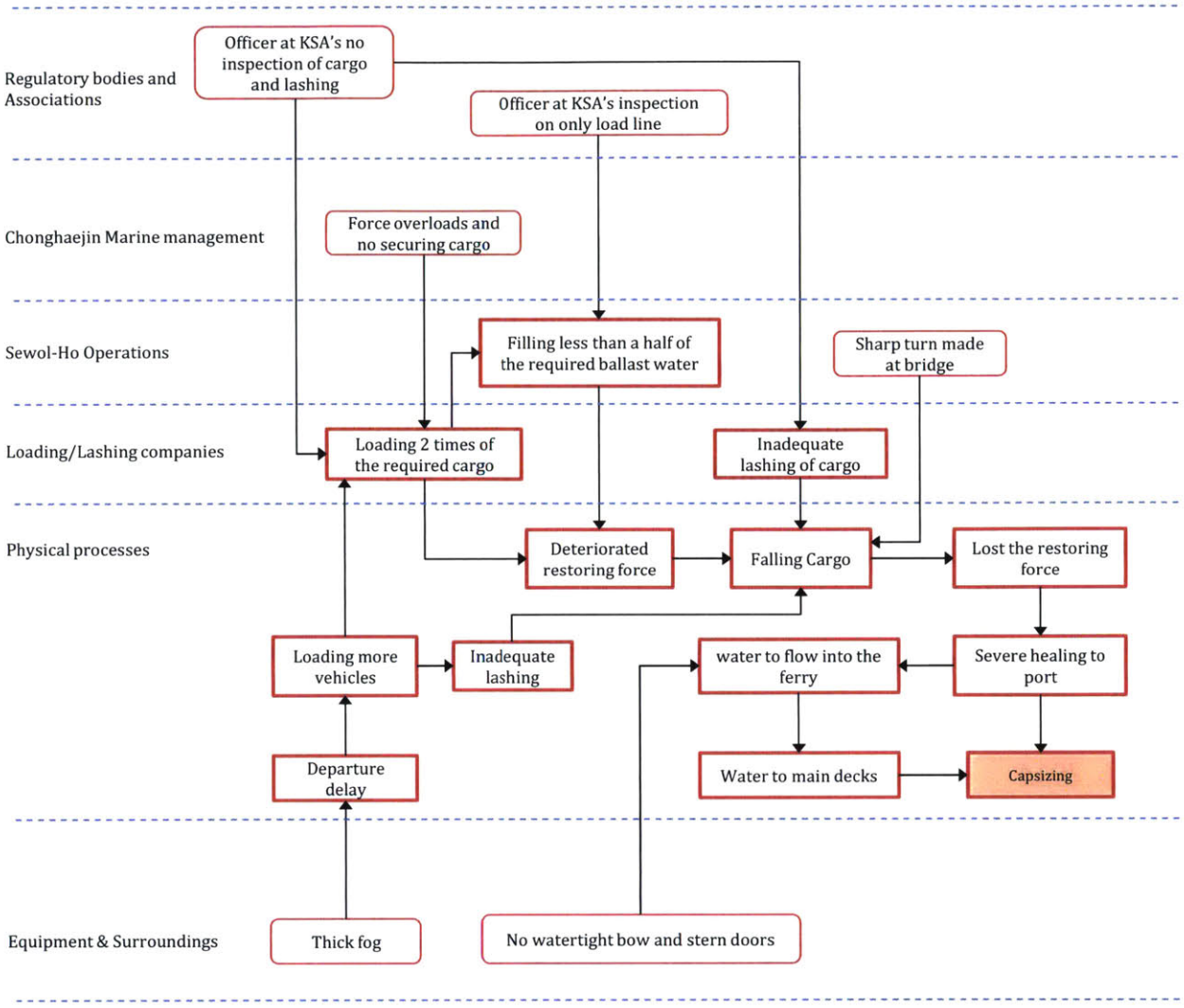


Figure 6 Graphical Summary of Process 1: Safe operations of the ferry

Figure 6 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
- Rectangular orange box: End event

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

There are several parties involved in this process, and therefore, applying different font styles to the chronology as in the following is useful to understand who made and involved the event.

- ✓ Underlined: Events involving the crew and passengers in the Sewol-Ho
- ✓ *Italic*: Events involving ROKCG Search and Rescue units on scene (ROKCG Patrol Vessel-123, DOOLA ACE, ROKCG Helicopters)
- ✓ **Bold**: Events involving all ROKCG units other than ROKCG Search and Rescue units on scene (ROKCG VTS, Group Mokpo, District West, HQ)

For examples, the font style involving communication between VTS and the Sewol-Ho are bold and underlined (**1130**), the one for an event involving the crew on the ferry are underlined (1130), and the one involving communication between Patrol Vessel-123 and ROKCG Group Mokpo are bold and italic font (***1130***).

April 16, 2014

0848: Choi, Duk-Ha, a Danwon high school student aboard the ferry made the first emergency call on 119, the Korea National Emergency Service Call Number, and ***reported that the Sewol-Ho was capsizing***. Later, several passengers called on 119, reporting that the Sewol-Ho was capsizing.

0850: The Chief engineer, Park, Ki-Ho on the bridge of the ferry stopped the engines on his own judgment. Later, the Captain ordered the Chief engineer to stop the engines which were in "dead slow ahead" condition, and the Chief engineer stopped them.

0850: Communications watchstanders at the ROKCG Station Jindo-VTS (Vessel Traffic Service), who were monitoring data sending from the ferry's AIS (Auto Identification System), did not detect the abnormal turn of the Sewol-Ho.

0850: A crewmember at the Guest Services Desk of the ferry, Park, Ji-Young had called the bridge more than ten times for several minutes on her hand-held two-way radio

transceiver about what to do and whether the evacuation had to be announced, but was unsuccessful in contacting the bridge.

0852: The Chief engineer ordered, on his own judgment, evacuation of the engine room through a call to the third engineer.

0852: Immediately, the second mate, Kim, Young-Ho pressed the button to turn on the anti-heeling pumps to return the ferry to its upright position, but the pumps were not working. Later, the Captain, who was in his cabin, rushed to the bridge and ordered the bridge to turn on the anti-heeling pumps. Helmsman, Park, Kyung-Nam pressed the button again to turn on the anti-heeling pumps, but the pumps were not working.

0853: A communications officer, Kang, Hae-Seong at the Guest Services Desk of the ferry made ***the announcement of the order for "passengers to stay put"*** on his own judgment, without reviewing the Operation Management Regulations Document or having permission from the Captain or the Chief communications officer. Later the Captain ordered the Guest Services Desk, using the hand-held two-way radio transceivers, to keep announcing the order of "passengers to stay put." The announcements were continued until water began flooding passenger compartments and cabins, about 0952.

0854: Passengers came back to their cabins when they heard the order announced in the ferry's PA system, that passengers should stay put in their cabins. Most passengers started sending text messages using their cell phones to their parents and friends about the ferry's capsizing. They sent and received text messages until the ferry sank. Teachers had stayed together with students in their cabins, so they could help the students to obey the order of "passengers to stay put."

0854: Choi, Duk-Ha was connected to the Group Mokpo for 2 minutes. The Group Mokpo noticed that there were many people who had stayed inside the ferry.

0854: The ferry captain ordered the Chief engineer to go the engine room but did not provide clear action items, perhaps checking the generator to run the anti-heeling pumps. On the way down to the engine room, the Chief engineer met his engineers staying in the

aisle of their cabins on the third deck and stayed there with them because the list of the ferry prevented him from going to the engine room and the generator.

0855: The Sewol-Ho's first mate, Kang, Won-Sik came to the bridge and made the first distress call to Station Jeju-VTS (Vessel Traffic Service, under KMOF directly) on VHF FM channel 12 on his own judgment, after switching from the VHF FM channel 67 which was set for communication with the ROKCG Station Jindo-VTS, reporting that the ferry was capsizing and in danger.

0855: All of the ferry's mates and helmsmen were on the bridge.

0855: The second mate, Kim, Young-Ho received several calls from the Guest Services Desk on his hand-held two-way radio transceiver asking what to do and whether an evacuation had to be announced, but he did not answer the Guest Services Desk.

0857: The Station Jeju-VTS asked the Sewol-Ho to switch to VHF FM channel 21 from VHF FM channel 12 to prevent communication interferences with other ships. The Station Jeju-VTS also told the first mate to order the passengers to put on personal floatation devices (PFDs) and more clothing.

0857: The Incident Command Center at the Group Mokpo opened a group chat room on an online messenger program for communication about the rescue operations and invited all related ROKCG units to the chat room except the Station Jindo-VTS.

0858: The Captain ordered the second mate to announce that passengers put on lifejackets and more clothing. The second mate tried to announce the order to passengers, mistakenly pressing only the side button of the hand-held microphone, but found that it was not working. The second mate had to press two additional buttons, emergency and alarm ones to make emergency announcements to all areas of the ferry. From that moment, ***all crewmembers including the Captain on the bridge assumed that all broadcasting systems on the bridge were out of order***, and therefore, no one tried them again. Additionally, an emergency alarming sound system was on the bridge, which required pressing the emergency alarm button that was located under the desk, and a telephone line to announce the emergency calls from the bridge to all areas in the ferry by pressing "zero"

was there too. There was another emergency alarm lever at the outside rail of the bridge. Nobody on the bridge had tried these additional ways of making the announcements. All communication with the crewmembers at the Guest Services Desk was made only with hand-held two-way radio transceivers. Using a hand-held two-way radio transceiver, the second mate ordered the Chief communications officer, Yang, Dae-Hong at the Guest Services Desk to announce "passengers stay put."

0858: The Incident Command Center at the Group Mokpo ordered the Patrol Vessel-123 100 tons to depart to the scene, which was the closest ROKCG Search-and-Rescue (SAR) unit to the ferry, and also ordered Helicopters B511, B512 and B513 to rescue the people in the distressed ferry. At that time, the Station Jeju-VTS called the ROKCG Group Jeju about the ferry.

0900: The Patrol Vessel-123 was approaching the scene, with information that the ferry was capsizing and many passengers were on the ferry.

0902: The ROKCG Group Jeju called the Group Mokpo and noticed that the Patrol Vessel-123 was already dispatched.

0903: The Incident Command Center at the Group Mokpo ordered on TRS (Trunked Radio System) all ROKCG Search-and-Rescue units to go to the scene. The Station Jindo-VTS did not, however, listen to TRS.

0903: While approaching the scene, the Patrol Vessel-123 made two calls to contact the Sewol-Ho on VHF FM channel 16 as requested by the Group Mokpo but was unsuccessful in communicating with the Sewol-Ho.

0904: The communications officer at the Guest Services Desk of the Sewol-Ho made a distress call on 122, the Korea National Maritime Distress Service Call Number, and notified the Group Mokpo that ***the ferry was capsizing and the order for "passengers to stay put in their cabins" was announced to passengers by the Guest Services Desk.*** The Group Mokpo authorized him to keep maintaining the announcement of the order, but ***did not share with other ROKCG units about this authorization of the announcement of "passengers to stay put in the cabins."***

0905: Due to the failure in communication with the Sewol-Ho, the Patrol Vessel-123 focused particular attention on a cooperation plan with nearby ships because they were told that there were many passengers on the ferry. This attention to a cooperation plan prevented the Patrol Vessel-123 from communicating with the helicopters and the Sewol-Ho. Moreover, the primary function of the Patrol Vessel-123 was to rescue people in the water, and therefore, the members assumed that to rescue people in water was the pre-defined role.

0905: The second mate confirmed, from the Chief communications officer on his hand-held two-way radio transceiver, that the announcement made from the bridge at 0858 was not broadcasted. The second mate ordered the Chief communications officer on his hand-held two-way radio transceiver that the passengers put on lifejackets.

0906: The communications officer at the Guest Services Desk announced the passengers to put on lifejackets. Most passengers, however, already wore their lifejackets by 0903.

0906: The Group Mokpo notified the Station Jindo-VTS, which was the closest ROKCG VTS unit, about "the capsizing ferry." Communications watchstanders at the Station Jindo-VTS, who were monitoring data from the ferry's Auto Identification System (AIS), did not know about the abnormal turn of the Sewol-Ho until notified by the Group Mokpo.

0906: The Station Jindo-VTS immediately called the Sewol-Ho on VHF FM channel 67 but did not receive any answer from the ferry, and instead, called and requested DOOLA ACE which was an oil tanker and whose captain was Moon, Ye-Sik, to rescue people evacuated from the ferry.

0907: The first mate on the bridge of the ferry began communicating with the Station Jindo-VTS on VHF FM channel 67. The first mate notified the Station Jindo-VTS that the ferry was capsizing and the broadcasting system on the bridge did not work, and requested the help of the Coast Guard.

0909: The Station Jindo-VTS notified two other ships, DOOLA ACE and Ying Xiang that the Sewol-Ho was capsizing, with the DOOLA ACE confirming that it had visual contact with the Sewol-Ho from 2.1 miles away.

0910: The first mate on the bridge notified the Station Jindo-VTS on VHF FM channel 67 that passengers could not move due to the list. And he requested the Station Jindo-VTS to provide a decision on when the evacuation should be ordered.

0911: The DOOLA ACE reported to the Station Jindo-VTS the wrong information on VHF FM channel 67 that the passengers had evacuated from the ferry by riding the liferafts.

0912: After receiving the report from the DOOLA ACE, the Station Jindo-VTS asked the Sewol-Ho whether passengers already were on the liferafts, but received a message from the ferry that no one was in liferafts yet.

0914: Helmsman, Park, Kyung-Nam after the first mate left to call Chonghaejin Marine, notified the Jindo VTS on VHF FM channel 67 that the total number of passengers was about 450 on the ferry, passengers could not move and that evacuation was impossible due to the ferry's list.

0914: The Station Jindo-VTS informed the DOOLA ACE on VHF FM channel 67 that there were about 450 passengers on the ferry, but did not notify the Patrol Vessel-123 and Helicopters B511, B512 and B513 that there were about 450 passengers on the ferry.

0915: Two Helmsmen, Cho, Joon-Ki and Oh, Yong-Seok went to the starboard side in order to drop liferafts, which was their role in the Operation Management Regulations Document, without receiving the order from the Captain or the first mate, but failed to reach the liferafts due to the list of 40 degrees.

0916: The ROKCG District West appointed the Commander of Patrol Vessel-123 as the On-Scene-Commander (OSC).

0916: The second mate after Helmsman Park, communicated with the Station Jindo-VTS on VHF FM channel 67 and notified that no information about passengers was available because the announcement made from the Guest Services Desk was not broadcasting on the bridge, passengers and crew could not move due to the list, and all crewmembers were staying on the bridge. He also notified that no information about how much the ferry was submerged was available.

0917: The first mate called the Incheon branch of Chonghaejin Marine to report the capsizing. The Incheon branch had five phone calls with the first mate over the next 35 minutes.

0918: The Station Jindo-VTS notified the DOOLA ACE on VHF FM channel 67 that the passengers and crew could not move due to the list and requested the DOOLA ACE to stay near the ferry and rescue people evacuated from the ferry.

0921: The apprentice first mate, Shin, Jeong-Hoon on the bridge of the ferry switched VHF FM channel 16 to channel 67 on his own judgment and reported to the Station Jindo-VTS that the ferry listed more than 50 degrees to port.

0923: The Station Jindo-VTS notified the apprentice first mate that the Patrol Vessel-123 would arrive at the ferry in 15 minutes, and ordered the bridge to announce to the passengers, using all possible means of communication, to put on personal flotation devices.

0924: When the second mate replied on VHF FM channel 67 that the broadcasting equipment was out of order, the Station Jindo-VTS told the second mate to order the passengers to put on lifejackets and more clothing, using all means of communication. The second mate did not, however, follow the order.

0925: The Group Mokpo notified on TRS that about 450 passengers were on the ferry and it was listing 50 degrees to port. The Patrol Vessel-123 detected the information provided through TRS but the helicopters did not.

0925: Helmsman Park asked the Station Jindo-VTS on VHF FM channel 67 about whether all could be **rescued if an abandonment or evacuation was ordered now**.

0925: The Station Jindo-VTS asked the ROKCG District West, the higher level at ROKCG structure, about whether to order evacuation or not, but received no decision.

0926: The Station Jindo-VTS answered Helmsman Park that the Captain had to decide as quickly as possible if an abandonment was necessary, stating that the Station Jindo-VTS did not have enough information to make the evacuation decision. When Helmsman Park asked about the rescue, the Station Jindo-VTS replied that the Patrol Vessel-123 would

arrive in 10 minutes and an ROKCG Helicopter in a minute. The Captain then replied that there were too many passengers for the Helicopter.

0926: As the Captain of DOOLA ACE listened on VHF FM channel 67 to the conversation about the evacuation decision between the Station Jindo-VTS and the Sewol-Ho, he shouted "abandon the ferry" on VHF FM channel 67. Helmsman Park kept, however, asking the Station Jindo-VTS if a rescue was possible.

0926: Helmsman Park on the bridge tried to contact the Patrol Vessel-123 on VHF FM channel 16 but received no answers.

0927: Helicopter B511 of the Group Mokpo arrived on scene without knowing how many people were on the ferry and how to rescue them. It departed from Mokpo at 0910. The two rescuers saved several passengers who stayed on the decks because they had no information about the order for "passengers to stay put in the cabins."

0927: The Captain on the bridge ordered the second mate to announce to the passengers to evacuate from the ferry. On the hand-held two-way radio transceiver, the second mate ordered the Guest Services Desk to announce the evacuation but did not check whether crewmembers at the Guest Services Desk heard and announced the order. The second mate notified the Station Jindo-VTS on VHF FM channel 67 that the order of the evacuation was announced. The announcements made in the ferry's PA system were, however, not broadcasted and heard on the bridge due to the improper setting. And survivors testified at the court (07/29/2014) that the ferry's PA system repeatedly announced passengers not to move.

0928: The second mate on the bridge tried to contact the Patrol Vessel-123 on VHF FM channel 16 but received no answers.

0930: The Patrol Vessel-123 arrived on scene as the first SAR ship. The Patrol Vessel-123 was not, however, aware of the conversations made between the ferry and the Station Jindo-VTS because the two parties had communicated on VHF FM channel 67 while the Patrol Vessel-123 was communicating with other units on VHF FM channel 16, SSB and TRS.

0932: Helicopter B513 of the ROKCG Group Jeju arrived on scene without knowing how many people were on the ferry and how to save them. It was dispatched when patrolling the nearby sea.

0933: The ROKCG HQ, the highest level of ROKCG structure, ordered the ROKCG District West to command directly all ROKCG units.

0933: After confirming that nearby ships and fishing boats had volunteered to help with the rescue operations, the Station Jindo-VTS told nearby ships to drop lifeboats for the passengers.

0937: The Patrol Vessel-123 reported to the ROKCG HQ about the status of the ferry: there were no passengers on the decks of the ferry or in the water.

0937: On VHF FM channel 67, the second mate notified the Station Jindo-VTS that the ferry's list to port was 60 degrees and the passengers were ordered to evacuate to the port side. This was the last communication between the Station Jindo-VTS and the ferry.

0937: Helmsman Park with the first mate's help tried to reach liferafts on the port side to drop them but gave up doing so due to the list of 60 degrees.

0938: The Vessel-123 dispatched a rubber boat to the ferry, and the boat rescued all engineers of the ferry including the Chief engineer, who had stayed on the third deck of the ferry.

0940: After rescuing the crewmembers, a member of the Patrol Vessel-123, Lee, Hyung-Rae went up the ferry to drop liferafts and dropped two liferafts. One activated immediately and the other activated after a while. After dropping the two liferafts, he just came back to the boat, without letting passengers know the evacuation order.

0943: The Patrol Vessel-123 reported to the ROKCG HQ about the status of the ferry: "passengers stayed put in the cabins" and "they could not move," which was reported by the rescued crew.

0944: The Patrol Vessel-123 was alongside the bridge of the ferry.

0945: Helicopter B512 of the Group Mokpo arrived on scene without knowing how many people were on the ferry and how to save them. It was dispatched to the scene from an ROKCG Cutter-3009 at 0908. The rescuers saved several passengers who stayed only on the decks because they had no information on the order for "passengers to stay put in the cabins."

0946: The Patrol Vessel-123 rescued crewmembers including the Captain, who had stayed on the bridge.

0947: The ROKCG District West ordered the Patrol Vessel-123 to send their crew to climb and enter the ferry.

0949: A member of the Patrol Vessel-123, Park, Sang-Wook went into the bridge, found nobody was there and simply came back without doing anything other than releasing the mooring rope of the Patrol Vessel-123. The Patrol Vessel-123 released itself from the ferry because the ferry was sinking.

0949: Fishing boats rescued people on the decks and in the water.

0950: The ROKCG HQ ordered the Patrol Vessel-123 to send the members to climb and enter the ferry. The third deck exit was submerged.

0952: The fourth deck exit was submerged, and the inside of the ferry was dark due to a power outage. The broadcasting system at the Guest Services Desk was submerged and was not working. The communications officer started shouting to passengers to evacuate, and passengers started going to the port side and jumping into the water. The Chief communications officer, Yang, Dae-Hong, the communications officer, two crewmembers at the Guest Services Desk, Ahn, Hyeon-Young and Park, Ji-Young, the high school teachers and adult passengers helped students to escape from the submerging cabins.

0953: The Patrol Vessel-123 notified the ROKCG HQ that it was impossible for their crew to climb the ferry due to the severe list but instead, helicopters could rescue passengers from the starboard side.

0955: The ROKCG HQ ordered the Patrol Vessel-123 to help passenger evacuation by announcing "abandon the ferry."

0956: The Commander of Group Mokpo on the ROKCG Cutter-3009 made his first order to the Patrol Vessel-123 to announce "abandon the ferry" using its loudhailer and guide passengers to evacuate. However, the Patrol Vessel-123 did not follow the order.

1006: The Patrol Vessel-123 approached again the ferry and rescued several more passengers after breaking the cabin window glass.

1007: The ROKCG District West asked the Patrol Vessel-123 if there were ways to prevent or delay the ferry from capsizing.

1013: The Patrol Vessel-123 reported that it had completely pulled away from the ferry due to the severe capsizing (all port side exits of the ferry were submerged due to the list).

1014: The ROKCG HQ ordered the Patrol Vessel-123 to rescue the passengers on the ferry.

1020: Helicopter B511 of Group Mokpo reported that the ferry had sunk 90%.

1024: The ROKCG HQ ordered the Patrol Vessel-123 to send their crew to climb and enter the ferry (the ferry was listing 110 degrees to port).

Figures 7 and 8 show the graphical summary of the events in the process of Rescue operations of people on the distressed ferry. Indications of elements in the graphics are the following:

- Round-rectangular pink line boxes: Trigger events
- Rectangular pink line boxes: Events in chain
- Rectangular black line boxes: End but no-use events
- Rectangular orange boxes: End events
- Red dot arrows: Communication on VHF FM CH. 67
- Black centerline arrows: Communication on hand-held two-way radio transceivers
- Blue centerline arrows: Communication on the broadcasting systems in the ferry
- Purple dot line arrow: Communication on direct voice

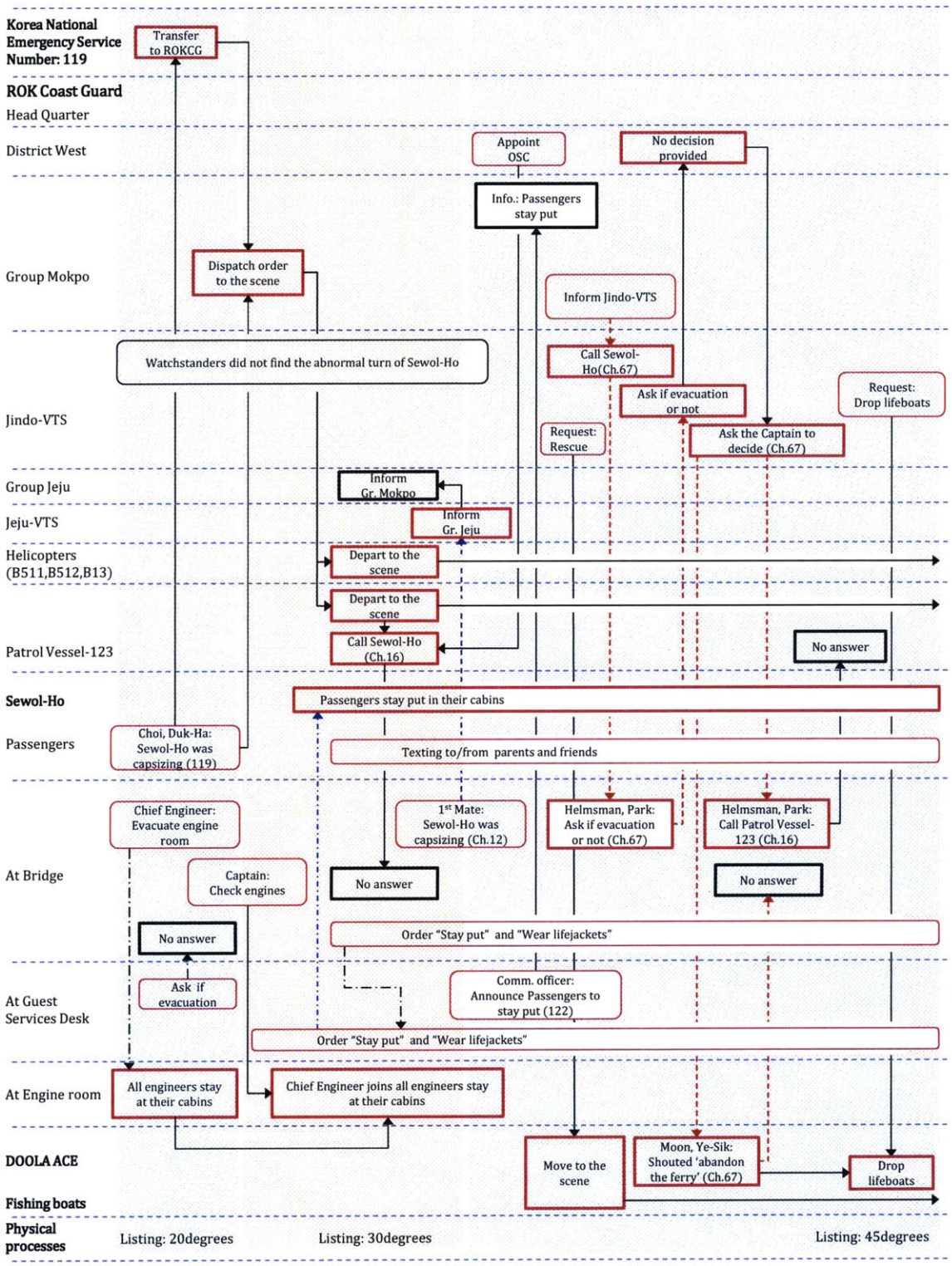


Figure 7 Graphical Summary of Process 2: Rescue operations of people on the distressed ferry (1/2)

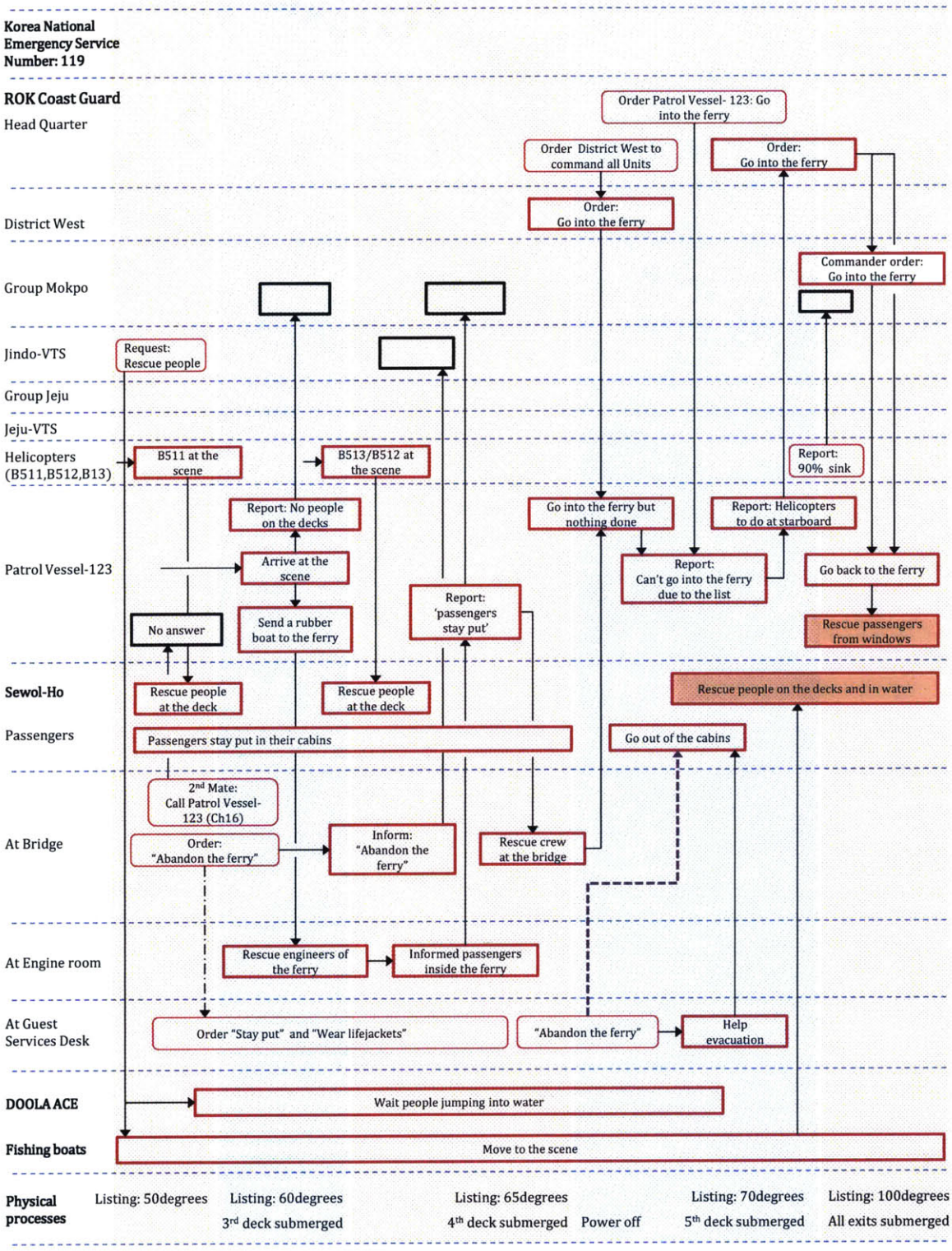


Figure 8 Graphical Summary of Process 2: Rescue operations of people on the distressed ferry (2/2)

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.

The analysis is presented for each individual process; Process 1 of Safe operations of the ferry and Process 2 of Rescue operations of people on the distressed ferry.

• Process 1: Safe operations of the ferry

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.

• Process 2: Rescue operations of people on the distressed ferry

Emergency and Safety Equipment involved in Rescue operations of people on the distressed ferry: Partial list

There are a number of pieces of physical equipment involved in the process.

Emergency communication equipment

- 119: The Korea National Emergency Service Call Number
- 122: The Korea National Maritime Distress Service Call Number

- VHF FM channels: Channel 16 is for international distress, safety and calling; Channel 67 is for calling between ROKCG Station Jindo-VTS and commercial ships; and Channel 12 is for calling between KMOF Station Jeju-VTS and commercial ships.
- TRS (Trunked Radio System): Two-way radio system allows sharing of relatively few radio frequency channels in ROKCG.
- SSB (Single-SideBand modulation): Communication with an unlimited number of people on scene.
- Cell phones: Calling to 119 and 122.
- Hand-held two-way radio transceivers: Communication between the bridge and the Guest Services Desk in the ferry.
- PA system in the ferry
- Loudhailers and Sirens in ROKCG Patrol Vessel-123
- Loudhailers and Sirens in ROKCG Helicopters B511, B512, B513

Emergency and safety equipment

- AIS (Auto Identification System) in the ferry: An automatic tracking system used in the ferry and by vessel traffic services (VTS) for identifying and locating the ferry.
- Emergency alarms on the bridge in the ferry
- Interphones on the bridge and Guest Service Desk in the ferry
- Personal floatation devices (PFDs) or Lifejackets in the ferry
- 44 Liferafts in the ferry
- 4 Marine Evacuation Systems (Chutes) in the ferry
- The Advanced Maritime Surveillance System (AMSS) in ROKCG Station Jindo-VTS: In 2011, the ROKCG built the AMSS for 2 million dollars which could monitor ships and boats, analyze the motions, detect any abnormal patterns and alert the ROKCG units. However, the AMSS had made spurious alarms many time, and therefore, the alarming function had been turned off most times. At that time, the AMSS could not detect the ferry's sharp turn because some critical functions had been out of order for the last four days or the alarming function was turned off as usual.

Safety Requirements and Constraints violated

- Provide an evacuation and the safety equipment to all passengers when the ferry is in distress, as defined in Chonghaejin Marine's Sewol-Ho Operation Management Regulations Document.
- Maintain effective communication and coordination among all ROKCG SAR units on scene, between all ROKCG units and the distressed ferry and among all ROKCG units.
- Provide all ROKCG units an indicator of the ferry's sharp turn using the AMSS.

Failures and Inadequate Controls

- Inadequate PA system for evacuation announcement: PA system on the bridge did not work properly.
- Inadequate evacuation system: Liferafts did not work properly.
- Inadequate monitoring of the ferry's sharp turn: The AMSS did not detect the sharp turn.

Physical Contextual Factors

- Communications between the bridge and the Guest Services Desk had made only with hand-held two-way radio transceivers.
- Communications among ROKCG units on scene and between on the ROKCG units on scene and the ferry on VHF FM channel 16 not possible: The Advanced Maritime Surveillance System at the ROKCG Station Jindo-VTS and VHF FM channel 16 interfered. When the Patrol Vessel-123 had tried to contact the ferry several times on VHF FM channel 16, the VHF FM channel 16 was not working properly. The ROKCG Helicopter B511 could not contact the ferry when it tried the communication on VHF FM channel 16. The ferry did call the Patrol Vessel-123 several times on VHF FM channel 16 but could not contact it either.
- The alerting function of the AMSS at the ROKCG Station Jindo-VTS was out of order or turned off because the system used to cause many spurious alarms.

Table 2 Summary of Physical Safety Controls Analysis Results

	Process 1: Safe operations of the ferry	Process 2: Rescue operations of people on the distressed ferry
Safety Requirements and Constraints violated	• Load 987 tons or less. • Load 88, 60 and 247 as the number of passenger cars, trucks and 10 feet cargo containers. • Load ballast water at least 1,703 tons. • 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.	• Provide an evacuation and the safety equipment to all passengers when the ferry is in distress. • Maintain effective communication and coordination among all ROKCG SAR units on scene, between all ROKCG units and the distressed ferry and among all ROKCG units. • Provide all ROKCG units an indicator of the ferry's sharp turn using the AMSS.
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: o Anti-heeling pumps to return the ferry to its upright position did not work.	• Inadequate PA system for evacuation announcement. o PA system on the bridge did not work properly. • Inadequate evacuation system. o Liferafts did not work. • Inadequate monitoring of the ferry's sharp turn. o The AMSS did not detect the sharp turn.
Physical Contextual Factors	• Securing tools 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. • 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.	• Communications in the ferry had made only with hand-held two-way radio transceivers. • Communications among ROKCG units on scene and between on the ROKCG units on scene and the ferry on VHF FM channel 16 not possible. • The alerting function of the AMSS was out of order or turned off because the system used to cause many spurious alarms.

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. Any human decisions or flawed control actions need to be understood in terms of that the information available to the decision makers as well as any required information that was not available; the context and environment in which the decision maker is working; the value structures underlying the decision; any flaws in the process or mental models of those making the decisions and why those flaws existed. A goal represents an end state while a motive explains why that end state was chosen. Explanations based on goals and motives depend on assumptions that cannot be directly measured or observed by the accident investigator (Leplat, 1987, pp. 311 – 316). 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. The testimonies at the court might have limited details and motives of their decisions and actions. Moreover, a number of "whys" about their decisions and actions and the context in the processes could not be answered with the details provided by testimonies at the court. However, the testimonies at the court might be the best information in finding their mentalities in the context of the two processes.

The analyses of the safety control structures and controllers of two processes are presented in this section. And all illegal control actions with the intentions are excluded in the analyses, which were addressed in the KMST and BAI's RCA analyses.

- **Process 1: Safe operations of the ferry**

The process begins with loading and securing cargo and vehicles on the ferry and ends with the ferry's sharp turn causing the listing. In the process, the following controllers need to be included in the CAST analysis:

- 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
- ROKCG Group Incheon: Officer as reviewers
- Korea Ministry of Oceans and Fisheries (KMOF): The Minister of KMOF

Sewol-Ho Operations:

Captain:

The Captain was responsible for the following:

- Follow and practice rules of safe operations in the Sewol-Ho's Operation Management Regulations Document.
- Check the total weight of both cargo and vehicles are 987tons (or less), and total numbers of passenger cars, trucks and 10ft-cargo containers are 88, 60 and 247 (or fewer) respectively.
- Assign an officer to check that ballast water is 1,703tons or more (no ballast information is in the Sewol-Ho's Operation Management Regulations Document).
- Check cargo container size to be loaded is 10ft as defined in Chonghaejin Marine's the Sewol-Ho Operation Management Regulations Document.

- Assign an officer to check that each passenger car is secured by four nylon lashing bands as defined in Chonghaejin Marine's the Sewol-Ho Operation Management Regulations Document. Correct if needed.
- Assign an officer to check the minimum distance between vehicles is 2ft as defined in Chonghaejin Marine's the Sewol-Ho Operation Management Regulations Document.
- Assign an officer to check that each truck is secured by ten nylon lashing bands as defined in Chonghaejin Marine's the Sewol-Ho Operation Management Regulations Document.
- Assign an officer to check that each cargo container is secured by lashing bars, turnbuckles, and corner fittings as defined in Chonghaejin Marine's the Sewol-Ho Operation Management Regulations Document.
- Assign an officer to check that each stacked cargo container is secured by lashing bars, turnbuckles, twist locks and bridge fittings as defined in Chonghaejin Marine's Sewol-Ho Operation Management Regulations Document.
- Assign an officer to check that the bow and stern doors are closed and watertight before the departure as defined in Chonghaejin Marine's Sewol-Ho Operation Management Regulations Document.
- Assign an officer to submit "Ferry safety inspection chart: before-departure" to an Operation Officer at the KSA and get the signature before the departure.

The Captain, Lee Joon-Seok was 69 years old, received the Second Mate License in 1986, had twenty-five years of ferry experiences as the first mate and joined Chonghaejin Marine in 2008. He was the first Captain of the Sewol-Ho. The Captain had been a part-time captain since he retired from the company several months ago. He knew that the first mate had used ballast water as a means to satisfy the load line but could not correct him because the ballast water was the only way to satisfy the load line. He knew the ferry had been overloaded, and the ballast was reduced to satisfy the load line which was the only checkpoint by officers at the KSA. His feedback to Chonghaejin Marine were critically important to the safe operation of the ferry, but after experiencing several frustrations of them not accepting his feedback, he stopped providing feedback.

Regular Captain (was not on the ferry):

The responsibilities are the same as the ones of the Captain. The regular Captain, Shin, Bo-Sik had complained to the associate manager of Logistics team, Kim, Jung-Soo about the ferry's severe rolling. He used to talk at the company as a joke about the ferry being the most dangerous one in South Korea. The company's management did not accept the complaints. On November 29, 2013, the ferry was listed about 15 degrees, causing bricks and bottles loaded on the first deck to slide and hit the walls. The accident report was submitted to the top management including the president, but no the corrective actions were directed and implemented. Due to the safety issue, some crewmembers who were on the ferry on that day left the company. He also was looking for a job to leave the company for the same reason.

However, a regular Captain, Park, Jin-Hwan of the other ferry, Ohamana-Ho, which made the same trip as the Sewol-Ho did, traveling from Incheon to Jeju Island, had taken a firm stand against the overload due to safety concerns. On April 14, 2014, a day before when the Sewol-Ho departed, he rejected loading extra heavy construction equipment of about 60 tons. The equipment was loaded on the Sewol-Ho on April 15, 2014 instead.

Table 3 The role of Captain in the accident (Process 1: Safe operations of the ferry)

	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 each cargo container is secured by lashing bars, turnbuckles, and corner fittings per the OMR • Check each stacked cargo container is 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 • Daily operations • Capsizing or sinking accidents were rare. • 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. • Did not carry out safety training or drills. • 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 "overlook" by the first mate. • Insufficient controls to correct "overlook" by the first mate. • 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.

First Mate:

The first mate was in charge of supervising loading and securing cargo safely before the departure. The first mate, Kang, Won-Sik was 41 years old, received the First Mate License in 1991, had three years of ferry experiences as the first mate and joined Chonghaejin Marine on December 15, 2012. The first mate had complained to the associate manager at Logistics team, Kim, Jung-Soo about the ferry's severe rolling when it was traveling on windy days. The associate manager did not accept the complaints. He had also observed that the regular Captain complained to the associate manager about the overloading, but no corrections were made. Therefore, he simply stopped making the complaints. When he was asked by the associate manager, Kim, about where to load the extra heavy construction equipment of about 60 tons which was rejected by the Captain of the Ohamana-Ho on the last day and left at the port, he could not raise the overload issue for the same reason mentioned above.

To get the approval for the departure from the Operation Officer at the KSA who just checked the load line for the approval, he had to adjust ballast water, mostly taking out the water to compensate for the overload. He knew that the ferry would be dangerous due to reduction of the restoring force if ballast was less than that required and due to free surface effects when the tanks were not fully filled. However, everybody including the first mate and the Operation Officer at the KSA thought that the load line was the only critical factor to guarantee the ferry's safe operation as he testified at the court (08/29/2014). When the bow and stern doors were closed, the ferry was not watertight due to the bad condition of the rubber packing seals. He reported the issue to the company to fix them several weeks earlier, but no repair was done. He testified at the court (10/08/2014) that he had no means to do more than the report to the company. The inadequate maintenance process allowed the ferry (it was an RORO ship too) to travel with the bow and stern doors not watertight.

Third Mate:

The third mate was responsible for submitting "Ferry safety inspection chart: before-departure" before the departure. The third mate, Park, Han-Gyeol was 26 years old, received the Third Mate License in 2012, had about one year of ferry experience as the third mate and joined Chonghaejin Marine on December 10, 2013. The third mate testified at the court (10/06/2014) that she learned how to record "Ferry safety inspection chart: before-departure" from the predecessor; marked "good" on all conditions of the ferry's hull, engines, communication equipment, and loading and securing cargo and vehicles; marked "perfect" on life saving equipment, fire extinguishers and navigation equipment; left boxes empty for number of passengers and crew, vehicles and containers and total cargo weights; gave the copied paper of the chart to the Operation Officer at KSA; and after the departure, called to the Operation officer to give the final numbers for the empty boxes, which were fictitious ones received from the first mate and the Guest Services Desk and much lower than the actual ones. She assumed that this process was the formal process to record the chart. She also testified at the court (10/06/2014) that one day, she noticed too many cargo and trucks were loaded, reported the information to the regular Captain and told him not to depart with the overloaded cargoes and trucks, but her report and command were rejected by the Captain who replied that "Unloading some of the trucks will cause a lot of claims from the truck drivers." After that time, she did not make any safety-related reports regardless of how much the ferry was overloaded.

At 0730, she and Helmsman, Cho, Joon-Ki began her scheduled 4-hour shift on the bridge. About 1 hour later, the Sewol-Ho traveling at about 18 knots entered the Maenggol Channel, located 11 miles away from Jindo Island. When the ferry entered the wider sea after passing the Maenggol Channel, the Captain went to his cabin. At 0848, she was monitoring the radar and radio on the bridge and gave two orders to Helmsman Cho to turn the ferry; first to 140 degrees, and then to 145 degrees. She was told by the regular Captain, Shin, that because the ferry's restoring force was low, a turn should be made 5 degrees or less. The helmsman heard her orders and made the first turn of five degrees to starboard. Once

the ferry was directing to 140 degrees, the helmsman, then, steered it to 145 degrees, but the ferry was listing sharply to port. Due to the list, the helmsman might have turned the ferry to port, but after hearing her order for a restoration of balance, "turn in the opposite direction," he might have turned it to starboard again. The Captain testified at the court (09/02/2014) that when he came to the bridge, he saw the steering gear set 15 degrees to starboard. The actions made by the two were still in question, but the second turn of 10 degrees in one second was a sharp turn. In that situation, she had to make the order "port" instead of "turn in the opposite direction" because she could not see if the helmsman turned to port or starboard.

When the ferry was starting to list, she could not do anything to fix the list, but instead, she rushed to call the Captain to notify him about the list. One of the actions for which the third mate was criticized was calling in the Captain immediately, rather than trying to fix the listing problem. She testified at the court (10/06/2014) that she did it that way because she was told by the regular Captain that she had to contact the Captain immediately when any unexpected things happened.

Helmsman (on the bridge):

The helmsman was in charge of following the mate's order and steering the ferry safely. Helmsman, Cho, Joon-Ki who was 56 years old, had about twenty-five years of ocean-going fishing ships as a helmsman and joined Chonghaejin Marine on October 22, 2013.

At 0730, Helmsman, Cho, Joon-Ki and the third mate, Park, Han-Gyeol began her scheduled 4-hour shift on the bridge. About 1 hour later, the Sewol-Ho traveling at about 18 knots entered the Maenggol Channel. At 0848, the third mate was monitoring the radar and radio on the bridge and gave two orders to him to turn the ferry; first to 140 degrees, and then to 145 degrees. However, he testified at the court (10/01/2014) that he heard the third mate's first order only, and once the ferry was listing, he turned it to port after hearing her order, "turn in the opposite direction." The Chief engineer who was on the bridge testified at the court (10/07/2014) that he also heard two orders made by the third mate. The Captain testified at the court (09/02/2014) that when he came to the bridge, he saw the

steering gear positioned at 15 degrees to starboard. Based on the testimony, he was thinking something else at that moment. From the interview at the prosecutor-police Sewol-Ho accident investigation, some of crewmembers stated that the helmsman had controlled the ferry roughly and therefore, the regular Captain did not allow him to take the wheel when leaving port and arriving in port. Moreover, he had been in trouble with other crewmembers including the third mate, and he was transferring to the other ferry after the trip. On that morning, the helmsman and the third mate had arguments on the bridge before their shift. For him, the travel was planned as his last trip in the Sewol-Ho.

Table 4 The roles of Mates and Helmsman in the accident (Process 1: Safe operations of the ferry)

	Sewol-Ho Operations First Mate	Sewol-Ho Operations Third Mate	Sewol-Ho Operations Helmsman
Safety Related Responsibilities	• Follow rules of OMR • Supervise loading and securing cargo safely before the departure	• Follow rules of OMR. • Prepare and submit "Ferry safety inspection chart: before-departure" to the KSA.	• Follow the Mate's order and steer the ferry safely.
Context in which Decisions made	• Poor morale • Inadequate training • Daily operations • KSA just checked the load line for the safety. • Captain stopped submitting safety-related reports and feedback to company. • Captain overlooked overload and less ballast. • OMR was not made for the right lashing of cargo containers and vehicles.	• Poor morale • Inadequate training • Learned how to record the chart from the predecessor. • KSA received the empty chart. • Captain overlooked the chart report process.	• Poor morale • Inadequate training • Regular captain did not allow taking the wheel at leaving port and arriving in port. • Been in trouble with other crewmembers. At that morning, had argued with the third mate before their shift. • Planned to transfer to the other ferry after the trip. • Planned as his last trip in the Sewol-Ho.
Unsafe Decisions and Control Actions	• Reduced ballast water. • Overlooked overloading by Logistics team. • Did not report safety-related issues to company. • Did command overload. • Did command improper lashing cargo and vehicles. • Inadequate maintenance process to fix not-watertight bow and stern doors	• Documented fictitious training records every 10 days. • Submitted the chart without required data. • Received fictitious data from the first mate and the Guest Service Desk. • Informed fictitious data to KSA on the phone. • Ordered helmsman "the opposite" instead of "port." • Stopped fixing the listing problem but instead called to the captain.	• Controlled the ferry roughly • Made turning to "the opposite" while turning to "port."
Process Model Flaws	• Believed the ferry was safe. • Believed steering with small angle could avoid unsafe situations.	• Believed the chart report process learned was formal. • Believed helmsman to turn the ferry to starboard. • Believed calling the captain to notify the list immediately was important rather than trying to fix the listing problem.	• Believed the ferry was safe.

Chonghaejin Marine:

Associate manager in Logistics team:

The associate manager in Logistics team was in charge of providing the day cargo plan to the Sewol-Ho Operations, the KSA and the loading and lashing service companies in advance of the safety review and of coordinating the loading and lashing of cargo for safe operation. An associate manager of the Logistics team, Kim, Jung-Soo testified at the court (08/27/2014) that he knew the overload would cause the restoring force to be lower. However, he did not know how bad it was and how much the maximum load limit described in the Sewol-Ho's Operation Management Regulations Document was. He understood that the meaning of "the Sewol-Ho's restoring force was so bad" was a weight balancing problem and therefore, the problem could be improved if the ferry was balanced neutrally by loading cargo evenly.

He simply followed the direction provided by his manager of the Logistics team, Nam, Ho-Min: Loading as much as possible without any empty space. When cargo and vehicles were loaded less than usual (i.e. not fully overloaded) due to the concern of the ferry's safety and complaints from personnel of the loading service company, his manager, Nam, directed him to load more and called him a coward. To load more, the personnel of the loading and lashing service companies had to untie the lashing bands, move cargo and vehicles, and lash them again, and therefore, the lashing could not be done properly due to lack of space and time. Moreover, vehicles arriving at the port 10 minutes before the departure were allowed to be loaded, which would result in them being secured inappropriately. His manager, Nam, assumed that adding more loads to the ferry helped the ferry to be more stable.

After the modifications were finished and the KR reviewed the Sewol-Ho, the KR approved it to load only 10 feet size cargo containers. However, he directed personnel from the loading service company to load 60 8 feet cargo containers on the decks, which were designed to load and stack only 10 feet cargo containers, and therefore, the lashing was improperly finished.

President:

The president was in charge of creating and maintaining the organizational safety culture and establishing the organizational safety policy. The president, Kim, Han-Sik, testified at the court (10/24/2014) that the Sewol-Ho's restoring force was inadequate after the modifications of adding more cabins, and he also knew the overload would make restoring worse. However, he did not know how serious the overload was because no one told him about the issue in detail, but instead, he assumed the issue could be resolved by loading cargo evenly to maintain the ferry's balance. He also believed that the ferry could carry the cargo capacity and the ballast required before the modifications. He had encouraged his members to work harder in order to make more profits.

With the ferry's modifications of adding more cabins, he believed that carrying more passengers would increase the profit but it turned out the opposite occurred due to much fewer passengers than expected and the cost of the modifications. The financial problems led the management to cut the safety margins; overloading cargo and vehicles, improperly securing cargo containers and vehicles, and filling less ballast water.

The president testified at the court (10/24/2014) that he did not know the exact meanings of "restoring force, ballast water, maximum load limit and load line." The president's leadership created the safety culture, which had, in the end, driven the crew's poor behaviors.

Safety Director:

Safety Director was responsible for establishing the operations safety policy and creating a safety control structure with appropriate responsibilities, accountability and authority, safety controls, and feedback channels. The Safety Director who was in charge of the safe operations also had to establish a safety management plan and ensure that a safety information system and continual learning and improvement processes were in place and effective.

After the modifications of the ferry, the director, Ahn, Ki-Hyun knew that as approved by the KR, the total weight of both cargo and vehicles was 987 tons and the ballast water was 1,703 tons or more. He was the person to lead a team to purchase the ferry from a Japanese company, and therefore, knew the most about the ferry's conditions at the company. Even though he was the safety director in charge of the safe operations, he could not raise the overload issue to the Logistics team and the president of the company because the revenues from transporting cargo were 70 – 75% of the total revenues coming from the ferry. On November 29, 2013, the ferry was listed about 15 degrees, causing bricks and bottles loaded on the first deck to slide and hit the walls and in February 2014, the ferry could not depart due to the severe rolling. However, he did not assess the incident reports and provide improvement actions to the operations.

The director testified at the court that he knew the overload, two times more than the limit, would deteriorate the ferry's restoring force, but simply forgot the issue over time as no serious accidents had occurred related to the overload.

Table 5 The role of Chonghaejin Marine Logistics in the accident (Process 1: Safe operations of the ferry)

	Chonghaejin Marine Logistics
Safety Related Responsibilities	• Provide the day cargo plan to Operations, KSA and loading and lashing service companies in advance for the safety review. • Coordinate loading and lashing cargo for the safe operation.
Context in which Decisions made	• Poor morale • Inadequate training • His manager directed loading as much as possible with no empty space available.
Unsafe Decisions and Control Actions	• Did not provide the day cargo plan to Operations, KSA and loading and lashing service companies. • Directed personnel from loading service company "overloads." • Directed personnel from loading service company to load 60 of 8ft cargo containers on the second decks. • Overlooked the improper lashing.
Process Model Flaws	• Believed the ferry could carry the cargo authorized before the modifications. • Believed loading cargo evenly improved the restoring force. • Believed not much overload. • Believed adding more loads helped the ferry more stable.

Table 6 The roles of Chonghaejin Marine's President and Safety Director in the accident (Process 1: Safe operations of the ferry)

	Chonghaejin Marine President	Chonghaejin Marine Safety Director
Safety Related Responsibilities	• Provide and maintain the organizational safety culture • Establish the organizational safety policy	• Establish operations safety policy • Develop OMR based upon critical data approved and certified by KR. • Develop a safety control structure with appropriate responsibilities, accountability and authority, safety controls, and feedback channels.
Context in which Decisions made	• Pressure to satisfy budgetary and financial goals. • No one told about Sewol-Ho's safety issue after modifications. • No one reported overload-related issues. • High personnel turnover.	• Cargo as the main revenue source. • No critical accident over time due to overloading. • Forgot reporting overloading related safety issues to management over time • High personnel turnover.
Unsafe Decisions and Control Actions	• Approved insufficient OMR. • Inadequate capability understood how serious overloading was. • Inadequate capability understood restoring force, ballast water, maximum load limit and load line. • Direction to stop overloading not provided. • Direction to stop poor lashing not provided. • Inadequate capability to detect overloading related issues • Insufficient controls to correct "overloads." • Insufficient controls to correct "overlook." • Insufficient controls to collect "feedback."	• Developed insufficient OMR. • Did overlook overloading. • Did not process safety-related issues on time. • Did not provide feedback on time. • Did not add ballast information in OMR. • Did not stop overload and less ballast. • Did not stop improper lashing cargo and vehicles. • Insufficient controls to correct "overlook." • Insufficient controls to detect and correct "no feedback on safety related reports." • Insufficient controls to detect and correct report process of "Ferry safety inspection chart: before-departure." • Insufficient controls to correct dysfunctional communications between Operations and Logistics about overloading related issues. • Inadequate maintenance process to fix not-watertight bow and stern doors.
Process Model Flaws	• Believed loading cargo evenly solved overloading related issues. • Believed the ferry could carry the cargo capacity and the ballast required before the modifications.	• None.

Loading Service Company (Woo-Ryun Transportation Co.):

Foreman as an on-site manager:

The foreman was responsible for supervising loading vehicles, cargo containers and construction equipment to the Sewol-Ho safely based upon the day cargo plan and the Sewol-Ho's OMR. A foreman, Lee, Joon-Soo did not receive the day cargo plan from the associate manager, Kim, but instead just followed the loading procedures that the associate manager directed. On April 15, 2014, when the foreman was asked by the associate manager to load the extra heavy construction equipment of about 60 tons on the second deck, which was usually loaded on the first deck due to the weight, the foreman replied back to the associate manager, Kim "it was too heavy to put on the second deck." However, the associate manager said to him "just do it," and the first mate who stayed together also said "it is okay." As the associate manager directed, about 20 tons of steel I-beams and 150 tons of steel reinforcing bars were also simply stacked on the cargo containers. He testified at the court (08/22/2014) that the loading was completed under the associate manager's direction. Because adding more cargo was also beneficial to their business, the manager and management of Woo-Ryun Transportation Co. had ignored the overloading over time. The struggle for a good safety culture ended so easily that they stopped the fight against the functional pressures of the work environment.

Lashing Service Company (Won-Kwang Co.):

Union members at Incheon port:

Because Chonghaejin Marine had only a contract for loading and lashing with Woo-Ryun Transportation Co., which had no license for lashing, the Woo-Ryun Transportation Co. contracted with Won-Kwang Co. which had the license. Therefore, Won-Kwang Co. had no direct contract with Chonghaejin Marine, and simply hired about 300 union members of the Incheon port to lash cargo and vehicles for the ferry.

The described process of the loading and lashing in the OMR was the following:

1) Loading a cargo or vehicle
2) Lashing and securing it
3) Repeat steps 1 and 2.

However, due to the time pressure, the loading work for all cargo were finished first and followed by lashing of them later. One of the union members, Jang, Kwang-Young who worked on April 15 2014, testified at the court (08/22/2014) that on the day, the Sewol-Ho had little space, no lashing points and not enough equipment (lashing bands, lashing bars, turnbuckles, twist locks, bridge fittings) to do lashing due to the unplanned overloads. And he also said that the only contact person to discuss and complain about the lashing works was the foreman, Lee of the Loading Service Company, who supervised the loading but had no authority to load cargo as the OMR described. About 20 tons of steel I-beams and 150 tons of steel reinforcing bars stacked on the cargo containers were simply fastened by regular fiber ropes. Moreover, new or foreign brand vehicles recently sold in S. Korea which had different types and locations of hooks, could not be lashed securely as defined in the OMR. Because of the different types and locations of hooks, they were blamed for any tiny scratches occurring when the lashing bands rubbed the vehicles' bumpers. Therefore, personnel at the lashing service company lashed all vehicles as simply as they could. They did try their best in lashing of them without knowing the day cargo plan but with the given loading situation.

Table 7 The roles of Loading/Lashing Services Companies in the accident (Process 1: Safe operations of the ferry)

	Loading Service Company On-site manager	Lashing Service Company Union member at Incheon port
Safety Related Responsibilities	• Supervise loading vehicles, cargo containers and construction equipment safely based upon the day cargo plan and the Sewol-Ho's OMR	• Secure vehicles, cargo containers and construction equipment safely based upon the day cargo plan and the Sewol-Ho's OMR
Context in which Decisions made	• Inadequate training • Loading more cargo beneficial to the business. • Did not receive the day cargo plan, instead Logistics team directed the loading. • Mate allowed loading heavy construction equipment. • Vehicles arrived at port 10 minutes before the departure. • No lashing license • Did ignore overload over time. • Operations and Logistics team overlooked overloading. • KSA overlooked overloading.	• Inadequate training • Did not receive the day cargo plan, instead the foreman directed the lashing. • Proper lashing was not possible due to wrong drawings and overloading. • Did ignore proper lashing over time. • Vehicles arrived at port 10 minutes before the departure. • Operations and the foreman overlooked poor lashing. • KSA overlooked poor lashing. • New or foreign brand vehicles not fitted for the lashing.
Unsafe Decisions and Control Actions	• Did direct members to load 8ft cargo containers and heavy construction equipment on 2nd deck. • Did direct members to stack 20tons of steel I-beams and 150tons of steel reinforcing bars on cargo containers. • Did direct improper lashing works. • Did not report safety-related issues to the management.	• Did secure heavy construction equipment, 8ft cargo containers and steel I-beams and steel reinforcing bars improperly. • Did secure vehicles poorly • Did not report the safety-related issues to the management.
Process Model Flaws	• Believed overloading, wrong cargo container size and poor lashing did not impact safe operations. • Believed Logistics team and Mate had more knowledge on safe operations	• Believed overloading, wrong cargo container size and poor lashing did not impact the safe operations.

Korea Shipping Association:

Korea Shipping Association's businesses were sales of marine insurances and oils and safety management for ship operations. The KSA was enhancing activities to prevent marine accidents by establishing a field-oriented safety management system, which provided specialized education and conducted maritime transport safety measures. However, the main business was sales of marine insurances and therefore, the KSA did not provide much support to the Operation Officers who oversaw maritime transport safety measures.

Operation officer:

The Operation Officer was responsible for the following:

- Review "Ferry safety inspection chart: before-departure" submitted by the ferry captain before the departure.
- Physically check and examine safety-related equipment and watertight bow and stern doors before the departure.
- Physically check and examine a number of passengers and total weight of both cargo and vehicles before the departure, which are based on the OMR.
- Physically check and examine how well cargo and vehicles are secured before the departure, which are based on the OMR.

On April 14, 2014, the day before the Sewol-Ho departed, the Operation Officer, Jeon, Jung-Yoon at the KSA held up the Ohamana-Ho's departure because he found that the load line was under water. Operation officers at the KSA have the authority to stop the departure when any safety issues are found. However, the decision was not easy for them when issues are found because of the relation between the KSA and the company. The KSA, to which the officer belonged, was an association of marine transportation business companies including Chonghaejin Marine, which received a big portion of their budget from them. Therefore, no authority was practically given to the operation officers at the KSA to initiate a cancellation of the voyage when any unsafe situation was found; even if

they saw the overloading and unsafe lashing. The loading of cargo and vehicles that was completed just before the departure also prevented him from checking the unsafe lashing. Not enough time for examination of all cargo and vehicles and the securing conditions was provided to him. The departure of the ferry had to be made on time even though the loading was made later than scheduled.

As a result of learning from a fire accident of Seolbong-Ho in September 2011, the KSA directed all Operation officers to physically examine a number of passengers and cargo containers and compare them with the data in the "Ferry safety inspection chart: before-departure" before the departure. When an operation officer stopped the loading and examined conditions of lashing and securing cargo and vehicles, however, the crew of the ferry and passengers complained about the departure delay. Due to the complaints, he briefly checked the conditions and approved the departure. He reported this issue of "the crew of the ferry and passengers were complaining about the delay" to his manager at the KSA, but no direction on that issue was provided from the manager. After that time, he had simply stopped reporting the overloading and improper lashing unless the load line was not satisfied.

"Ferry safety inspection chart: before-departure" did not describe the total weight of both cargo and vehicles, 987 tons, and total numbers of passenger cars, trucks and 10ft-cargo containers as 88, 60 and 247 respectively. Therefore, he did not pay attention much on checking the total weight loaded. *Besides, no quantitative methods for assessing the total weight of both cargo and vehicles were provided to him and therefore, he assumed that reading the load line was the only quantitative measurement.* The reading was confirmed using binoculars at the office 300 feet away from the ferry. *He also assumed that ballast water should be filled as much as required in the ferry.*

Due to "the ferry having to depart on time," he did not have enough time to complete the review of "Ferry safety inspection chart: before-departure" before the departure. And after the departure, he wrote down the information on the chart, which was provided by the

Sewol-Ho on the phone and contained all fictitious data. Then, he filed the copied chart into a cabinet. No one checked the documentation of the numbers.

The third mate, Park, Han-Gyeol testified at the court (10/06/2014) that she learned how to record "Ferry safety inspection chart: before-departure" from her predecessor; marked "good" on all conditions of the ferry's hull, engines, communication equipment, and loading and securing cargo and vehicles; marked "perfect" on rescue equipment, fire extinguishers and navigation equipment; left boxes empty for number of passengers and crew, vehicles and containers and total cargo weights; gave the copied paper of the chart to the Operation Officer at KSA; and after the departure, called to the Operation officer to give the final numbers for the empty boxes, which were fictitious ones received from the first mate and the Guest Services Desk, much lower than the real ones.

Manager:

The manager was responsible for supervising and supporting Operation officers to follow the rules and policies. The manager did not pay much attention to the follow up on "Directed all Operation officers to physically examine the number of passengers and cargo containers and compare with the data in the "Ferry safety inspection chart: before-departure" before the departure." His negligence caused Operation officers to stop reporting the overloading and improper lashing and to ignore them.

The Korea Shipping Association was an organization of marine transportation business companies including Chonghaejin Marine, which received a big portion of the budgets from them. Therefore, the manager appeared to have practically no authority to support the Operation Officer to initiate the cancellation of the voyage when any unsafe situation was found.

Table 8 The roles of Korea Shipping Association's Operation officer and Manager in the accident (Process 1: Safe operations of the ferry)

	Korea Shipping Association Operation officer	Korea Shipping Association Manager
Safety Related Responsibilities	• Review "Ferry safety inspection chart: before-departure" submitted by the ferry captain before the departure. • Physically check and examine safety-related equipment and watertight bow and stern doors before the departure. • Physically check and examine a number of passengers and total weight of both cargo and vehicles before the departure, which are based on the OMR. • Physically check and examine how well cargo and vehicles are secured before the departure, which are based on the OMR.	• Supervise and support Operation officers to follow the rules and policies for Safety Management for Ship Operation.
Context in which Decisions made	• Inadequate training • Crew and passengers complained about departure delay. • Quantitative methods for assessing the total weight of both cargo and vehicles not provided. • Vehicles arrived at the port 10 minutes before the departure. • Appropriate time for examination of all cargo and vehicles and the securing conditions not provided. • "Ferry safety inspection chart: before-departure" process overlooked by supervisor. • Relied on voluntary compliance with guidelines.	• KSA as an association of marine transportation business companies. • Chonghaejin Marine managers complained about departure delay. • Sewol-Ho's inspection certificate and critical data not provided. • Required ballast water not provided in the OMR.
Unsafe Decisions and Control Actions	• Inadequate capability to detect overloading related issues. • Did not report the safety-related issues to manager. • Did not inspect bow and stern doors closed and watertight. • Did not inspect 8 ft cargo containers. • Did not inspect a passenger car secured by four lashing bands. • Did not inspect minimum distance between vehicles. • Did not inspect each truck secured by ten nylon lashing bands. • Did not inspect each cargo container secured by lashing bars, turnbuckles, corner fittings. • Did not inspect each stacked cargo container secured by lashing bars, turnbuckles, twist locks and bridge fittings. • Inadequate capability in understanding restoring force, ballast water, load limit and load line. • Direction to stop overloading not provided. • Direction to stop poor lashing not provided. • Did overlooked submitting inspection chart without data after the departure. • Insufficient controls to correct "overloads."	• Relied on voluntary compliance with guidelines. • Direction to check ballast water not provided. • Feedback on officers' safety-related issues and reports not provided. • Insufficient controls to detect "overlook" by officers. • Insufficient controls to correct "overlook" by officers. • Insufficient controls to correct "no feedback on safety related reports" from officers.
Process Model Flaws	• Believed the load line was the only critical factor to guarantee the ferry's safe operation. • Believed ballast water filled as much as required.	• None.

Korea Register of Shipping:

The Korea Register of Shipping provides classification and legal services and assistance to the maritime industry and regulatory bodies as regards maritime safety and pollution prevention. Ship classification verifies the structural strength and integrity of essential parts of the ship's hull and its appendages, and the reliability and function of the propulsion and steering systems, power generation and those other features and auxiliary systems that have been built into the ship in order to maintain essential services on board.

The KR examined the Sewol-Ho in early 2013 as it was being redesigned to handle more passengers. The KR reduced the authorized cargo capacity to 987 tons from 2,482 tons and increased the required ballast water to 1,703 tons from 370 tons to stay balanced. The KR provided Chonghaejin Marine the inspection certification with the official data with a belief that the Sewol-Ho Operations would follow the requirements but never checked that this was done.

Inspector:

The inspector was responsible for reviewing the modification plan drawings based upon the restoring force calculation and physically inspecting that the ferry was modified based upon the drawings received when Chonghaejin Marine submitted the request to add more cabins to the ferry. If modifying the main structure of the ferry (i.e. hull) was needed, Chonghaejin Marine had to submit the request to an administrator of a Provincial Government under the Korean Ministry of Oceans and Fisheries. Once the review and inspection were successfully finished, the KR provided the inspection certificate to Chonghaejin Marine. With the certification, total cargo weight and ballast water, methods of loading and lashing cargo containers and vehicles, and sizes of cargo container were provided as the mandatory requirements to maintain the safe operations.

In the case of the Sewol-Ho after the extensive modifications made by adding cabins to the third, fourth, and fifth decks to accommodate additional 117 passengers and an exhibition hall at the fifth deck, the new and existing requirements were updated as the following:

- Total weight of both cargo and vehicles shall be 987 tons (or less), and total numbers of passenger cars, trucks and 10 feet-cargo containers should be 88, 60 and 247 (or fewer) respectively.
- Ballast water shall be 1,703 tons or more.
- Cargo container size to be loaded shall be 10 feet.
- A passenger car shall be secured by four nylon lashing bands.
- The minimum distance between vehicles shall be 600 mm or 2 feet
- A truck shall be secured by ten nylon lashing bands.
- A cargo container shall be secured by lashing bars, turnbuckles, and corner fittings.
- A stacked cargo container shall be secured by lashing bars, turnbuckles, twist locks and bridge fittings.

The ferry, however, carried 2,143 tons of cargo and others and 761 tons of ballast water. The inspector believed that Chonghaejin Marine and the crewmembers would follow the requirements.

The inspector at the KR certified the modifications without reviewing the modification plan drawings for lashing and securing passenger vehicles. 58 of the total 66 passenger vehicles could not be lashed and secured properly. He did not find the problem while carrying out the inspection. The inspector assumed that the modification plan drawings for lashing and securing passenger vehicles could be satisfied for Korean and European vehicles.

ROKCG Group Incheon:

Officers as reviewers:

Officers as reviewers were responsible for reviewing the Sewol-Ho's Operation Management Regulations Document based upon data of the critical load limits, which were approved and certified by the KR. Officers as reviewers of the Sewol-Ho's Operation Management Regulations Document at the ROKCG Group Incheon reviewed and approved the Sewol-Ho's OMR without comparing it with the data of the critical load limits that were approved by the KR. They simply assumed that the OMR was written based on the data

approved by the KR; total weight of goods was 3,794 tons (3,963 tons in the OMR); total numbers of passenger cars and small trucks and 24 tons, trucks were 81 and 8 (88 and 60 in the OMR) respectively. The Group Incheon had not received the data directly from the KR but through Chonghaejin Marine. They did not know that the ballast water of 1,703 tons approved by the KR was not described in the OMR, which should have been in the OMR and reviewed by the reviewers.

Table 9 The roles of Korea Register of Shipping and ROKCG Group Incheon in the accident (Process 1: Safe operations of the ferry)

	Korea Register of Shipping Inspector	ROKCG Group Incheon Officers as reviewers
Safety Related Responsibilities	• Review modification plan drawings based upon the restoring force calculation. • Provide load and ballast information to meet the restoring force requirement. • Physically inspect modifications and lashing methods with drawings. • Provide required load limit, type of cargo containers, ballast and lashing methods to Chonghaejin Marine, KSA and ROKCG.	• Review OMR based upon critical data approved and certified by KR. • Inspect lashing methods/devices to vehicles and cargo containers. • Inspect safety equipment operable.
Context in which Decisions made	• Lashing of various vehicles and stacked containers not available during physical inspection. • Relied on voluntary compliance with regulations, policies and guidelines (KSA, Chonghaejin Marine).	• The Sewol-Ho's Inspection Certificate and required load limit, type of cargo containers, ballast and lashing methods not provided by KR.
Unsafe Decisions and Control Actions	• Did not inspect drawings with actual structures. • Did not inspect lashing methods for new Korean and European vehicles. • Did not provide required load limit, type of cargo containers, ballast and lashing methods to KSA and ROKCG.	• Did not validate data in OMR with the data approved by the KR. • Did not find ballast water not described in OMR. • Did not inspect lashing methods/devices to vehicles and cargo containers. • Did not inspect safety equipment. • Relied on voluntary compliance with guidelines.
Process Model Flaws	• Believed Chonghaejin Marine followed required load limit, ballast water and lashing methods. • Believed Chonghaejin Marine would provide required load limit, ballast water and lashing methods to KSA and ROKCG. • Believed modification plan drawings of lashing and securing passenger vehicles satisfied with new Korean and European vehicles.	• Believed OMR written based on the data approved by the KR • Believed safety equipment and lashing methods/devices operable and ready to use.

Korea Ministry of Oceans and Fisheries:

The Minister:

The Minister was responsible for enforcing legislation, regulations and policies applying to construction and operation of maritime transportation systems and providing oversight and feedback loops to ensure that maritime transportation system regulatory bodies (KR, KSA, ROKCG, Liferafts/Chutes Inspection Certified Company) are carrying out their responsibilities adequately. Although regulatory agencies such as the KR and the KSA were included in the Safety Control Structure, there was no implication that the KMOF government level body was required for safety. The only requirement was that responsibility for safety was distributed in an appropriate way throughout the safety control structure. However, if the private companies or industries such as Chonghaejin Marine, Woo-Ryun Transportation Company and Won-Kwang Company were unwilling or incapable of carrying out the safety responsibilities, then the government should have stepped in to achieve the overall safety goals. For example, Chonghaejin Marine had assigned an annual budget of US $2 for the safety training of a crewmember, which was used to buy a piece of certificate paper, and had not provided the crew with the planned training. In addition, travelers and ships using Maritime Transportation in South Korea had increased every year: passengers - 1.6 millions in 2013 vs. 0.94 millions in 2001, and ships - 173 in 2013 vs. 159 in 2001. However, the number of Operation officers at KSA had been reduced: 74 in 2012 vs. 91 in 1995. This trend appeared to cause the Operation Officer to skip inspecting critical safety-related checkpoints such as loading and lashing conditions and reviewing "Ferry safety inspection chart: before-departure" before the departure. The responsibility should have shifted from the individual companies to the government because the companies no longer had the ability to control the risks around them and were demanding that the government assume greater responsibility for ensuring safety through laws and various forms of oversight and regulation as the companies struggled to balance safety risks with pressure to satisfy budgetary and financial goals. However, the KMOF did not detect and correct the safety issues overlooked by the KR, KSA and Liferafts Inspection Company before the accident.

Table 10 The role of Korea Ministry of Oceans and Fisheries in the accident (Process 1: Safe operations of the ferry)

	Korea Ministry of Oceans and Fisheries The Minister
Safety Related Responsibilities	• Enforce legislation, regulations and policies applying to construction and operation of maritime transportation systems. • Provide oversight and feedback loops to ensure that maritime transportation system regulatory bodies (KR, KSA, ROKCG, Liferafts/Chutes Inspection Certified Company) are carrying out their responsibilities adequately.
Context in which Decisions made	• Antiregulatory culture. • Relied on voluntary compliance with regulations, policies and guidelines (KR, KSA, Liferafts/Chutes Inspection Certified Companies, Chonghaejin Marine).
Unsafe Decisions / Control Actions	• Did not oversight Chonghaejin Marine, KR, KSA and Liferafts/Chutes Inspection Certified Company. • Insufficient controls to detect and correct "overlook" by Chonghaejin Marine. • Insufficient controls to detect and correct "overlook" by KR. • Insufficient controls to detect and correct "overlook" by KSA. • Insufficient controls to detect and correct "overlook" by Life-raft Inspection Certified Company.
Process Model Flaws	• None.

Figure 9 shows the actual state of Safety Control Structure for Process 1 of "Safe operations of the ferry." The red dot lines in Fig. 9 highlight control actions, controlled variables, measured variables, and control feedback that were either missing or incomplete in the actual Safety Control Structure. And the red line arrows in Fig. 9 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.

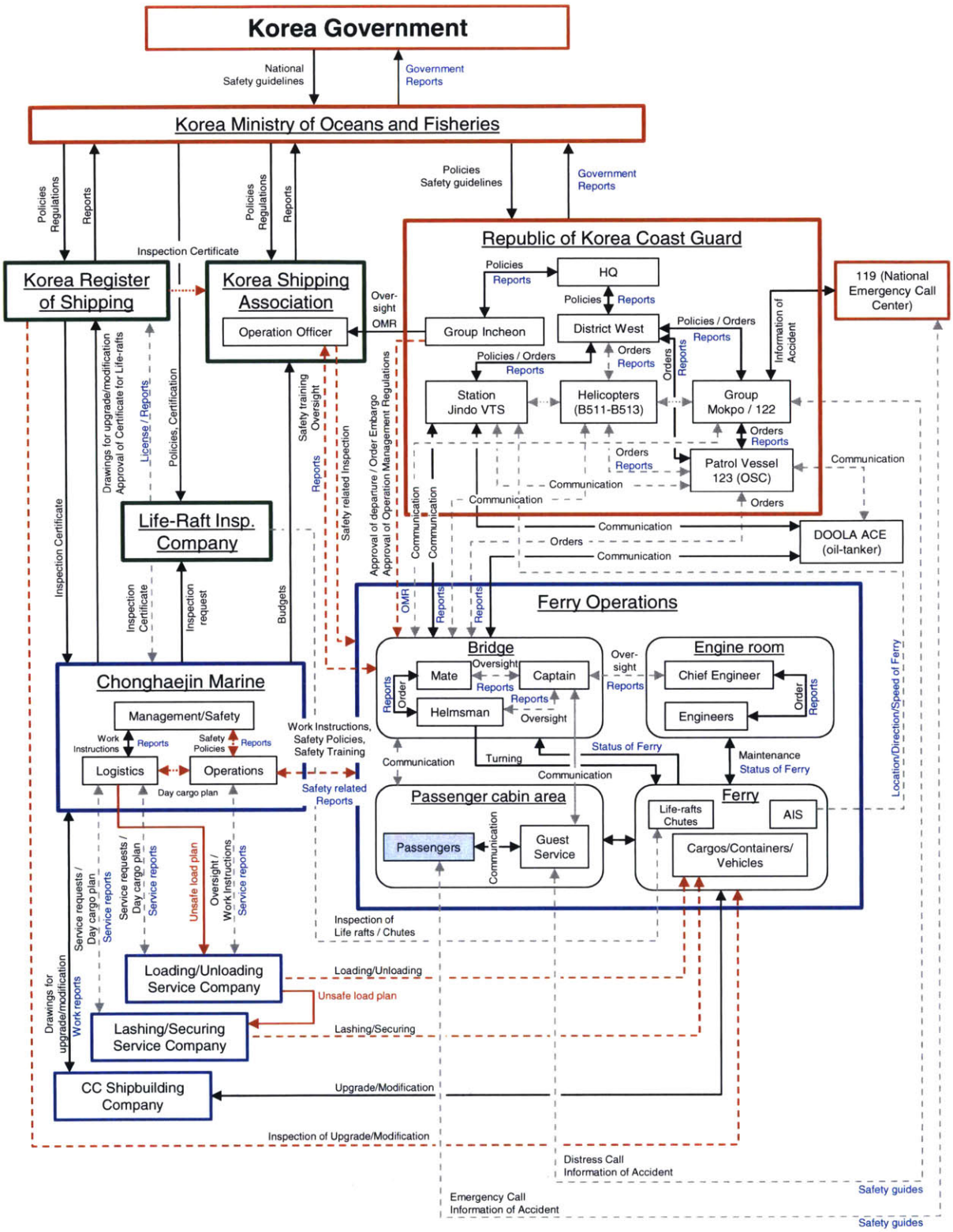


Figure 9 Actual state of Safety Control Structure for Process 1 of "Safe operations of the ferry"

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

The process begins with the ferry's listing and ends with the ferry's sinking. In the process, the following controllers need to be included in the CAST analysis:

- Passengers: Passengers in the cabins, Teachers, Passengers in the lobby, Students and passengers who stayed on decks, the first rescued person
- Sewol-Ho Operations: Crewmembers at the Guest Services Desk - the Chief communications officer and communications officer; Crewmembers on the bridge - Immanuel and Alex (singers), Captain, First, Second, and third mates, three Helmsmen; Crewmembers in the engine room - Technicians, the Chief engineer, First and Third engineers
- Chonghaejin Marine Company: Safety Director, Management
- ROKCG: The commander of Patrol Vessel-123, the pilots and rescuers of Helicopters B511, B512, and B513, the communications operation officer of Station Jindo-VTS, the watchstander (monitoring ships) of Station Jindo-VTS, the communications officer of Group Mokpo (receiving the distressed calls on 122, the Korea National Maritime Distress Service Call Number), and the commanders of Group Mokpo, District West, and HQ
- Liferafts Inspection Company (Korean Marine Safety Systems Co.): Inspector
- Korea Register of Shipping (KR): Inspector
- Korea Ministry of Oceans and Fisheries (KMOF): The Minister of KMOF
- ROKCG Group Incheon: Officer as reviewers
- Others: The Captain of DOOLA ACE, Fishing boats

For better understanding this process, the ferry's Operations was split into three groups of controllers by considering their independence due to the disconnected communication among them: Crewmembers at the Guest Services Desk, Crewmembers on the bridge, and Crewmembers in the engine room. By splitting into three groups, more associated reviews were possible about safety related responsibility, unsafe decisions and control action, process model flaw and context instead of individually describing each controller.

Passengers:

Passengers in the cabins:

When the ferry started to list, some of them tried to go out from the cabins, but came back to their cabins when they heard the announcement for "passengers to stay put in their cabins." Especially passengers who stayed together in the larger cabins and were mostly students followed the announcements until the power in the ferry went out and water came into the cabins. Some of them tried to go out when they heard the helicopters, but gave up, came back and stayed in the cabins because they had heard the announcement for "passengers to stay put in their cabins." Therefore, most passengers did not do anything but send and receive SNS texts to/from parents and friends until they saw water coming into the cabins. Students in the cabins on the port window side who saw water coming in earlier went out first, and many of them survived, while only one of twenty-one who stayed in the cabins at the middle with no windows survived. Even after water came into the cabins, most students moved to the aisle orderly and stood in queues awaiting their turn calmly because they were told that a few ROKCG SAR units were rescuing people. During the time, 23 calls were made to 119 including Choi, Duk-Ha's call, 13 of 23 were connected to 119 to inform about the situation in the distressed ferry.

They believed that the crewmembers and the ROKCG would rescue them. They believed that they had to wait for their rescue turn as a few ROKCG units were busy in rescuing other passengers, and also the crewmembers should have more information and experiences about the rescue operations and because they had seen several crewmembers at the Guest Services Desk were busy in helping passengers, they believed ultimately that the crewmembers would guide them be rescued.

Teachers:

Teachers followed the announcement of "passengers stay put" and therefore, helped students stay in the cabin by staying together with the students until the cabins were submerged. Teachers asked students to obey the order and therefore, most students had stayed with teachers in the cabins.

After water came in the cabins, they helped students move to the aisle orderly and stood in queues awaiting their turn. Most of them were not rescued because they waited for their turn after the students.

Until water started coming in, they believed that the crewmembers and the ROKCG would rescue them. They believed that they had to wait their turn as the ROKCG units were busy in rescuing other passengers and also the crewmembers should have more information and experiences about the rescue operations.

Passengers in the lobby:

When some passengers aggressively asked and complained to the crewmembers at the Guest Services Desk about the evacuation plan, an old passenger advised them not to do that. Therefore, the passengers stopped asking and complaining about it further.

Choi, Jae-Young who was a passenger and truck driver, had stayed in the lobby for about 1 hour after the list and jumped into water when he saw water coming. When he was rescued by the ROKCG Patrol Vessel-123, he told the ROKCG officers that there were many passengers inside, but it was too late to rescue the passengers when the ROKCG Patrol Vessel-123 came back to the ferry (around 1000).

He had tried to get all the information about the situation: the ferry's listing, the water level in the ferry, and the rescue activities of the ROKCG units. Based on what he learned, he decided to escape from the ferry by himself.

Students and passengers who stayed on decks:

Shin, Woo-Hyuk who stayed on a deck when the ferry started to list, saw the ferry's listing and cargo containers were falling into water and stayed outside waiting for the rescue. Some passengers who stayed outside at that moment did not follow the announcement but instead, helped other passengers climb the deck from the cabins, cafeteria and lobby because they thought the situation was so serious. They were all rescued and survived. He testified at the court (07/29/2014) that even though he heard the announcement for "passengers to stay put in their cabins," he did not go back and wait in the cabin, but instead, helped others put on the lifejackets and climb out to the decks because he saw the cargo containers were floating on water when the ferry started to list.

Kim, Dong-Soo was a passenger and truck driver who frequently traveled from Incheon to Jeju Island using the ferry and therefore, knew the ferry's inside pretty much. When the ferry was listing, he went up to the rooftop to check the situation and came back to rescue students who stayed in the cafeteria and the lobby. He also helped passengers get in the rescue basket dropped from one of the helicopters because no rescuers came down at the time, around 1000 when the ferry was listing to port almost 90 degrees.

All of them physically saw the severity of the ferry with their naked eyes, decided to escape, and helped others do so.

The first rescued person:

Kim, Jong-Im was the cook and the first person rescued by the Helicopter, B511. When the ferry was about to list, she got her ribs broken in the kitchen but climbed to the 4th deck through crew-only-stairs while ignoring the announcement about "safety" i.e. "passengers stay put." She did not notify the rescuers that there were many passengers inside nor was she asked by the rescuers about the situation in the ferry (at 0934).

Table 11 The roles of Passengers in the cabins, and in the lobby and on decks in the accident (Process 2: Rescue operations of people on the distressed ferry)

	Passengers in the cabins	Passengers in the lobby and on decks
Safety Related Responsibilities	• Watch and listen passenger safety announcement. • Understand what to do in an emergency.	• Watch and listen passenger safety announcement. • Understand what to do in an emergency.
Context in which Decisions made	• The departure was delayed due to fog. • More than a half of passengers were high school students on a field trip. • No one on the ferry experienced this type of accident before. • Teachers stayed together with students in their cabins when the order of "passengers stay put" was announced. • Teachers asked students to obey the order of "passengers stay put."	• They had seen the situations outside to get all information about the situation: the ferry's listing, the water level in the ferry, and the rescue activities of the ROKCG units.
Unsafe Decisions and Control Actions	• Did not watch passenger safety announcement video on monitors.	• Did not watch passenger safety announcement video on monitors.
Process Model Flaws	• Believed the announcement. • Believed the crew and ROKCG rescued them. • Believed they had to wait their rescue turn as a few ROKCG units were busy in rescuing other passengers. • Believed the crewmembers would have more information and experiences about the rescue operations. • Believed the crewmembers would guide them be rescued because they had seen several crewmembers at the Guest Services Desk were busy in helping passengers.	• Based on what they got, they judged to escape from the ferry for himself.

Sewol-Ho Operations - Crewmembers at the Guest Services Desk:

When the ferry was listing, three of five hand-held two-way radio transceivers were lost. Only the Chief communications officer and another crewmember, Park, Ji-Young at the Guest Services Desk held them. When the second mate called the Guest Services Desk to order to announce "evacuation" several times with his hand-held two-way radio transceiver, they appeared to be too busy in helping passengers to receive the calls. The survivors testified at the court (07/29/2014) that they had heard the order for "passengers to stay put."

There were no commands provided to crewmembers at the Guest Services Desk to announce "evacuation." The crewmembers including the Chief communications officer and even Ahn, Hyun-Young, who was an entertainment show staff, had stayed with passengers and thus helping them to die. They followed the procedures as shown in a table of Emergency Deployment Readiness Exercise (EDRE) of the Sewol-Ho's Operation Management Regulations Document. They appeared to be enough contact points to the passengers and have the full responsibilities of the passengers' safety and therefore, they had been with passengers to the final moment.

Chief communications officer:

When the ferry was in distress, the Chief communications officer was responsible for announcing safety and evacuation as the Captain ordered and for helping passengers to evacuate. The Chief communications officer, Yang, Dae-Hong was 45 years old and joined Chonghaejin Marine in 2010. When the ferry started to list, the Chief communications officer had helped passengers stay safe. After 5 minutes, he ordered the communications officer to announce about "safety" but did not give him the details. Helping passengers by moving around appeared to prevent him from maintaining communication with the bridge effectively because no communication channels were available other than using hand-held two-way radio transceivers. He appeared not to hear and respond to the order of "evacuation."

When water came into the cabins, the Chief communications officer with other crewmembers at the Guest Services Desk, Ahn, Hyeon-Young, Jeong, Hyun-Seon and Park, Ji-Young, the high school teachers and some adult passengers helped students to escape from the submerging cabins.

Communications officer:

The communications officer was responsible for guiding passengers when the ferry was in distress. The communications officer, Kang, Hae-Seong was 33 years old. The communications officer made the first announcement for "passengers to stay put" on his own judgment and later, got the order of the announcement from the Chief communications officer, Yang, Dae-Hong. The communications officer assumed that because there was no straightforward process or procedure for an announcement of what to do for safety, the announcement about safety procedures should give the passengers "a sense of security or safety." However, he did not ask for details about what announcement was required. Moreover, he thought passengers' moving would make the listing of the ferry worse.

He had waited for an order of evacuation from the Chief communications officer or the bridge and continued waiting for it until the broadcasting system was submerged and not working. He thought that he could not make the announcement without an order from the bridge because he had no safety training. He could not know the rescue progress and means because he had stayed inside of the ferry to help injured passengers.

Table 12 The roles of the Guest Services Desk (Process 2: Rescue operations of people on the distressed ferry)

	Guest Services Desk Chief communications officer	Guest Services Desk Communications officer
Safety Related Responsibilities	• Announce safety and evacuation as the captain ordered. • Help passengers evacuate the distressed ferry.	• Announce safety and evacuation as the captain or Chief communications officer ordered. • Help passengers evacuate the distressed ferry.
Context in which Decisions made	• Inadequate training. • No one on the ferry experienced this type of accident before. • Dysfunctional communication channels to the bridge other than using hand-held two-way radio transceivers. • Had been busy in helping passengers.	• Inadequate training • No one on the ferry experienced this type of accident before. • Dysfunctional communication channels to the bridge other than using hand-held two-way radio transceivers. • No rescue operations feedback from ROKCG when and after made the distressed call.
Unsafe Decisions and Control Actions	• Did not listen the evacuation order from the bridge.	• Did not listen the evacuation order from the bridge.
Process Model Flaws	• Believed staying inside the ferry was safer than in water. • Believed the captain would order the evacuation.	• Believed staying inside the ferry was safer than in water. • Believed the captain would order the evacuation. • Believed the announcement about "safety" would be giving "a sense of security or safety" to passengers, but he did not know details about the announcement of "safety." • Believed passengers' moving would make the listing of the ferry worse.

Sewol-Ho Operations - Crewmembers on the bridge:

The crewmembers including the Captain testified at the court (10/20/2014) that they had no intentions of abandoning passengers. They did make the distress calls, orders to put on PFDs and to evacuate, tried to activate liferafts and to help the ROKCG rescue passengers. They could not do more because the ferry was listing severely and they were in mental panic. The testimony at the court included limited detail and motives of the crewmembers' actions during the rescue operations process. A number of "whys" about the crew's actions and the context in the rescue operations process could not be answered with the details provided by the court testimony.

They had arrived on the bridge hoping they could recover from the listing of the ferry. The crewmembers including the Captain however, found that the ferry's listing could not be reversed, and therefore evacuation was required. Therefore, it could be concluded that the crew might experience strong emotions when they found no further possible operation means on the bridge.

The first problem was that the order of the evacuation decision did not seem to be assigned to anyone other than the Captain. While the rule of "the Captain only can order the evacuation" might seem reasonable, it had a serious drawback because one consequence of such a lack of assigned control responsibility was that the crew on the bridge might think that the Captain would take the initiative. What if the Captain was in panic and could not judge the situation correctly? Although the crew on the bridge should report problems when necessary, the Captain had the actual responsibility, authority, and accountability to do so as the OMR stated. There should also be backup procedures for others to step in when the Captain did not execute his or her responsibility correctly.

When the second mate on the bridge tried to announce the order to passengers, he mistakenly pressed only the side button of the hand-held microphone and found that it was not working. No one knew they could use a telephone line to announce emergency calls from the bridge to all areas in the ferry "simply by pressing zero." Based on their actions, they appeared not to have been trained on physical emergency and rescue operations.

All crewmembers including the Captain on the bridge were rescued by the Patrol Vessel-123. As they were rescued, they saw people coming out from the inside and thought that the announcement to evacuate had been made. Therefore, they did not activate another emergency alarm lever at the outside of the bridge.

Immanuel and Alex (singers):

Immanuel and Alex, who were a Pilipino couple and entertainers hired to perform on the ferry. When the ferry was listing, they got lifejackets in their cabin and went to the bridge to ask what to do. Alex testified at the court (07/28/2014) that when she arrived on the bridge, she saw all crewmembers including the Captain were just standing without doing anything and in silence. When Alex saw the Captain did not make any safety orders, she asked her husband, Immanuel to say "lifeboats" to the Captain, and then, the Captain ordered the activation of the liferafts. Based on that testimony, it appears that the operational procedures for emergencies described in the OMR were not working at all.

The Captain:

The Captain was responsible for the following:

- Providing safety training and drills to the crew periodically every 10 days.
- Making distress calls to ROKCG, the company, nearby ships and VTSs and coordinating the safety operations with them when the ferry is in emergency situations.
- Commanding all crewmembers to carry out each safety roles and to provide safety operations to passengers when the ferry is in emergency situations.

Because he was a part time Captain, he had not provided any safety training to the crewmembers. When the ferry was listing to port, he was in panic and shivering, and he could not sense the situation well, murmuring that "the ferry was not listing anymore," and collapsed. He made some decisions related to the safety as crewmembers asked, i.e., an order to put on lifejackets and an order to activate liferafts. The OMR did not describe who the higher level officer was if the Captain was not capable of managing the situation. Someone on the ferry like the Chief communications officer or the first mate had to be nominated to take the place of the Captain. However, it was almost impossible to do so

unless the Captain was physically injured. Without the Captain's control or granting permission, three mates and one helmsman randomly had communicated with the Station Jindo-VTS on VHF FM channels.

When the Station Jindo-VTS asked the Captain to decide on an order of "evacuation," he did not make a decision immediately for three reasons: ROKCG SAR units would arrive soon; the DOOLA ACE was not suitable to rescue passengers; the water current was fast, and the temperature was too low for people to survive. However, he did not consider that listing 55 degrees was too steep for passengers to escape from the cabins. When the Helicopter B511 arrived on scene and the first mate asked the Captain to announce the order to evacuate, the Captain ordered the second mate to announce it. The Captain did not check whether the Guest Services Desk received and announced the order. Unfortunately, the announcement from the Guest Services Desk was set not to broadcast on the bridge, and therefore, he simply assumed that the order was announced to passengers. At the court, the Captain had apologized for his actions saying that he was "confused" at the time of the accident and was unaware of that abandoning the passengers would lead to many deaths.

The First Mate:

The first mate was responsible for controlling the operations and activating and operating the chutes on the starboard side. Because the Captain was in panic and the third mate, (who should have been in charge of making distress calls to VTS or ROKCG) was crying, the first mate made the first distress call to the Station Jeju-VTS (under the KMOF directly) on VHF FM channel 12 on his own judgment without an order from the Captain, after switching from the VHF FM channel 67 which was set for communication with the Station Jindo-VTS. He reported that the ferry was capsizing and in danger and asked them to notify the ROKCG about the ferry's listing. It can be inferred from the call asking ROKCG's help that he might have had strong emotions during the time. He could call ROKCG directly on 122 or VHF FM channel 16, but instead the first mate thought that the ferry was close to Jeju Island because he forgot about the 2.5 hours of the departure delay.

Table 13 The role of the Captain on the bridge (Process 2: Rescue operations of people on the distressed ferry)

	Sewol-Ho crewmembers on the bridge Captain
Safety Related Responsibilities	• Follow and practice rules of safe operations per the OMR. • Provide safety training and drills to the crew periodically every 10 days. • Make distress calls to ROKCG, the company, nearby ships and VTSs and coordinating the safety operations with them when the ferry is in emergency situations. • Command all crewmembers to carry out each safety role and to provide safety operations to passengers when the ferry is in emergency situations.
Context in which Decisions made	• Poor morale. • Insufficient safety operations guidelines in the OMR. • The OMR did not describe who the higher level officer was if the captain was not capable of managing the situation. • No one on the ferry experienced this type of accident before. • The ferry's listing and the resulting capsizing were progressing too fast. • Inadequate training. • The captain was a part-time and did not provide any safety training to the crewmembers. • The captain was in panic and collapsed absent-mindedly at a corner on the bridge. • The captain made some decisions related to the safety as the crewmembers and the singers on the bridge asked and requested. • Three Mates and one Helmsman randomly had communicated with the Station Jindo-VTS on VHF FM channels.
Unsafe Decisions and Control Actions	• Did not notify "passengers stay put" to ROKCG. • Did leave the ferry before the passengers. • The captain asked the third mate to document the fictitious training records every 10 days. • Inadequate capability to contact ROKCG units on scene. • Inadequate capability to detect and correct "the wrong procedure in making emergency announcement on the bridge" of the second mate. • Inadequate capability to detect and correct "the wrong procedure in making distress call to the Station Jeju-VTS" of the first mate. • Inadequate capability to order the crew to activate liferafts and chutes on time. • Inadequate capability to order the evacuation order on time. • Insufficient controls to confirm the Guest Services Desk made "the announcement of the evacuation order." • Insufficient controls to activate additional emergency alarms.
Process Model Flaws	• Believed accidents by capsizing or sinking were rare. • Believed more ROKCG SAR units would arrive soon. • Believed the DOOLA ACE not suitable to rescue passengers. • Believed the water current was fast and the temperature was low for people. • Believed "the announcement of the evacuation order" received and made by the Guest Services Desk. • Believed the severe list prevented the crew from going to where the passengers were. • Believed the severe list prevented the passengers from escaping from the inside.

The weather was so good, and therefore, the call from the Sewol-Ho on VHF FM channel 12 was received by the Station Jeju-VTS although the distance between the two was 60 miles while communication on the VHF-FM was usually possible only for 20 miles. Later, he contacted the Station Jindo-VTS, which was the closest VTS, and asked about whether to order evacuation, but received no directions about evacuation from the Station Jindo-VTS.

After the communication, he went to his cabin to get his cell phone to call the safety team at Chonghaejin Marine. He talked with the safety team at Chonghaejin Marine for 35 minutes and therefore, had neither time to oversee the operations nor time to control the bridge on behalf of the Captain. Due to the absence of the Captain and the first mate, several crewmembers had been involved in communication with the Station Jindo-VTS without providing the information about the passengers being told to stay put.

He told the Captain that the clips of the liferafts did not work when he received the order from the Captain and therefore, could not activate them. He already knew the liferafts did not work. However, as the OMR directed, he tried to reach the liferafts and chutes at port side but could not reach them due to the list.

Later, when the Patrol Vessel-123 came to the ferry, an officer, Lee, Kyung-Rae went up the ferry to activate the liferafts. Judging from this, the first mate could have reached and activated the liferafts if he had taken the required safety training.

The Second Mate:

The second mate was responsible for activating and operating the chutes on the port side. When the Captain ordered the second mate, Kim, Young-Ho to announce that passengers put on lifejackets and more clothes, the second mate tried to announce the order to passengers, mistakenly by pressing only the side button of the hand-held microphone, but found that it was not working. The second mate had to press two additional buttons, emergency and alarm ones to make emergency announcements to all areas in the ferry.

Table 14 The role of the First Mate on the bridge (Process 2: Rescue operations of people on the distressed ferry)

	Sewol-Ho crewmembers on the bridge First Mate
Safety Related Responsibilities	• Follow and practice rules of safe operations per the OMR • Conduct the scene when distressed. • Take safety training and drills periodically every 10 days. • Activate and operate chutes at starboard side.
Context in which Decisions made	• Poor morale. • Insufficient OMR safety operations guidance. • No one on the ferry experienced this type of accident before. • The ferry listed initially with 30 degrees, and therefore, he could not reach liferafts and Chutes. • The ferry's listing and the resulting capsizing were progressing too fast. • Inadequate training. • Drills for emergency response not provided. • The ferry departure was delayed 2.5 hours and he forgot the delay. • The captain was in panic and collapsed absent-mindedly at a corner on the bridge. • The OMR did not describe who the higher level officer was if the captain was not capable. • The third mate was crying, who was in charge of making distress calls. • He had talked with the company on his cell phone for more than 30 minutes. • The weather was so good and the call from the Sewol-Ho was received by the Station Jeju-VTS. • Directions about the evacuation not given from the Station Jindo-VTS when he contacted the VTS and asked about "to order evacuation." • Inadequate communication with ROKCG on VHF FM channel 12. • Fell down the wing bridge where the Vessel-123 was waiting for rescuing people, triggering all crew escaped from the bridge • The ROKCG did not ask the identity during the escape.
Unsafe Decisions and Control Actions	• Physical safety training and life-raft drills not taken. • Did leave the ferry before the passengers. • Exact status of the situation not provided to ROKCG. • Relied on the captain in panic to make the evacuation decision. • Inadequate capability to make first distress call. • Inadequate capability to detect and correct "the wrong procedure in making emergency announcement on the bridge" of the second mate. • Inadequate capability to reach liferafts and chutes. • Inadequate capability to activate additional emergency alarms. • The scene not conducted and crew on the bridge on behalf of the captain not controlled.
Process Model Flaws	• Believed accidents by capsizing or sinking were rare. • Believed the severe list prevented the crew from going to where the passengers were. • Believed the severe list prevented the passengers from escaping from the inside. • Believed all broadcasting systems on the bridge out of order. • Believed all communication means on the bridge not working (an emergency alarming sound system and a telephone line).

From that moment, all crewmembers including the second mate on the bridge assumed, however, that all broadcasting systems on the bridge were out of order, and therefore, no one tried them again. Also, he assumed all communication means on the bridge were not working, which included an emergency alarming sound system and a telephone line to announce the emergency calls to all areas in the ferry. All communication with crewmembers at the Guest Services Desk had made only with hand-held two-way radio transceivers. Judging from this situation, the second mate could try again to announce the broadcasting systems including the emergency announcement system if he had had the required safety training.

When the second mate notified the Station Jindo-VTS on VHF FM channel 67 that the broadcasting equipment was out of order, the Station Jindo-VTS told the second mate to order the passengers personally to put on lifejackets and more clothing. The second mate did not, however, follow the order.

From the testimony of several crewmembers at court (10/20/2014), their escape happened accidently. The first mate who was leaning against the bridge's door fell to the wing bridge as the door was falling. The first mate hit Helmsman Park, who tried to reach liferafts on the port side, falling to the wing bridge where the Patrol Vessel-123 came alongside the wing bridge. The second mate shouted to the Captain who collapsed in the corner, and to Alex and Immanuel to move. The second mate also helped the third mate and the rest of crewmembers move. He assumed that the ROKCG officers noticed they were the crewmembers but allowed them to escape from the ferry

Once he was rescued and went back to the ferry to rescue passengers together with ROKCG officers of the Patrol Vessel-123, he volunteered to rescue passengers and practice artificial respiration. Judging from this situation, the second mate could have helped evacuate passengers if rescue operations had been ordered.

Table 15 The role of the Second Mate on the bridge (Process 2: Rescue operations of people on the distressed ferry)

	Sewol-Ho crewmembers on the bridge Second Mate
Safety Related Responsibilities	• Follow and practice rules of safe operations per the OMR • Take safety training and drills periodically every 10 days. • Activate and operate chutes at port side.
Context in which Decisions made	• Poor morale. • Insufficient OMR safety operations guidance. • No one on the ferry experienced this type of accident before. • The ferry listed initially with 30 degrees, and therefore, he could not reach liferafts and Chutes. • The ferry's listing and the resulting capsizing were progressing too fast. • Inadequate training. • Drills for emergency response not provided. • The captain was in panic and collapsed absent-mindedly at a corner on the bridge.
Unsafe Decisions and Control Actions	• Physical safety training and life-raft drills not taken. • Did leave the ferry before the passengers. • Exact status of the situation not provided to ROKCG. • Relied on the captain in panic to make the evacuation decision. • Inadequate capability to make emergency announcements to all areas in the ferry. • Inadequate capability to reach liferafts and chutes. • Inadequate capability to detect and correct "the wrong procedure in making distress call to the Station Jeju-VTS" of the first mate. • Inadequate capability to confirm the Guest Services Desk made "the announcement of the evacuation order." • Inadequate capability to activate additional emergency alarms.
Process Model Flaws	• Believed accidents by capsizing or sinking were rare. • Believed the severe list prevented the crew from going to where the passengers were. • Believed the severe list prevented the passengers from escaping from the inside. • Believed all broadcasting systems on the bridge out of order. • Believed all communication means on the bridge not working (an emergency alarming sound system and a telephone line). • Believed "the announcement of the evacuation order" received and made by the Guest Services Desk.

The Third Mate:

The third mate was responsible for assisting the Captain and communicating with ROKCG units and VTS as the OMR directed. The third mate, Park, Han-Gyeol testified at the court (10/06/2014) that she participated a fire drill exercise in February 2014, which was just reading each role in the paper and, as the predetermined instruction provided, was responsible for announcing "evacuation" when the Captain ordered it. With that as her only safety training, she had no knowledge of how to handle non-routine events. However, under the direction of the regular Captain, she had recorded the fictitious training information in the Sewol-Ho's logbook every ten days as described in the OMR.

When the ferry listed, she just obeyed the Captain's orders as she had been told to do. However, when the Captain was in panic, she could not make any evacuation decisions because there were experienced crewmembers on the bridge, including three more mates who were at a higher level than her. She did not know how to assist the Captain in panic, and without his direction, could not communicate with ROKCG units and VTS.

Table 16 The role of the Third Mate on the bridge (Process 2: Rescue operations of people on the distressed ferry)

	Sewol-Ho crewmembers on the bridge Third Mate
Safety Related Responsibilities	• Follow and practice rules of safe operations per the OMR • Take safety training and drills periodically every 10 days. • Assist the captain. • Communicate with ROKCG units and VTS.
Context in which Decisions made	• Poor morale. • Insufficient OMR safety operations guidance. • No one on the ferry experienced this type of accident before. • The ferry listed initially with 30 degrees, and therefore, he could not reach liferafts and Chutes. • The ferry's listing and the resulting capsizing were progressing too fast. • Inadequate training. • Drills for emergency response not provided. • The ferry departure was delayed 2.5 hours. • The captain was in panic and collapsed absent-mindedly at a corner on the bridge. • The third mate was crying and scared.
Unsafe Decisions and Control Actions	• Physical safety training and life-raft drills not taken. • Did leave the ferry before the passengers. • Exact status of the situation not provided to ROKCG. • Relied on the captain in panic to make the evacuation decision. • Dysfunctional communication with ROKCG units. • Inadequate capability to detect and correct "the wrong procedure in making distress call to the Station Jeju-VTS" of the first mate. • Inadequate capability to detect and correct "the wrong procedure in making emergency announcement on the bridge" of the second mate. • Inadequate capability to activate additional emergency alarms.
Process Model Flaws	• Believed accidents by capsizing or sinking were rare. • Believed all broadcasting systems on the bridge out of order. • Believed all communication means on the bridge not working (an emergency alarming sound system and a telephone line).

Helmsmen:

The Helmsmen were responsible for activating the liferafts on the port and starboard sides as the OMR directed. Two Helmsmen, Cho, Joon-Ki and Oh, Yong-Seok went to the starboard side to drop liferafts without receiving the order from the Captain or the first mate, but failed to reach the liferafts due to the list of 60 degrees.

Another Helmsman, Park, Kyung-Nam who was 60 years old, the second oldest crewmember on the bridge and had a fourth Mate license, communicated with the Station Jindo-VTS on VHF FM channel 67. He asked about if abandonment or evacuation had to be ordered. The Station Jindo-VTS replied that the Captain had to make the decision, explaining that the Station Jindo-VTS could not make the decision because they did not have the required information available about the state of the ferry. He also tried to contact the Patrol Vessel-123 on VHF FM channel 16 but was unsuccessful. He was not responsible for communicating with the ROKCG units and the VTS but he could do it on the bridge because he was the second oldest crewmember (the captain was the oldest) and had a fourth Mate license.

Once they were rescued and went back to the ferry to rescue passengers together with ROKCG officers of the Patrol Vessel-123, they volunteered to break window glass and rescue passengers. Judging from this situation, the Helmsmen could have helped evacuate passengers if orders for the rescue operations had been made to them.

Sewol-Ho Operations - Crewmembers in the engine room:

They had waited in the cabins as the Guest Services Desk announced that "passengers should stay put." They saw that two cooks had fallen from the fourth deck and injured seriously. They were so terrified that they forgot to notify the ROKCG, the bridge or the Guest Services Desk about the injured cooks.

They assumed that they could not be rescued due to too many passengers on the distressed ferry. They were scared of not being rescued and assumed that rescuing about 400 passengers would require too much time for the small Patrol Vessel and a few of

helicopters to rescue all of them. They drank beer to calm down when they saw the cooks were bleeding from their heads, and they were terrified as they had not got any rescue help from the ROKCG SAR units for the previous 10 minutes. Therefore, they waved for help when they saw a boat coming from the Patrol Vessel-123. Without taking the two injured cooks, they simply escaped to the boat. Even though some of them wore uniforms and the third engineer said she was a crewmember to the ROKCG officers, the officers helped them come across to the boat from the distressed ferry due to the severe list and urgent situation. They were the first rescued by the Patrol Vessel-123. Based on the testimony by the crewmembers at the court (08/12/2014), the ROKCG officers shouted to them "Jump into the boat. It is capsizing now. Hurry up." Therefore, they moved to the boat. However, an officer, Park, Eun-Seong testified at the court (08/13/2014) that due to the urgent situation, he did not remember what she said but that he shouted to her, "lady first."

Technicians:

The technicians were responsible for activating the chutes and lowering ladders on the port and starboard sides as the OMR directed. They were all terrified. They waited for orders from the engineers. Some of them assumed from a fire drill exercise held in February 2014, that rescuing passengers was the responsibility of crewmembers including the Chief communications officer at the Guest Services Desk.

The Chief technician, Jeon, Young-Joon, had joined the Sewol-Ho for the first time and therefore, did not know what to do but waited for orders from the engineers. He had not received any safety training or guide from Chonghaejin Marine.

The Chief engineer:

The Chief engineer was responsible for conducting all engineers and the engine room as the OMR directed. The Chief engineer, Park, Ki-Ho, 54 years old, ordered on his own judgment, evacuation of the engine room over inter-phone to the third engineer. When the Captain ordered the Chief engineer to go the engine room but did not specify what to do, perhaps checking the generator to run the anti-heeling pumps, the Chief engineer went out to the engine room from the bridge. On the way down to the engine room, he slid down on

the stairs, gave up going down to the engine room, and instead, joined his engineers in the aisle of their cabins on the third deck. He stayed there with them until rescued.

The First engineer:

The First engineer was responsible for activating the liferafts and chutes on the starboard side as the OMR directed. The First engineer, Sohn, Ji-Tae, 58 years old was wondering about the announcement for "passengers to stay put" while waiting in the cabin, but assumed that he could not do anything without orders from the Chief engineer or the Captain. He had not received any information about evacuation from the bridge and did not know the rescue status. He was scared of not being rescued.

The Third engineer:

The Third engineer was responsible for assisting the Chief engineer as the OMR directed. The third engineer, Lee, Soo-Jin, 26 years old, was the engineer on duty in the engine room. She and two other engineers escaped from the engine room when the Chief engineer ordered "evacuation from the engine room" on the inter-phone. They were terrified as the ferry was listing and the engines stopped and therefore, they had no idea what to do. They simply climbed the stairs and arrived at the cabins where other engineers stayed. They stayed all together until rescued by the ROKCG.

At the court (09/02/2014), when she was asked why she stayed in the cabin instead of helping passengers, she testified that she did not know what to do because she had no information about the status of passengers and the evacuation decision. Instead, she and others, including the Chief engineer, in their cabins had simply waited for orders from the bridge or the Guest Services Desk such as activating liferafts and helping passengers escape. They had waited in the cabins as the Guest Services Desk had announced. She was so terrified that she made her last call to her parents to say "I may die."

The third engineer testified at the court (09/30/2014) that when the ferry listed about 45 degrees to port, she suggested to engineers that they jump into the water but they rejected the suggestion and asked her to calm down. She simply followed those who had more than 20-year experience.

Table 17 The role of the crewmembers in the engine room (Process 2: Rescue operations of people on the distressed ferry)

	Sewol-Ho crewmembers in the engine room
Safety Related Responsibilities	• Follow and practice rules of safe operations per the OMR • Take safety training and drills periodically every 10 days. • Activate chutes and lower ladders at port and starboard sides.
Context in which Decisions made	• Poor morale. • No one on the ferry experienced this type of accident before. • The ferry listed initially with 30 degrees, and therefore, he could not reach liferafts and Chutes. • The ferry's listing and the resulting capsizing were progressing too fast. • Inadequate training. • Drills for emergency response not provided. • The captain did not order anything. • They were scared and terrified not being rescued due to too many passengers.
Unsafe Decisions and Control Actions	• Physical safety training and life-raft drills not taken. • Did leave the ferry before the passengers as the first rescued persons. • Did not follow the safety operations per the OMR • Relied on the captain in panic to make the evacuation decision. • Dysfunctional communication with the bridge. • Did stay together in their cabins without helping passengers. • Did not notify "passengers stay put" to ROKCG when rescued. • Did leave two injured cooks.
Process Model Flaws	• Believed accidents by capsizing or sinking were rare. • Believed rescuing passengers was the responsibility of crew at the Guest Services Desk. • Believed they follow the orders from the bridge or the Guest Services Desk such as activating liferafts and helping passengers escape.

Chonghaejin Marine:

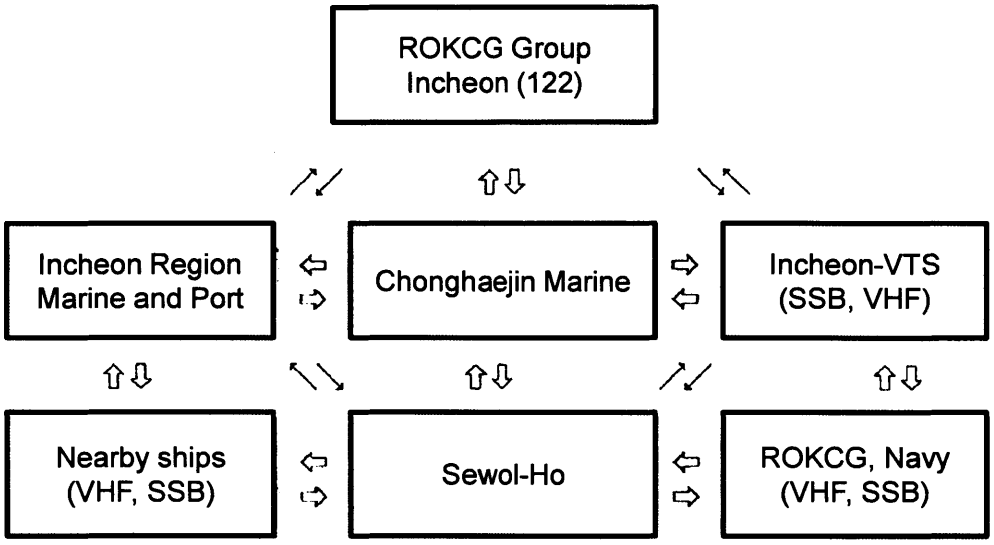
Safety Director and Management:

The Safety Director and Management were responsible for the following:

- Provide and maintain the organizational safety culture.
- Establish the organizational safety policy.
- Develop a safety control structure with appropriate responsibilities, accountability and authority, safety controls, and feedback channels.
- Develop Emergency Deployment Readiness Exercise (EDRE) of Chonghaejin Marine's Sewol-Ho Operation Management Regulations Document (OMR).
- Develop rules and procedures for Rescue Operations of Passengers in the OMR, which help the crew rescue passengers when the ferry is in distress.
- Plan, provide and oversee safety training and evacuation drills for the crew of the ferry as defined in the table of the EDRE in the OMR.
- Plan, provide and oversee safety training and evacuation drills for the crew of the ferry as defined in the rules and procedures of Rescue Operations of Passengers (ROP) in the OMR.
- Establish rules and procedures for effective communication between crew on the bridge and the Guest Services Desk, when the ferry is in distress, in the Operation Management Regulations Document.
- Receive the inspection certificate for the ferry' operations and safety equipment annually.

The Safety Director and Management did not provide and oversee safety training and evacuation drills for the crew other than an exercise practiced for the preparation of ROKCG's safety audit. The budget for safety training per a crew at the company for a year was US $2, which was used to buy a piece of certificate paper.

[Emergency contacts]



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Sewol-Ho's Operation Management Regulations

Figure 10 Emergency Contacts of the ferry's Operation Management Regulations Document (OMR)

The Safety Director and Management assumed that the Sewol-Ho Operation Management Regulations Document was good enough to carry out the rescue operations when the ferry was in distress, and the crewmembers knew how to carry out the procedures because some were experienced crewmembers including the Captain, who would conduct the evacuation when the ferry was in distress. The Safety Director and the Management also believed that the big ferry was safe. Unfortunately, morale at Chonghaejin Marine was very low, and there was a widespread belief among the crew that the management had taken drastic measures to increase profits and the attention to details that ensure safe operations were absent from the management's minds.

Specific rescue operation actions and procedures in the various emergency situations had to be provided explicitly in the Operation Management Regulations Document. The following are what the OMR did not provide about appropriate rescue operation actions:

- The Operation Management Regulations Document said only that the Captain was to make the order to "abandon the ferry" when the ferry should be abandoned. It did not what to do if the Captain was not available or could not make the decision, namely, who else it was to make the decision, (the mate, ROKCG, or the company) and when it was to be announced. The Safety Director and the Management believed that the Captain had enough experience to control and manage the evacuation operations when the ferry was in distress.
- The Operation Management Regulations Document did not describe an effective communication process when there were issues in communication between the bridge and the Guest Services Desk. The crew could not find alternatives other than using hand-held two-way radio transceivers when they made mistakes in the operation of the emergency communication equipment. The Operation Management Regulations Document did not provide the communication process step by step for emergencies but only an emergency contact list as shown in Fig. 10. The Safety Director and the Management believed that the crewmembers on the bridge were good enough at operating equipment and could operate the emergency communication equipment without exercises or training.
- The OMR said that not only could the Captain order the evacuation but also the ROKCG could do so too, which means that there were two controllers to order the evacuation or make an excuse to the other if not ordered.

The Safety Director and the Management thought that because the crew had operated the ferry pretty well for the last year without causing any critical safety-related accidents, they were also experienced enough to carry out rescue operations. They also believed the big ferry was safe because they had not experienced any serious accident before and the crew could easily follow the EDRE in the OMR to rescue passengers, as they testified at the court (10/24/2014). The management was a key to safety, setting the culture, creating the safety policy, and establishing the safety control structure. The management wanted to operate the ferry safely but misunderstood the tradeoffs required to run it safely.

Table 18 The roles of the Safety Director and Management at Chonghaejin Marine (Process 2: Rescue operations of people on the distressed ferry)

	Chonghaejin Marine Safety Director and Management
Safety Related Responsibilities	• Provide and maintain the organizational safety culture. • Establish the organizational safety policy. • Develop a safety control structure with appropriate responsibilities, accountability and authority, safety controls, and feedback channels. • Develop Emergency Deployment Readiness Exercise (EDRE) of OMR. • Develop rules and procedures of Rescue Operations of Passengers of OMR, which guide the crew rescue passengers on the ferry when the ferry is in distress. • Plan, provide and oversight safety training and evacuation drills to the crew of the ferry as defined in the table of the EDRE and the rules and procedures of Rescue Operations of Passengers of OMR. • Receive the certificate of the ferry' operations and safety equipment annually.
Context in which Decisions made	• No critical accident over time. • High personnel turnover.
Unsafe Decisions and Control Actions	• Developed an insufficient EDRE for the OMR. • Developed insufficient rules and procedures for Rescue Operations of Passengers in the OMR. • Did not provide any oversight safety training and evacuation drills to the crew other than an exercise practiced for the preparation of ROKCG's safety audit. • Did not establish rules and procedures of OMR for effective communication between crew on the bridge and the Guest Services Desk when the ferry is in distress. • Provided US $2 for the annual budget for safety training per crew member.
Process Model Flaws	• Believed the EDRE and the rules and procedures of Rescue Operations of Passengers in the OMR were good enough for the crew to carry out the rescue operations. • Believed the crewmembers knew how to carry out the rescue procedures without training. • Believed the captain had enough experiences to control and manage the evacuation operations. • Believed the big ferry was safe.

ROKCG:

In February 2013, the Ministry of Land, Transport and Maritime Affairs was divided into two Ministries: the Ministry of Land, Infrastructure and Transport and the Ministry of Oceans and Fisheries to which the ROKCG belonged.

All ROKCG SAR units on scene, the Patrol Vessel-123 and Helicopters B511, B512, and B513 had the primary role of rescuing people in water or on the decks of the ships or boats in distress. Only 57% of ROKCG annual SAR training requirements had been exercised between 2010 and 2013. Moreover, the members of HQ, District West and Group Mokpo had taken most of the training even without physical exercises or drills. One of the main reasons for the reduction of the training was that some of the SAR tasks were privatized without considering how they would affect the SAR performances of the ROKCG SAR units.

Commander of Patrol Vessel-123:

The commander of the Patrol Vessel-123 as the On-Scene-Commander (OSC) was responsible for rescuing people in the distressed ferry and for this purpose, reporting the latest situation to the ROKCG higher level units when they arrived on scene, and assigning and coordinating rescue operations with the ROKCG Helicopters and the nearby ships. The ROKCG specifically required its personnel to assess the situation before making any attempt to rescue people in the distressed ferry. To assess the situation, the personnel should establish and maintain communications with the people on the distressed ferry, ensure that they are putting on PFDs, and evaluate the rescue operations risks. If the commander had reevaluated the situation as required, he might have realized that it was much more severe than he had thought. The information collected and the initial action taken on scene were critical to the SAR success. Information must be gathered and evaluated to determine the nature of the distress and what action should be taken. However, the ROKCG SAR manual did not include the rescue operations for car ferries and cruises in distress: priorities of ROKCG SAR units on scene, ways of passengers search, putting crewmembers on board to assess the situation and coordination of ROKCG SAR units on scene.

The ROKCG District West appointed the commander of the Patrol Vessel-123 as the On-Scene-Commander (OSC) while the Vessel was approaching the scene. The commander, Kim, Kyung-Il of the Patrol Vessel-123 made two calls to contact the Sewol-Ho on VHF FM channel 16 as requested by the Group Mokpo and described in the SAR manual but was unsuccessful in communicating with the Sewol-Ho. The communication on VHF FM channel 16 between ROKCG units on scene and the Sewol-Ho was not possible because the AMSS running at ROKCG Station Jindo-VTS and VHF FM channel 16 sometimes interfered. An expert of the company that had maintained the AMSS stated in "Report: The Sewol-Ho's abnormal turn" that when the AMSS was set to analyze motions of ships and boats in the area, the System might prevent the ROKCG unit's calls on VHF FM channels including channel 16 from being received by the Sewol-Ho. This interference might cause the communication problem between ROKCG units on scene and between ROKCG units and the Sewol-Ho on VHF FM channel 16. Instead, the commander focused particular attention on cooperation plan with nearby ships on SSB (Single-SideBand modulation) because he was told that there were many passengers on the ferry. This attention to the cooperation plan prevented him from communicating with the helicopters and the Sewol-Ho at that time.

Moreover, **the primary function of the Patrol Vessel-123 was to rescue people in the water, so the commander and members assumed that rescuing people in water was their pre-defined role to perform**. The commander stated at the court that he initially believed that he was on a routine rescue that could be resolved by rescuing people in water. Arriving on scene and seeing the listing ferry and no people waiting on the decks, the crewmembers including the commander were surprised, and then, he forgot reporting the situation of the ferry and passengers to the Group Mokpo. Instead, he launched a rubber boat to the ferry. An officer, who was the acting commander at the Group Mokpo on behalf of Group Mokpo Commander who was on ROKCG Cutter-3009 at that time, did not order the OSC to report the situation when the OSC arrived on scene. The acting commander appeared not to know the procedures described in ROKCG SAR 4-4: Identify type and structure of the ferry, the location of the crew and passengers, the possibility of evacuation or abandonment, and whether the crew and passengers had put on PFDs. The

communication between the Patrol Vessel-123 and the Sewol-Ho was a critical factor in monitoring for changes that occurred and feeding these back to the higher ROKCG units. As rescuing people in water was not needed, the rescue operation plan was obsolete, and reevaluation and updating actions or rescue operations plan was required.

The early plan of "rescuing people in water" the commander made while approaching the ferry appeared to be very strong and unambiguous to him. When he arrived on scene, found no one was in water or on decks and saw the ferry was listing about 60 degrees, he did not update the plan. He assumed that the evacuation had already been ordered in the ferry. For the first 20 minutes, he had not received any feedback that suggested the plan should be abandoned. Even when the commander received and acknowledged the feedback from the Group Mokpo, the new information could not change the plan because it was too late to abandon the plan and follow the order.

While the boat was maneuvering alongside the center of the ferry, it went to the stern when an officer saw people at the third deck waving for the help, who were the Sewol-Ho's engineers including the Chief engineer. Some of them even were wearing the company's uniforms, and a woman engineer identified herself as crew when rescued. The ROKCG officers helped them come across to the boat from the distressed ferry due to the severe list and urgent situation. They were the first rescued persons. Based on the testimonies by the crewmembers at the court, the ROKCG officers shouted to them "Jump into the boat. It is capsizing now. Hurry up." However, the officer, Park, Eun-Seong testified (08/12/2014) that due to the urgent situation, he did not remember what she said and did not notice the uniforms because they wore lifejackets. The ROKCG officers knew that they were the crewmembers at 1110 because they did not move to the bigger ship and say who they were.

When the boat went to the ferry for the third time, another officer, Lee, Kyung-Rae went up the ferry to activate the liferafts. He dropped two liferafts, one activated immediately and the other activated after a while. After dropping the two liferafts, he came back to the boat despite passing the doors of the cabins on the third and fourth decks where passengers were staying put because he did not know that they had been told to do that. He testified at

the court that passengers would move out to the decks when they saw and heard the helicopters and the ships, and therefore, he focused attention on activating the liferafts for rescuing many people coming out from inside.

The Patrol Vessel-123 was maneuvering alongside the bridge of the ferry when a person waved for the help. The commander, Kim, Kyung-Il, and another officer, Park, Sang-Wook, testified at the court (08/13/2014) that they thought some passengers went to the bridge and stayed on the bridge due to the rapid list because some of them were foreigners, including the singers hired for the entertainment show on the ferry and one of them was a woman who was the third mate, Park, Han-Gyeol. They believed that crewmembers working on the bridge of the domestic ferries were all men and Koreans.

Park, Sang-Wook went up to the bridge to check if people remained there and released the Patrol Vessel-123's mooring rope, which was tied to the bridge's door and used to help the crewmembers move to the Patrol Vessel-123. Park, Sang-Wook testified at the court (08/13/2014) that the mooring rope, which was tied at the Sewol-Ho, needed to be released at that time because the Patrol Vessel-123 might be in danger because the Sewol-Ho was sinking. He released it based on his judgment about the situation not on the commander's order.

At 0946 when the ferry was listing to port 65 degrees and the fourth deck was submerging, the commander was notified by one of the rescued people that passengers were in the cabins. The commander reported the information to the Group Mokpo and received the order from the Group Mokpo, the District West and the HQ to climb on the ferry and rescue passengers. However, he did not order his members to do so. And he reported to the ROKCG units that he could not do so due to the severe list but the helicopters could continue to rescue passengers. Ironically, one of his members, Park, Sang-Wook was on the ferry. However, the commander did not notice that Park, Sang-Wook had remained on the ferry at that time. The commander testified at the court (08/13/2014) that he could not order his members to climb on the ferry because it was listing too much and the tidal current was strong. He also stated at the court that he and his members had never taken

training to climb listed ships and rescue people who stayed on listing ships, and that only members of ROKCG 1000 tons or bigger SAR Cutters had taken the training. During the communications, the commander of Group Mokpo edged into the conversation and ordered the OSC several times to announce "evacuation" using its loudhailer. The OSC did not, however, follow the order because he assumed it was too late already. Suddenly, the Patrol Vessel-123 rushed to the Sewol-Ho again when some of the members saw several passengers waving for help behind a window. The crewmembers of the Sewol-Ho and the Patrol Vessel-123 worked together to break the window and rescue people using a steel rod and a hammer, which were not adequate to break windows. The Patrol Vessel-123 had no means to break windows to rescue people inside. They had made all rescue actions based on what they had seen, not on what they were ordered or planned. Due to these unexpected urgent situations, the OSC did not try to communicate with the helicopters and Station Jindo-VTS at all.

The Patrol Vessel-123 had no real-time video/audio transmission systems to transmit the status of the ferry in real time to the ROKCG District West and Group Mokpo, and therefore, the ROKCG units did not know the exact situation of the ferry. This information delay caused the ROKCG units to assume differently and make unacceptable or unrealistic orders to the Patrol Vessel-123: they assumed that only one vessel and one helicopter were on scene (at that time, there were actually three helicopters); misunderstanding of the listing of the ferry; asking the Patrol Vessel-123 if there were ways to prevent or delay the ferry from listing; ordering the Patrol Vessel-123 to rescue the passengers on the ferry and to send their crew to climb and enter the ferry (at that time, the ferry was listing 110 degrees to port).

Because the Patrol Vessel-123 forgot to turn on its AIS, the Station Jindo-VTS did not know that the Patrol Vessel-123 was on scene until 0953.

Table 19 The role of the Commander of Patrol Vessel-123 (Process 2: Rescue operations of people on the distressed ferry)

	Group Mokpo, ROKCG Commander of Patrol Vessel-123
Safety Related Responsibilities	• Rescue people in water or on the decks of the ships or boats in distress (routine one). • Follow and practice rules of SAR manual (ROKCG SAR 4-4). . Rescue people in the distressed ferry. . Assess the situation before making any attempt to rescue people in the distressed ferry. . Establish and maintain communications with the crew and passengers on the distressed ferry. . Identify type and structure of the ferry and the location of the crew and passengers . Identify the possibility of evacuation or abandonment. . Ensure the crew and passengers putting on PFDs . Evaluate the rescue operations risks. • Report the latest situation to the ROKCG higher level units when arrived on scene (OSC). • Assign to and coordinate rescue operations with Helicopters and the nearby ships (OSC).
Context in which Decisions made	• Insufficient ROKCG SAR manual: . The rescue operations for car ferries and cruises in distress not included. . Priorities of ROKCG SAR units on scene not included. . Ways to perform passengers search not included. . Putting crewmembers on board to assess the situation not included. • Overwhelmed and surprised when seeing the listing ferry and no people waiting on the decks. • Inadequate training. • SAR training and drills for Car Ferries and Cruises not provided to crew of smaller Patrol Vessels. • Training to climb listed ships and rescue people who stay in the ships not provided. • AMSS and VHF FM channel 16 interfered. • Real-time video/audio transmission systems to transmit the status of the ferry in real time to ROKCG District West and Group Mokpo not available. • No the information of OSC responsibilities was available when appointed. • No the information of "passengers stay put" was available until the ferry listed 90 degrees. • The crew put on the lifejackets over the uniforms when rescued. • Several crewmembers were women and several people rescued on the bridge were foreigners.
Unsafe Decisions and Control Actions	• Focused particular attention on cooperation plan with nearby ships on SSB. • Did not communicate with Helicopters and the Sewol-Ho. • Did not carry out the SAR process including announcing "evacuation" using a loudhailer. • Did not report the situation of the ferry and passengers to the ROKCG. • Did not assess the situation. • Did not establish and maintain communications with the distressed ferry. • Did not identify type and structure of the ferry and the location of the crew and passengers. • Did not identify the possibility of evacuation or abandonment. • Did not ensure the crew and passengers putting on PFDs • Rescued the Sewol-Ho' engineers and the crewmembers on the bridge before the passengers. • Did not ask the identities when rescued the crew. • The early plan of "rescuing people in water" not updated. • Did not follow the orders from the ROKCG District West and Group Mokpo.
Process Model Flaws	• Believed rescuing people in water the pre-defined role was to do in the rescue operation. • Believed the evacuation was already ordered in the ferry. • Believed the engineers were passengers. • Believed the crewmembers on the bridge were passengers. • Believed ROKCG Helicopters announced "safety." • Believed climbing on the severely listed ferry dangerous for his members.

The pilots and rescuers of Helicopters B511, B512, and B513:

The pilots and rescuers of the ROKCG helicopters B511, B512, and B513 were responsible for rescuing people in the distressed ferry and water. They had only the information that 'a ferry was capsizing' when they received the order to rescue people and during the rescue operation. In the case of B-511, the order was received and delivered by another communications officer and therefore, the details could not be requested directly by the pilot. While flying to the scene and the rescue, the pilots could not focus attention on listening to communications on TRS because they had to fly the helicopters safely. At certain times, they could not hear well because TRS signals were weak due to the obstacles and locations. The rescuers usually did not ask the pilots about any details other than the given information.

They followed the routine rescue procedure: go to the scene; drop two rescuers with a rescue basket to the deck or a lifeboat on the water; pull the basket with people distressed to the helicopter; go back to the base or place; repeat the procedures listed above. They assumed that the evacuation was already ordered in the ferry. The rescuers did not know that passengers were told to stay put and therefore, they wondered about why there were no people on the decks. When they rescued people on the fifth deck, they asked one of them about the status in the ferry. Unfortunately, they learned from the person rescued wrong information about only 6 people inside due to the helicopter's loud noise making communication difficult. They, therefore, assumed that many people were already rescued. They also assumed that no one would stay on the seriously listed ferry. The pilot simply notified the Group Mokpo about the number of people who were rescued, but did not pay attention to communications on TRS. They had not gotten any information from the OSC, the commander of Patrol Vessel-123 about the number of passengers and how to rescue them.

Table 20 The roles of the pilots and rescuers of Helicopters (Process 2: Rescue operations of people on the distressed ferry)

	ROKCG The pilots and rescuers of Helicopters
Safety Related Responsibilities	• Rescue people in water or on the decks of the ships or boats in distress (routine one).
Context in which Decisions made	• Only the information that "a ferry was capsizing" was provided. • Listening to communications on TRS was not possible to control the helicopters safely. • AMSS running at ROKCG Station Jindo-VTS and VHF FM channel 16 interfered with each other. • Wondered when they saw no people waiting on the decks. • No information about passengers being told to stay put was provided. • Helicopter's loud noise. • No information received from the OSC.
Unsafe Decisions and Control Actions	• Did not communicate with Patrol Vessel-123 (OSC) and the Sewol-Ho. • Did not carry out the SAR process including announcing "evacuation" using a loudhailer. • Did not identify the possibility of evacuation or abandonment. • Inadequate assessment of the situation on the ferry when rescued people.
Process Model Flaws	• Believed the evacuation was already ordered in the ferry. • Believed ROKCG Patrol Vessel-123 commander or the other pilots had announced "evacuation." • Believed only a few people remained on the ferry, which they were told by one of rescued persons.

Communications operation officer at Station Jindo-VTS:

The communications operation officer at the Station Jindo-VTS was responsible for providing safety guidance to the distressed ferry, such as putting on Personal floatation devices (PFDs) and preparing the evacuation, and for notifying ROKCG SAR units about the details of the distressed ferry. The information, as much as possible, was collected based upon communication with the distressed ferry: type and structure of the ferry, the location of the crew and passengers, the possibility of evacuation or abandonment, and whether the crew and passengers had put on personal floatation devices (PFDs).

The communications operation officer at the Station Jindo-VTS did not share with the Group Mokpo and ROKCG SAR units on scene (Patrol Vessel-123 and Helicopters B511, B512, and B513) about what they obtained from communications with the Sewol-Ho and the DOOLA ACE: The bridge ordered passengers to put on PFDs, the ferry was listing to port 50 degrees, and the passengers could not escape from the inside due to the listing, and the crewmembers were on the bridge and could not move. The communications operation officer reported the information about "passengers could not move" only to the ROKCG District West which was the higher level in ROKCG. He assumed that the ROKCG District West would share the information with all ROKCG units including the ROKCG SAR units on scene. Because the Patrol Vessel-123 turned off its AIS, the watchstander and the communications operation officer of the Station Jindo-VTS did not notice the Patrol Vessel-123 was on scene until 0953 when the Group Mokpo updated the status of ROKCG SAR units on scene. The communications operation officer had communicated with the Sewol-Ho and the nearby ships on VHF FM channel 67 while all other ROKCG units including HQ, District West, Group Mokpo, Patrol Vessel-123 and Helicopters B511, B512, and B513 had communicated on TRS.

Table 21 The role of the communications operation officer at Station Jindo-VTS (Process 2: Rescue operations of people on the distressed ferry)

	Station Jindo-VTS, ROKCG Communications operation officer
Safety Related Responsibilities	• Provide safety guidelines to the distressed ferry such as putting on personal floatation devices (PFDs) and preparing the evacuation. • Notify ROKCG SAR units the details about the distressed ferry as much as possible, which were collected based upon communication with the distressed ferry: type and structure of the ferry, the location of the crew and passengers, the possibility of evacuation or abandonment, and whether the crew and passengers put on personal floatation devices (PFDs).
Context in which Decisions made	• The ROKCG Patrol Vessel-123's AIS turned off • All ROKCG units including HQ, District West, Group Mokpo, Patrol Vessel-123 and Helicopters B511, B512, and B513 had communicated on TRS and VHF FM channel 16. • Inadequate training
Unsafe Decisions and Control Actions	• Did not communicate with the Patrol Vessel-123 and Helicopters on scene on VHF FM channel 16. • Did communicate with the Sewol-Ho and the nearby ships on VHF FM channel 67. • Information obtained from communications with the Sewol-Ho not shared with Group Mokpo, and ROKCG SAR units on scene. • The information of "passengers could not move" reported only to the ROKCG District West. • Did not notice the Patrol Vessel-123 was on scene. • Insufficient controls to detect and correct "Dysfunctional communication with ROKCG units on scene." • Insufficient controls to detect and correct "no sharing of passengers could not move."
Process Model Flaws	• Believed the ROKCG District West would share the information with all ROKCG units including ROKCG SAR units on scene.

Watchstanders (monitoring and controlling ships) at Station Jindo-VTS:

The watchstanders were responsible for monitoring and tracking vessels in a designated region to detect any potential maritime accidents, such as distress, stranding or collision, and to provide the safety-related information to the ROKCG SAR units. Moreover, as the Station Jindo-VTS Operation Manual described, the watchstanders were also responsible for continuously monitoring and tracking car ferries and cruise ships carrying many passengers and ships carrying hazardous commodities when they were in the designated region.

It was "Sector 2" where the Sewol-Ho was capsized, which needed one watchstander to monitor and track the ferry while the ferry was in the sector. There were four operation officers as a team in the Station Jindo-VTS for a 24-hour shift: one for monitoring Sector 1, another for monitoring Sector 2, another for communications operations and the other for administration work or taking a rest. They had worked for 24 hours as a team with 4 turns: Sector 1 → Sector 2 → communications operation → administration work every 1.5 hours per position for the night and 1 hour for the day. For his turn from 0730 to 0900, the watchstander monitored and tracked the Sewol-Ho in Sector 2, which was traveling towards the south, until 0846 when the Sewol-Ho was passing the Maenggol Channel. He assumed that it would be okay to stop continuously monitoring and tracking the Sewol-Ho as the ferry passed the Maenggol Channel. At the same time, he found several fishing boats were close together, causing the potential for collisions and therefore, paid much attention to these boats. He also believed that the AMSS at ROKCG Station Jindo-VTS had the capabilities to monitor and detect the ferry's abnormal turn and to alert all ROKCG units including the Station Jindo-VTS if something happened. He did not know that the alerting function of the AMSS at ROKCG Station Jindo-VTS had been turned off because the system caused many spurious alarms or was often out of order.

The team and the watchstander were replaced by another team of four operation officers at 0900. A successor of the team and the watchstander had monitored Sector 2 together for 15 minutes from 0845 as described in the 17th rule of Rules of Maritime Transportation

monitoring and tracking Operations and Management. However, they had not detected the ferry's sharp turn for 15 minutes. The successor did not notice the ferry's capsizing until 0906 when the Group Mokpo notified them. Two of them had contacted four ships traveling in Sector 2 to receive reports of entry/exit into Sector 2. Even though there was no evidence about whether the Rules of Maritime transportation monitoring and tracking Operations and Management described what both of them had to do for the 15 minutes, the Rules described in detail about what information was to be shared and actions were to be carried out together. In addition, there was the overlapped area for monitoring the ferry traveling in the sector between the watchstander and the successors. Neither noticed the sharp turn while working together for the 15 minutes. The successor thought the watchstander monitored the screen, and the watchstander thought the successor did it. It appeared to be that no one monitored the screen.

Due to no available data and information about the resources and shift schedules, further investigation of the issues related to resources and shift schedules was not possible in this study. However, it could be assumed that personnel shortages might be one of the reasons why ROKCG adopted 24-hour shifts and for years, an operation officer had illegally watched two Sectors while the other one had worked on writing reports or taken a rest. Working 24 hours continuously might cause the operations duty officer to suffer from fatigue and therefore, not to pay much attention to the monitoring and tracking work around that time. The IALA's recommended staff is 18 people for 24 hours, but the VTS had only four.

Table 22 The role of the Watchstanders at Station Jindo-VTS (Process 2: Rescue operations of people on the distressed ferry)

	Station Jindo-VTS, ROKCG Watchstanders
Safety Related Responsibilities	• Monitor and track vessels in a designated region to detect any potential maritime accidents when they are in the designated region, and provide safety-related information to the ROKCG SAR units if needed. • Continuously monitor and track car ferries and cruise ships and ships carrying hazardous commodities when they are in the designated region.
Context in which Decisions made	• Inadequate training • Personnel shortages for watchstanders. • Fatigued working for 24 hours per a shift. • The ferry's capsizing was happened during the shift change time of 15 minutes. • Several fishing boats were close together, causing potential for collisions that needed to be monitored. • Alerting function of the AMSS was turned off or out of order. • The ROKCG Patrol Vessel-123's AIS turned off.
Unsafe Decisions and Control Actions	• Did not detect the ferry's capsizing. • Stopped continuously monitoring and tracking the Sewol-Ho as the ferry passed the Maenggol Channel. • One watchstander monitored two sectors illegally. • Did not find Patrol Vessel-123 was on scene. • Did not notice alerting function of the AMSS. • Insufficient controls to detect and correct whether alerting function of the AMSS was turned off or out of order.
Process Model Flaws	• Believed the Sewol-Ho would be safe after passing the Maenggol Channel. • Believed the AMSS would monitor and detect the ferry's capsizing and alert all ROKCG units. • Believed the successor watchstander monitored the sectors during the shift.

Communications operation officer of Group Mokpo (received the distressed calls on 122, the Korea National Maritime Distress Service Call Number):

The communications operation officer who received the distressed calls on 122, the Korea National Maritime Distress Service Call Number, was responsible for the following:

- Log all information provided by the callers
- Maintain communication until ROKCG SAR units arrive at the scene
- Keep asking questions about the situation.
- Provide all information to the supervisor

The communications operation officer received two distressed calls on 122, one from Choi, Duk-Ha at 0854, and the other from Kang, Hae-Seong at 0904. Choi, Duk-Ha who was a Danwon high school student aboard the ferry made the first emergency call on 119, the Korea National Emergency Service Call Number and was connected to the Group Mokpo. Choi, Duk-Ha informed the communications operation officer that many people were on the listing ferry. They had talked for 2 minutes and after that time did not maintain communication. While the communications operation officer was preparing the call report, he received the other call from Kang, Hae-Seong who was the communications officer at the Guest Services Desk of the Sewol-Ho, notifying that the ferry was capsizing and the order for "passengers to stay put in their cabins" had been announced to passengers by the Guest Services Desk. The communications operation officer at the Group Mokpo authorized him to keep maintaining the announcement of the order. However, the communications operation officer at the Group Mokpo did not share with other ROKCG units about this authorization of the announcement for "passengers to stay put in the cabins." The communications operation officer simply hung up the call because he assumed that the call was the same one as the call made by Choi, Duk-Ha several minutes before. He reported to his supervisor only the information that "the ferry was capsizing" and that there were "many people on the ferry" that he got from the first call. He assumed that the information that "the ferry was capsizing" was the most important and the facts from the second call were a duplication at that time. The information about announcement for "passengers to stay put in the cabins" from the call had not been shared at all. After these two calls, the

communications operation officer had received five more calls about the accident and treated these five calls like the first one. He assumed that the information that "the ferry was capsizing" and "many people were on the ferry" was the most important to be shared with other ROKCG units. It is reasonable to infer that the procedures he had carried out were incomplete and inadequate due to insufficient training. Only 57% of the ROKCG annual SAR training requirement had been exercised between 2010 and 2013. Moreover, the members of HQ, District West and Group Mokpo had taken most of the training without physical exercises or drills.

Clearing of the status data should not have been permitted until all of the data had been shared with other SAR units and probably not until the supervisor or commander at Mokpo had acknowledged seeing it.

Table 23 The role of the communications operation officer of Group Mokpo (Process 2: Rescue operations of people on the distressed ferry)

	Group Mokpo, ROKCG Communications operation officer
Safety Related Responsibilities	• Log all information provided by the callers. • Maintain the communication until ROKCG SAR units arrive at the scene. • Keep asking questions about the situation. • Notify supervisor the situations.
Context in which Decisions made	• Inadequate training. • Received seven calls from people on the ferry.
Unsafe Decisions and Control Actions	• Did not maintain the communication. • Authorized the crew on the ferry to keep maintaining the announcement of "passengers stay put in their cabins." • Did not log this authorization of the announcement for "passengers to stay put in the cabins" and share with supervisor and ultimately, other ROKCG units about. • Treated all seven calls in the same way as the first one.
Process Model Flaws	• Believed the information of "the ferry was capsizing" and "many people on the ferry" was the most important one to be shared with his supervisor and other ROKCG units. • Believed information obtained from seven calls was the same one.

Commander of Group Mokpo:

The commander of the Group Mokpo was responsible for the following:

- Requesting the closest ROKCG Vessels, Ships, Cutters and VTSs, and nearby fishing boats and ships to help rescue people.
- Commanding the ROKCG SAR units on scene to contact the distressed ferry and comprehending the current situation of the distressed ferry (ROKCG Emergency Management Manual III-1 and ROKCG SAR 4-4).
- Ordering the Captain or the owner to follow rescue operations if the commander judged that the Captain was working improperly (Korean Maritime Law 43-3).

The commander was on ROKCG Cutter-3009 3,000 tons seventy miles away from the Sewol-Ho when he received word that the ferry with 350 passengers was capsizing. The ROKCG Helicopter B512 departed from the ROKCG Cutter-3009. The commander assumed that an officer, the acting commander at the Group Mokpo on behalf of the commander had briefed the OSC and helicopters to report on the situation when they arrived on scene in order to identify the type and structure of the ferry, the location of the crew and passengers, the possibility of evacuation or abandonment and whether the crew and passengers had put on PFDs. The acting commander at the Group Mokpo appeared not to know the procedures described in ROKCG SAR 4-4 to provide this information. The ROKCG HQ ordered the acting commander at the Group Mokpo to contact the Captain of the Sewol-Ho four times, but the acting commander did not follow the order other than calling the Captain's cell phone once, with no answer received (the Captain's cell phone was in his cabin).

The commander also assumed that the commander of Patrol Vessel-123 as the OSC could carry out the rescue activities and coordinate the ROKCG SAR units including the ROKCG Helicopters based upon the ROKCG SAR Manual.

About 0956, when he realized the rescue procedures made by the Patrol Vessel-123 were inadequate, he ordered the OSC to use its loudhailer to announce "evacuation," which was

the only action made by him to the ROKCG SAR units on scene. He testified at the court (08/13/2014) that when he was asked why he did not ride the ROKCG Helicopter B512 to command SAR units on scene, he said he believed the helicopter's loud noise would prevent him from commanding the SAR units on scene and also that the ROKCG Cutter-3009 had better communication equipment. Though it was not evident that he was fatigued due to guiding foreign fishing boats in Korean sea the previous night, the fatigue might have prevented him from moving and commanding the ROKCG SAR units directly from the scene. The greater the distance between the commander and the ferry and the ROKCG SAR units on scene, the more difficult the communication and thus the greater the uncertainty and risk. That distance, however, between the commander and the ferry and the ROKCG SAR units on scene meant that the commander lost much direct information about the rescue operations to help him understand the state of the operation and the situation directly.

The ROKCG SAR Manual did not specifically describe what the commander had to do in unexpected situations such as the following:

- An acting commander was assigned at the Group Mokpo but the acting commander did not follow the manual.
- The District West, the higher level of the Group Mokpo, appointed the commander of the Patrol Vessel-123 as the On-Scene-Commander (OSC) but the OSC did not follow the SAR manual.
- The commander was on the ROKCG Cutter-3009 for another mission but when a helicopter was available, the higher level at ROKCG did not order him to go because the ROKCG District West had already appointed the commander of the Patrol Vessel-123 as the OSC.

For situations that were not specified in the ROKCG SAR Manual, the commander appeared to believe his choice, staying in the ROKCG 3009, was the best.

Table 24 The role of the Commander of Group Mokpo (Process 2: Rescue operations of people on the distressed ferry)

	Group Mokpo, ROKCG Commander
Safety Related Responsibilities	• Request ROKCG Vessels, Ships, Cutters and VTS, fishing boats and commercial/private ships near the scene to help rescue people in the distressed ferry. • Command ROKCG SAR units on scene to contact the distressed ferry and comprehend the current situation of the distressed ferry (ROKCG Emergency Management Manual III-1 and ROKCG SAR 4-4). • Order the captain or the owner to follow if the commander judged that the captain was working improperly (Korean Maritime Law 43-3).
Context in which Decisions made	• The commander was on the ROKCG Cutter-3009 3,000 tons seventy miles away from the scene. • The ROKCG Cutter-3009 had the Helicopter B512 which went to the scene. • The ROKCG District West did not order the commander to go because the ROKCG District West had already appointed the commander of the Patrol Vessel-123 as the OSC. • The commander might have been fatigued due to guiding foreign fishing boats in the Korean sea in the last night. • The acting commander at Group Mokpo appeared not to know the procedures well described in ROKCG SAR 4-4. • The ROKCG HQ ordered the acting commander at Group Mokpo to contact the Captain of the Sewol-Ho four times, but the acting commander did not follow the order other than calling to the Captain's cell phone once. • The acting commander did not follow the manual as the Group Mokpo commander was supposed to do.
Unsafe Decisions and Control Actions	• Assigned an acting commander who was not capable of ROKCG Emergency Management Manual III-1 and ROKCG SAR 4-4. • Did not go to the scene when the Helicopter B512 was available. • Did not contact the distressed ferry. • Did not have the current situation of the distressed ferry. • Provided insufficient controls to detect and correct "no safety announcement" by the OSC. • Provided insufficient controls to detect and correct "no on-scene reports" by the OSC. • Provided insufficient controls to detect and correct "no comm. with Helicopters and the ferry" by the OSC. • Provided insufficient controls to detect and correct "no safety announcement" by the pilots. • Provided insufficient controls to detect and correct "no on-scene reports" by the pilots. • Provided insufficient controls to detect and correct "no comm. with the OSC" by the pilots.
Process Model Flaws	• Believed the acting commander at the Group Mokpo on behalf of the commander had briefed the OSC and Helicopters to report the situation. • Believed the OSC could carry out the rescue activities and coordinate the ROKCG SAR units on scene including ROKCG Helicopters. • Believed the Helicopter's loud noise prevented him from commanding the SAR units on scene and the ROKCG Cutter-3009 had better communication equipment. • The commander and acting commander believed the District West had briefed the OSC and Helicopters to report the situation.

Commander of District West:

The commander was in charge of the following:

- Establish staff, equip and manage the SAR system in the District.
- Provide or arrange for SAR facilities and SAR resources in the District.
- Coordinate SAR training and exercises in the District.
- Promulgate SAR policies and supporting documents in the District.
- Coordinate ROKCG SAR units to execute the SAR operations in the District.

The District Organizational Manual prescribed the standard construct for organizing and administering the Coast Guard District to ensure a consistent organizational structure. It included standardized information such as the organizing principles and roles and responsibilities of various positions within the District organization.

The District West appointed the commander of the Patrol Vessel-123 as the On-Scene-Commander (OSC) but did not brief "the SAR procedures including the on-scene assessment" to Patrol Vessel-123. The District West appointed the commander of the Patrol Vessel-123 as the OSC but because the Patrol Vessel-123 belonged to the Group Mokpo, the West did not brief "the SAR procedures" to Patrol Vessel-123 immediately when the Patrol Vessel-123 arrived on scene. However, the acting commander in the Group Mokpo assumed that someone in either the District West or the commander of the Group Mokpo in the 3009 would brief it. The acting commander appeared to be reluctant to speak up to assist in the situation due to feeling that he would be overstepping his bounds. In the end, no one briefed it to the OSC. Therefore, the District West had not received the status of the ferry: the list of the ferry, the location of the crew and passengers, the possibility of evacuation or abandonment, and whether the crew and passengers put on PFDs.

No SAR training and drills for Car Ferries and Cruises in distress were provided to members of smaller Patrol Vessels: priorities of ROKCG SAR units on scene, how to perform passengers search, putting crewmembers on board to assess the situation, coordination of

ROKCG SAR units on scene. Moreover, 7 of 44 SAR personnel at the District West and its five Groups were disqualified, less than three years of the SAR experiences (the qualification is three years or more). Moreover, the regular training had been exercised informally.

Commander of Headquarters:

The commander was in charge of the following:

- Develop Search and Rescue (SAR) program training, tactics and policy.
- Establish staff, equip and manage the SAR system in the ROKCG.
- Provide or arrange for SAR facilities and SAR resources in the ROKCG.
- Coordinate SAR training and exercises in the ROKCG.
- Promulgate SAR policies and supporting documents in the ROKCG.
- Coordinate ROKCG SAR operations including providing guidelines and procedures based on ROKCG SAR Manual which provided the overall guidance to execute the SAR operation responsibilities.

The ROKCG Organizational Manual prescribes the standard construct for organizing and administering Coast Guard to ensure a consistent organizational structure. It included standardized information such as the organizing principles and the roles and responsibilities of various positions within the ROKCG.

The ROKCG HQ did not participate in critical training such as SAR operations when a passenger ferry capsizes or sinks.

No clear SAR Manual for Car Ferries and Cruises in distress was made for members of smaller Patrol Vessels: priorities of ROKCG SAR units on scene, was to do passengers search, putting crewmembers on board to assess the situation, coordination of ROKCG SAR units on scene.

Table 25 The role of the commanders of District West and Headquarters, ROKCG (Process 2: Rescue operations of people on the distressed ferry)

	District West, ROKCG Commander	Headquarters, ROKCG Commander
Safety Related Responsibilities	• Establish staff, equip and manage the SAR system in the District. • Provide or arrange for SAR facilities and SAR resources in the District. • Coordinate SAR training and exercises in the District. • Promulgate SAR policies and supporting documents in the District. • Coordinate ROKCG SAR units to execute the SAR operations in the District.	• Develop Search and Rescue (SAR) program training, tactics and policy. • Establish staff, equip and manage the SAR system in the ROKCG. • Provide or arrange for SAR facilities and SAR resources in the ROKCG. • Coordinate SAR training and exercises in the ROKCG. • Promulgate SAR policies and supporting documents in the ROKCG level. • Coordinate ROKCG SAR operations.
Context in which Decisions made	• Inadequate training. • 7 of 44 SAR personnel at the District West and its five Groups were disqualified. • SAR training and drills for Car Ferries and Cruises in distress not provided to members of smaller Patrol Vessels.	• Inadequate training
Unsafe Decisions and Control Actions	• Did not have the current situation of the distressed ferry. • Did not participate in training of SAR operations to a passenger ferry's capsizing or sinking situation. • Insufficient controls to detect and correct "no safety announcement" by the OSC. • Insufficient controls to detect and correct "no on-scene reports" by the OSC. • Insufficient controls to detect and correct "no comm. with Helicopters and the ferry" by the OSC. • Insufficient controls to detect and correct "no safety announcement" by the pilots. • Insufficient controls to detect and correct "no on-scene reports" by the pilots. • Insufficient controls to detect and correct "no comm. with the OSC" by the pilots. • Insufficient controls to detect and correct "one watchstander at Station Jindo-VTS monitored two sectors."	• Did not participate in critical training such as SAR operations to a passenger ferry's capsizing or sinking situation. • Did not have the current situation of the distressed ferry. • Insufficient controls to detect and correct "no on-scene reports" by the Group Mokpo.
Process Model Flaws	• Believed the commander of Patrol Vessel-123 as the OSC could carry out the rescue activities and coordinate the ROKCG SAR units including ROKCG Helicopters. • Believed the commander or the acting commander of the Group Mokpo did brief the OSC and Helicopters to report the situation.	• None.

Liferafts Inspection Company (Korean Marine Safety Systems Co.):

Inspector:

The inspector was responsible for inspecting that liferafts work functionally and providing accurate reports on the inspection to Chonghaejin Marine and the KR. The inspector inspected the Sewol-Ho's liferafts improperly, and the chutes illegally because he had no license to inspect chutes. He appeared to inspect only some of 44 liferafts operation and to check the rest by looking at the hardware's condition. He also inspected 4 chutes but seemed to inspect just the structures' conditions. After the Sewol-Ho accident, when the police inspected the liferafts and chutes of the Ohamana-Ho, which were inspected and certified by the company, the police found they were not working properly. He assumed that the liferafts and chutes would work properly if the hardware looked good.

Korea Register of Shipping:

Inspector:

The inspector was responsible for reviewing the certification and inspection reports of liferafts and chutes provided by the certified companies.

The certification and inspection reports of the Sewol-Ho's liferafts and chutes provided from the company which was responsible for the certification and inspection of liferafts, were provided to Chonghaejin Marine and then the KR to approve the inspection certificate of the Sewol-Ho. However, the inspector at the KR assumed that the company had the licenses to inspect both liferafts and chutes, and thus approved the operation of the Sewol-Ho two times, in February 2013 and 2014.

Korea Ministry of Oceans and Fisheries:

The Mokpo Region Marine and Port:

The Mokpo Region Marine and Port was responsible for reviewing and certifying companies which had the required licenses and resources to inspect liferafts and chutes.

The Mokpo Region Marine and Port approved the Korean Marine Safety Systems Company as the certified liferafts inspection service company. The Mokpo Region Marine and Port assumed that the company should inspect liferafts only as it was certified.

ROKCG Group Incheon:

Officer as reviewers:

Officers as reviewers were responsible for reviewing and approving the Sewol-Ho's Operation Management Regulations Document based upon practical processes and procedures for emergencies.

The officers at the Group Incheon reviewed the Sewol-Ho's Operation Management Regulations Document and approved the processes and procedures for emergencies without reviewing the details about whether the processes and procedures were practical and effective. Some examples are the following:

- The OMR described that only the Captain had to make the order of "abandonment" when the ferry should be abandoned. It did not describe the details if the Captain was not available or could not make the decision.
- When the ferry was in distress, the Captain had to call ROKCG and nearby ships on VHF or SSB, and the company on the phone as shown in the emergency contacts list in the OMR. However, the chart did not show the details of information/decisions to give and receive as the feedback.

The officers at ROKCG Group Incheon appeared to assume that the crew of the Sewol-Ho had practiced the processes and procedures to emergencies periodically without having any critical issues at the safety training and drills.

Table 26 The roles of Liferafts Insp. Co., KR, KMOF and ROKCG-Group Incheon (Process 2: Rescue operations of people on the distressed ferry)

	Liferafts Insp. Co. Inspector	KR Inspector	KMOF Mokpo Region Marine/Port	ROKCG-Group Incheon Reviewers
Safety Related Responsibilities	• Inspect liferafts operation and provide accurate reports on the inspection to Chonghaejin Marine and KR.	• Review the certification and inspection reports of liferafts and chutes from the inspection company.	• Review and certify companies which have the required licenses and resources to inspect liferafts and chutes.	• Review and approve the Sewol-Ho's OMR based upon practical processes and procedures to emergencies and rescue operations.
Context in which Decisions made	• Poor morale. • Inadequate training.	• List of Liferafts and Chutes Inspection certified companies not available.	• Relied on voluntary compliance with regulations, policies and guidelines.	• Relied on voluntary compliance with regulations, policies and guidelines.
Unsafe Decisions and Control Actions	• Did inspect liferafts improperly. • Inspected the chutes without a license to do so.	• Did not check list of liferafts and chutes Inspection certified companies. • Insufficient controls to detect "Inspection Company with no chute inspection certificate." • Relied on voluntary compliance with regulations, policies and guidelines.	• Did not provide KR a list of liferafts and chutes Inspection certified companies.	• Did approve the processes and procedures to emergencies of OMR without reviewing the details: • No details to make the order of "abandon the ferry" if the captain was could not make the decision. • No details of the emergency contacts list.
Process Model Flaws	• Believed liferafts and chutes would work properly if the hardware looked good.	• Believed Liferafts and Chutes Inspection Certified Company did inspect them physically. • Believed the Certified Companies had the licenses.	• Believed the company should inspect liferafts only. • Believed the company should inspect liferafts as policies and guidelines.	• Believed crew had practiced the OMR processes and procedures to emergencies periodically without having any critical issues.

OTHERS:

DOOLA ACE:

As the Captain, Moon, Ye-Sik of DOOLA ACE listened on VHF FM channel 67 to the conversation about the evacuation decision between the Station Jindo-VTS and the Sewol-Ho, he shouted on VHF FM channel 67 to the Sewol-Ho to announce "abandon the ferry" because he physically saw that the ferry was listing to 50 degrees, preventing the passengers from evacuating from the ferry. Time lags in the evacuation decision making at the levels of the ROKCG Station Jindo-VTS and the ferry's bridge might be overcome by the use of feedforward control like the DOOLA ACE Captain's decision to overcome the lack of feedback.

Fishing boats:

When they arrived on scene around 1000, there were no people on the decks; nearby ships including DOOLA ACE were just waiting without doing any rescue actions; and only the Patrol Vessel-123 and Helicopters B511, B512 and B513 were rescuing people so they thought the rescue operations were almost finished. They moved to the stern as they saw passengers waving for help. However, they did not listen well when one of the students shouted that "friends were inside" and pulled back their boats after rescuing the passengers at the stern. They did not try to open the doors to the aisle where students were orderly waiting for their turns because they had not received any information about passengers being told to stay in their cabins on SSB.

Figure 11 shows the actual state of Safety Control Structure for Process 2 of "Rescue operations of people on the distressed ferry." The red dot line arrows in Fig. 11 highlight control actions, controlled variables, measured variables, and control feedback that were either missing or incomplete in the actual Safety Control Structure. Moreover, the red line arrow between the Captain and the Customer Service Desk in Fig. 11 highlights the unclear control feedback. They should be corrected to prevent the unsafe control actions and feedback 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.

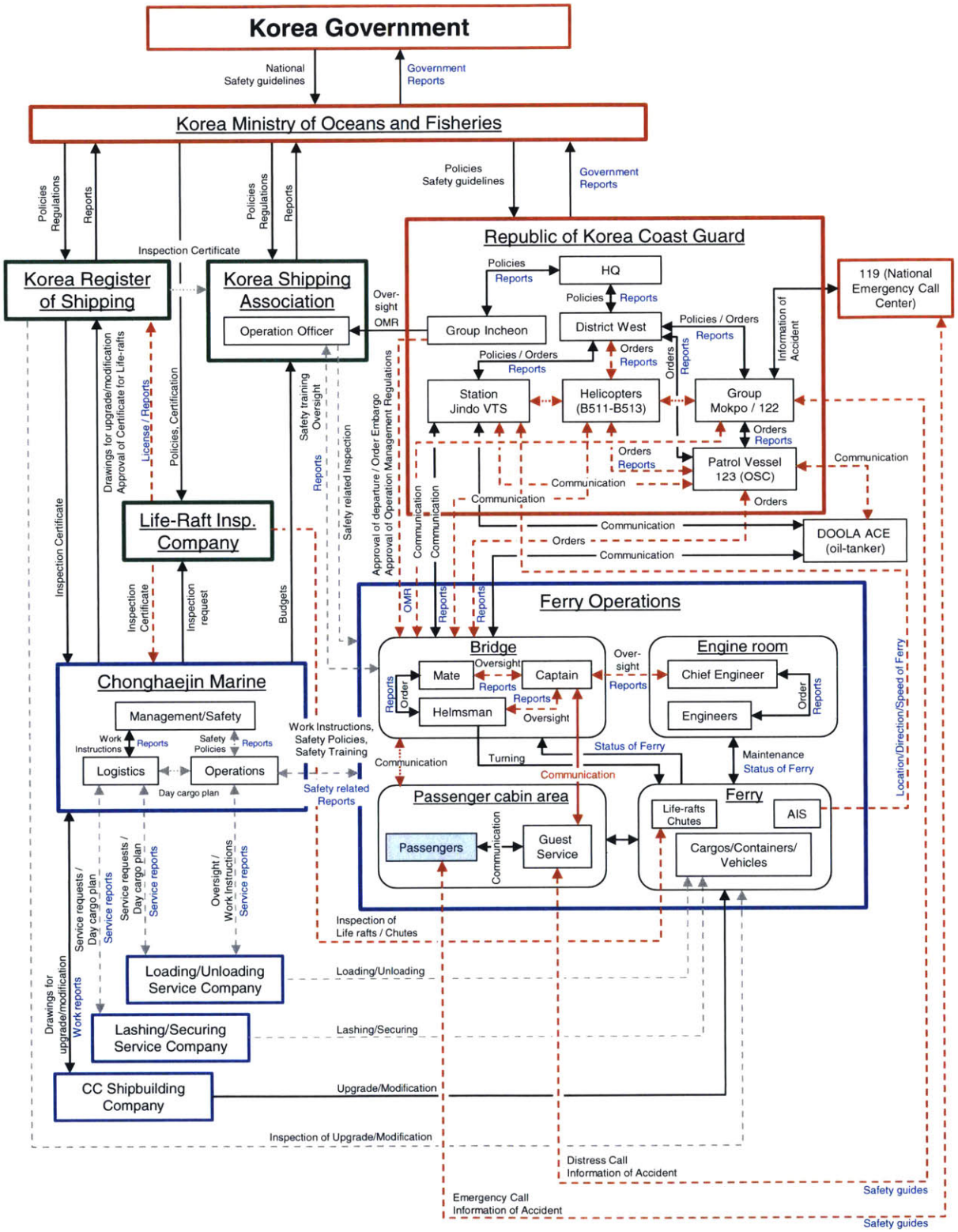

Figure 11 Actual state of Safety Control Structure for Process 2 of "Rescue operations of people on the distressed ferry"

CAST Step 7: Examine Communication and coordination Contributors

The inadequate decisions and control actions made by the controllers including the Sewol-Ho Operations, the ROKCG, the KSA, the KR, and the Service companies 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 Sewol-Ho Operations, between the KSA and the KR, between the Sewol-Ho Operations and the Service companies, between the ROKCG SAR units as well as between the Sewol-Ho Operations and the ROKCG.

In the process of "Safe operations of the ferry," dysfunctional interactions and communication between the KSA and the KR as shown in Fig. 9 resulted in the inappropriate comprehensive level of the operation officer at the KSA about the Sewol-Ho's required ballast water. It was evident from his incorrect mental model which led the officer to believe that the load line he had checked could be used as the metric to determine whether the ferry was safe or not. Chonghaejin Marine 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 Chonghaejin Marine had never been shared with the lashing service company. There was an overlap problem in communications between the Sewol-Ho Operations and Chonghaejin Marine Logistics. The Sewol-Ho Operations had no communications with the personnel of the lashing service company because the Captain and the first mate thought the Logistics commanded the personnel of the lashing service company but no parties at Chonghaejin Marine communicated with them about safety issues. Only the foreman who was an on-site manager of the loading service company did so. Therefore, the personnel of the lashing service company could not report any safety issues to Chonghaejin Marine directly but only to the foreman of the loading service company. The foreman filtered out the issues on his own judgment and provided no feedback to Chonghaejin Marine.

From Figure 11, it can be seen that there were many different communication channels for the process of "Rescue operations for the people on the distressed ferry," but they were not coordinated at all. The bridge of the Sewol-Ho communicated with the Guest Services Desk/Passengers using hand-held two-way radio transceivers. The critical communication between the ROKCG SAR units on scene and the bridge of the Sewol-Ho had not been made at all.

The Group Mokpo had very effective communication with the ROKCG Patrol Vessel-123. The Group Mokpo had been notified that the passengers had been told to go to their cabins by the communications officer at the Guest Services Desk but did not share this information with the ROKCG SAR units on scene, including the ROKCG Patrol Vessel-123 during coordinating and communicating with them. The Group Mokpo and the Korea National Emergency Service Call Center did not provide any feedback to the callers who made the distress calls or keep communicating with them. The feedback was critically important for the Group Mokpo to understand the situation inside the ferry. Without this feedback, the monitoring and feedback communication channels between the passengers and the Group Mokpo were lost. The ROKCG Jindo-VTS had coordinated and communicated with the bridge of the Sewol-Ho on VHF FM channel 67 and therefore, the latest situation information had not been shared with the ROKCG SAR units on scene.

Leplat suggests that accidents are most likely in overlap areas where two or more human controllers control the same process or processes with common boundaries. In overlap areas, the potential exists for ambiguity and conflicts among independent decisions. Responsibility for the control functions in boundary areas is often poorly defined (Leplat, 1987, pp. 181-191). For example, there was the overlapped area for making the evacuation decision between the Captain or the crewmembers on the bridge and the communications officer at the Station Jindo-VTS or eventually officers at the District West. No one could make the decision because the District West did not have the latest situation information on scene and the Captain did not know whether the ROKCG SAR units could rescue all the people. Another example is the overlap area for briefing "the SAR procedures

including the on-scene assessment" to Patrol Vessel-123 between District West and Group Mokpo. The District West appointed the commander of the Patrol Vessel-123 as the OSC but because the Patrol Vessel-123 was under the Group Mokpo command, the West did not brief "the SAR procedures" to Patrol Vessel-123 immediately when the Patrol Vessel-123 arrived on scene. The acting commander at the Group Mokpo assumed that either someone at District West or the command of the Group Mokpo on the 3009 would brief it. He appeared to be reluctant to speak up to assist in the situation due to feeling that he would be overstepping his bounds. Another overlap area is the announcement of "evacuation" between the Patrol Vessel-123 and Helicopters, B511, B512 and B513. Each of them had the loudhailer to alert people to escape from the ferry, but without having any communication among themselves, they assumed that someone else would do so.

The efforts made mostly at the lower levels of controllers such as the ROKCG units on scene – (the Patrol Vessel-123 and Helicopters, B511, B512 and B513, and the crewmembers on the bridge and the Guest Services Desk) achieved little success in the rescue operations because the bottom-up decentralized decision making led to incorrect rescue operation decisions. Each local decision might be "correct" in the limited context in which it was made but led the rescue operations in the wrong directions when the independent decisions and their behaviors interacted in unsafe ways. The decentralized decision making was required in time-critical situations, but like all safety-critical decision making, the decentralized decisions had to be made in the context of "system-level information" and from a total systems perspective to be effective in the rescue operations.

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.

In 2011, the ROKCG built the Advanced Maritime Surveillance System (AMSS) for 2 million dollars, which could monitor ships and boats, analyze their motions, detect any abnormal patterns and alert the nearby ROKCG units. However, it was found that the AMSS had an issue of interference with VHF FM channels. Since the time the AMSS was built, communications on VHF FM channels in the area had not worked well when the AMSS was set to analyze the motions of ships and boats. On that day, the Patrol Vessel-123 had tried to contact the Sewol-Ho two times on VHF FM channel 16 while approaching the scene but two calls were unsuccessful. The ROKCG Helicopter B511 could not contact the Sewol-Ho either when it tried to communicate on VHF FM channel 16. The Sewol-Ho did call the ROKCG units on scene several times on VHF FM channel 16, but could not contact anyone. No one checked the issue carefully before, and it was found only in the Sewol-Ho accident investigation.

Recently, the renewal process of captain license had been eased: evidence of two years of experience on ships was enough to renew the license instead of taking 2-day training. This renewal process might cause the Sewol-Ho's Captain to carry out the rescue operation improperly.

Until April 19, 2010, the Station Jindo-VTS had two watchstanders to monitor two sectors together. Later, to define the watchstanders' independent responsibilities, the ROKCG changed the watchstanding format; one watchstander to monitor one sector and one for the other sector. However, the Station Jindo-VTS illegally modified the format: one watchstander to monitor two sectors and the other to work on administration stuff including writing reports or taking a rest. They assumed that the new AMSS would take care of monitoring the hazards for them, and therefore, the modified format had been implemented illegally until after the accident occurred.

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. There were precursors signaling the increasing risks associated with the reduced safety margins in the form of minor incidents: on November 29, 2013, the ferry listed about 15 degrees, causing bricks and bottles loaded on the first deck to slide and hit the walls and in February 2014, the ferry could not depart due to severe rolling. However, the incident reports were not assessed by the management, and no improvement actions were provided to the operations. Over time, the management also appeared to skip the established safety practices including safety training and drills described in the Sewol-Ho's OMR.

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 Chonghaejin Marine to modify the ferry by reducing to less than a half of the previous cargo weight and four times more ballast water than previously. These conditions could not be followed by Chonghaejin Marine because more than 70% of revenues came from cargo. After the modifications, Chonghaejin Marine had loaded cargo and ballast based on the previous conditions. Therefore, the ferry moved toward a state where an accident would occur with small disturbances.

CAST Step 9: Generate Recommendations

There are two system level safety constraints defined in CAST Step 2: "the ferry must not capsize" and "all people must be rescued when the ferry is in distress." 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 constraints 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
- Sewol-Ho Operations and cargo loading and lashing services
- Chonghaejin Marine Company
- ROKCG
- Korea Shipping Association
- Korea Register of Shipping
- ROKCG Group Incheon
- Korea Ministry of Oceans and Fisheries

• Physical equipment

1. 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.
2. Consider quantitative methods or tools for assessing ballast water in the ferry to the KSA operation officer.
3. Upgrade protection means against water getting into the ferry through bow and stern doors.
4. Provide upgrades to emergency systems.
   a. Anti-heeling pumps should work properly at any time and return the ferry to its upright position when necessary.
5. Provide upgrades to PA system for announcing evacuation.

a. PA system on the bridge should broadcast announcements to passengers on the ferry at any time.

6. Provide upgrades to evacuation systems.
   a. Liferafts and chutes should be activated properly.
7. Provide upgrades to systems to monitor and detect the ferry's sharp turn.
   a. Advanced Maritime Surveillance System should detect the sharp turn and alert ROKCG.

- **Sewol-Ho Operations and cargo loading and lashing services**

1. Review and enforce safety policy rules in the OMR.
   a. Enforce detection and prevention of overload, less ballast, and improper lashing.
   b. Enforce loading only 10 feet size cargo containers on the designated decks.
   c. Enforce complying with the process of loading and lashing - loading a cargo container or vehicle, lashing and securing it, and repeating the steps.
   d. Enforce a review process to operations and maintenance (day, month and quarter).
   e. Enforce a report process for properly submitting safety-related issues to safety team and management.
   f. Review and clarify announcement about "safety" which provides "a sense of security or safety" to passengers. The announcement has to detail not only contents but also sequences.
   g. Enforce providing safety training or drills to crew every 10 days.
   h. 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.
   i. Update training with an assumption that the Captain is not capable of managing an emergency situation.
   j. Update training with an assumption that the first mate is not capable of controlling the emergency operation.
   k. Update training with an assumption that in an emergency situation, the third mate is not capable of communicating with ROKCG.

l. Update training with an assumption that the ferry lists and the capsizing progresses too fast (i.e. assuming the capsizing is completed in 30 minutes).
m. Update training for activating liferafts and chutes, with an assumption that the ferry lists up to 50 degrees.
n. Update training with an assumption that dysfunctional communications between the bridge and the Guest Services Desk and between the bridge and passengers occur.
o. Consider updating training to include physically activating liferafts and chutes.

2. Review and enforce a report process of "Ferry safety inspection chart: before-departure" to Operations.
   a. Enforce submitting the chart after filling with actual data.
   b. Enforce adding a checkpoint for reviewing ballast water.
3. Enforce maintenance schedules.
   a. Enforce maintaining bow and stern doors to prevent water from getting into the ferry.
4. Create a process for reviewing and updating the OMR.
   a. Add suitable means, methods, and maps for adequate lashing of cargo containers and vehicles to the OMR.
5. Regularize and improve safety communication (information and feedback) channels.
   a. Review and enforce effective communication channels for disseminating safety information.
   b. Improve feedback loops between Operations and the management.
   c. Improve feedback loops between Operations and personnel of the loading and lashing services companies.
   d. Improve feedback loops between Logistics team and personnel of the loading and lashing services companies.
   e. Improve communication channels between the bridge and the Guest Services Desk, between the bridge and the engine room and between the bridge and passengers, other than using hand-held two-way radio transceivers.

6. Provide a day cargo plan to Operations, the KSA and the loading and lashing service companies 24 hours in advance.
7. Enforce training for mates and helmsmen to reinforce the following elements:
   a. How to order turns without ambiguity – call "port" or "starboard" instead of "the opposite."
   b. Conduct a human factors review for defining responsibilities of mates and helmsmen.

- **Chonghaejin Marine Company**

1. Establish and reinforce organizational safety policy and culture.
   a. Improve morale in the company.
   b. Maintain leadership and commitment to safety as the highest priority.
   c. Enforce safety integrated into the organizational culture.
   d. Encourage Operations and contractors to contribute to safety-related decision making.
   e. Maintain minimum arrival time of vehicles and cargo to be loaded before departure.
   f. Allocate and execute an annual budget for safety training as planned.
2. Develop and enhance a safety control structure with appropriate responsibilities, accountability and authority, safety controls and feedback channels.
3. Enhance a review process of the OMR before submitting to ROKCG.
   a. Enhance the OMR to provide suitable means, methods, and maps for adequate loading and lashing of cargo containers and vehicles.
   b. Upgrade lashing points to secure new or foreign brand vehicles, and update the maps in the OMR.
   c. Enhance provide the information about ballast water the OMR to.
   d. Enhance the OMR to describe how and who to order evacuation, with an assumption that the captain is not capable of managing an emergency situation.
4. Review and enhance Emergency Deployment Readiness Exercise (EDRE) and Rescue Operations of Passengers (ROP) in the OMR.

a. Review and enhance detail procedures in the EDRE and ROP about how to correspond an emergency such as a ferry listing problem.
b. Review and enhance the EDRE and ROP to provide training with an assumption that the captain is not capable of managing an emergency situation.
c. Review and enhance the EDRE and ROP to provide training with an assumption that the first mate is not capable of conducting the scene.
d. Review and enhance the EDRE and ROP to provide training with an assumption that the third mate is not capable of communications with ROKCG in an emergency situation.
e. Review and enhance the EDRE and ROP to provide training with an assumption that the ferry lists and the capsizing progresses too fast (i.e. assuming the capsizing is completed in 30 minutes).
f. Review and enhance the EDRE and ROP to provide training for announcing emergency to passengers who are on the ferry.
g. Review and enhance the EDRE and ROP to provide training for activating liferafts and chutes with an assumption that the ferry lists 50 degrees.
h. Review and enhance the EDRE and ROP to provide training with an assumption that dysfunctional communications between the bridge and the Guest Services Desk and between the bridge and passengers occur.
i. Review and update the EDRE and ROP to provide how to make efficient distress calls when the ferry is in distress: which call number (i.e. Ch. 16), where to call (the closest VTS and 122) and what information (the status of the ferry: the list of the ferry, the location of the crew and passengers, the possibility of evacuation or abandonment, and whether the crew and passengers put on PFDs).
j. Review and reinforce the EDRE to provide training with an assumption that crew have to evacuate the ferry (i.e. leave the ferry after all of the passengers evacuate it).
k. Review and reinforce the EDRE to provide training about what crew have to do when they are rescued (for example, identify themselves).

5. Create and provide safety information training to the management and Logistics team.

a. Provide a complete understanding of restoring force, ballast water, maximum load limit and load line.
b. Update and reinforce safety information training policy for a part-time captain to provide safety training to his or her crew.

6. Enhance a process to detect and correct "no feedback on safety-related reports."
   a. The process should allow Operations and contractors to report safety information without fear and disregard.
7. Review and enhance a process to correct dysfunctional communications between Operations and Logistics about overloading related issues.
8. Review and enhance a maintenance process to safety-related equipment and safety devices.
   a. Enhance a maintenance process to fix "no watertight bow and stern doors."
9. Review and enhance safety training or drills.
   a. Enhance overseeing and auditing Operations' training, as defined in the OMR

- **ROKCG**

1. Review and enhance training on rules of SAR manual with a focus on the following elements at a minimum:
   a. How to rescue people on the distressed ferry.
   b. How to assess a situation before making any attempt to rescue people on the distressed ferry.
   c. How to establish and maintain communications with the crew and passengers on the distressed ferry.
   d. How to identify the type and structure of the ferry and the location of the crew and passengers.
   e. How to identify the possibility of evacuation or abandonment.
   f. How to ensure that the crew and passengers put on PFDs
   g. How to evaluate the rescue operations risks.

2. Review and update rules and policies of SAR manual with a focus on the following elements:
    a. Consider providing training on rescue operations for distressed car ferries and cruises to crew of Vessels 1,000 tons or smaller.
    b. Consider establishing priorities of SAR operations on the scene.
    c. Review and enhance means to perform passengers search on the ferry.
    a. Consider establishing a process for entering crewmembers on board to assess a situation.
    b. Consider adding real-time video/audio transmission systems on ROKCG Patrol Vessels 1,000 tons or smaller in order to transmit the status of the ferry to ROKCG District West and Group Mokpo in real time.
    c. Consider establishing a process for identifying crewmembers of the ferry when they are rescued.
    d. Consider establishing a process for using alternative communication channels or means to contact the distressed ferry if VHF FM channel 16 is no longer available.
    e. Enforce a process for turning on AISs of all ROKCG SAR units heading to or on the scene.
    f. Consider establishing communication channels with the surrounding with ROKCG units (i.e. OSC, Helicopters, District, Group, VTS).
    g. Enforce sufficient controls to detect and correct "Dysfunctional communication with ROKCG units on the scene."
    h. Enforce sufficient controls to detect and correct "critical information not shared."
3. Provide upgrades to the AMSS equipment in order to avoid interference with VHF FM channel 16, enabling stable signal quality and strength of VHF FM channels.
4. Enhance communications systems maintenance process to prevent the AMSS from being out of order.
5. Consider upgrades to the AMSS to prevent many spurious alarms from occurring. Consider conducting a human factors review for defining responsibilities of watchstander regarding the AMSS.

6. Review and update training on rules of SAR manual regarding On-Scene-Commander.
    a. Review and enhance procedures for briefing the information of OSC responsibilities to the OSC commander when the OSC is appointed.
    b. Enforce OSC training for communication with ROKCG units (i.e. District, Group, VTS), ROKCG units on the scene (helicopters) and the distressed ferry.
    c. Enforce OSC training for carrying out the SAR process including announcing "evacuation" using a loudhailer if needed.
7. Enhance watchstander qualification training to include or reinforce the following elements:
    a. How to monitor and detect the ferry's capsizing during 15 minutes of the replacement time as an overlapped area. Consider conducting a human factors review for defining responsibilities of watchstander during the replacement.
    b. How to work with the AMSS to detect the ferry's capsizing. Consider conducting a human factors review for defining roles of watchstander regarding the AMSS.
    c. How to detect that alerting function of the AMSS is turned off or out of order.
    d. How to maintain a watchstander per Sector. Consider conducting a human factors review for defining responsibilities of watchstander.
8. Enhance communications operation officer (122, Korea national maritime distress service call number) training to include or reinforce the following elements:
    a. How to maintain communication with distress callers.
    b. Types of communications to be logged.
    c. How to treat many calls about the same accident.
    d. Situations to require notification to a higher level.
9. Enhance Group/District/HQ commanders training (ROKCG Emergency Management Manual III-1 and ROKCG SAR 4-4) to include or reinforce the following elements:
    a. Consider establishing a process for commanding on-scene by Group commander with an assumption that the transportation means is available for Group commander and the OSC is already appointed by ROKCG District. Consider

conducting a human factors review for defining responsibilities of commander with this assumption.

b. Consider establishing a process for assigning Group commander to command ROKCG units on the scene and the distressed ferry with an assumption that ROKCG HQ or District already ordered an acting commander at the Group to contact the ferry and the Group commander is also available to command the units on the scene. Consider conducting a human factors review for defining responsibilities of commander with this assumption.
c. Consider establishing commander training to all potential officers who can be an acting commander.
d. How to detect and correct the OSC or the helicopters' pilots on the scene who do not make "evacuation announcement," "on-scene reports," and "communications with ROKCG units on the scene and the ferry."

- **Korea Shipping Association**

1. Enforce a review process of "Ferry safety inspection chart: before-departure."
   a. 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.
   b. Allow appropriate time to physically check and examine safety-related equipment and watertight bow and stern doors.
   c. Allow appropriate time to physically check and examine a number of passengers and total weight of both cargo and vehicles before departure.
   d. Allow appropriate time to physically check and examine how cargo and vehicles are secured before departure, which should be lashed based on the OMR: Cargo containers size (10 feet only), a passenger car secured by four lashing bands, each truck secured by ten nylon lashing bands, minimum distance between vehicles (2 feet), each cargo container secured by lashing bars, turnbuckles and corner fittings,

and each stacked cargo container secured by lashing bars, turnbuckles, twist locks and bridge fittings.

2. 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.
3. Regularize and improve safety communication (information and feedback) channels.
   a. Review and enforce effective communication channels for disseminating safety information.
   b. Improve feedback loops between operation officers and the supervisor.
   c. Improve feedback loops between operation officers and the ferry's Operations.
   d. Improve feedback loops between the KSA and the management of Chonghaejin Marine Company.
4. 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.
5. Consider establishing a process for reviewing the ferry's inspection certificate and critical data.
   e. 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**

1. Review and enhance processes for approving the ferry's inspection certificate.
   a. Enforce a physical inspection process for lashing of various vehicles including new Korean and European vehicles and stacked containers.
   b. Enforce a review process for inspecting drawings with actual structures.
   c. 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.
2. Improve safety related communication channel to the KSA and ROKCG.

a. Provide load limit, type of cargo containers, ballast and lashing methods directly to the KSA and ROKCG.

3. Review and enhance a process for checking a list of liferafts and chutes inspection certified companies. The list should be provided directly by the KMOF.
4. Consider adding a process for physically checking liferafts and chutes to the process for approving the ferry's inspection certificate.

- **ROKCG Group Incheon**

1. Review and enhance a process for approving the OMR.
   a. Receive technical data including critical load limits and ballast directly from the KR and review the OMR with the KR's approved data.
   b. Physically review the applicability of lashing of vehicles and cargo containers.
   c. Review and enhance emergency processes and procedures (i.e. EDRE and ROP) in the OMR with the following details: whether to order to "abandon the ferry" if the captain is not capable of making the decision, and if needed, not only contents but also sequences in the emergency contacts list.

- **Korea Ministry of Oceans and Fisheries**

1. Enforce maritime transportation regulatory system to ensure that regulators carry out their responsibilities adequately.
   a. Enforce a process for overseeing and feeding back liferaft inspection certified companies about inspection certificate of liferafts.
   b. Consider establishing a process for reviewing the records of liferaft inspection.
   c. Enforce a process for overseeing and feeding back Chonghaejin Marine Company about safety training.
   d. Enforce a process for overseeing and feeding back the KSA about conducting maritime transport safety measures.
   e. 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 errors, negligence, mistakes and unsafe actions made by the human controllers at the lower levels appear to be more reasonable when considered with respect to the environment and context in which their decisions and control actions took place. The CAST analysis also 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. It provides solutions to enhance the safety control structure so that the controllers have better information with which they can make the right decisions.

Chapter 7: Comparison of KMST and BAI Root Cause Analyses and CAST

As reviewed in Chapters 4 and 5, the traditional Root Cause Analyses performed by the Korea Maritime Safety Tribunal (KMST) and Board of Audit and Inspection of Korea (BAI) are focused on finding and correcting the operational errors or mistakes made by the management, which are most about human errors found by the use of ***hindsight bias***. The following are some of the findings taken from Chapters 4 and 5.

- The company management did not provide the required safety training and drills to the crew.
- The company management did not provide training of proper methods of loading and lashing cargo and vehicles to the crew of the ferry and the personnel of loading and lashing service companies.
- The crew of the ferry, operation officers at Korea Shipping Association (KSA), the personnel of loading and lashing companies did not pay attention to the requirements.
- The crew abandoned the sharply listing ferry without providing any safety means and ways to the passengers.
- The KSA poorly inspected the overloading and improper lashing conditions before the ferry's departure.
- The KR approved the modifications without reviewing the plan drawings of lashing vehicles.
- The KR certificated the ferry's operation with fictitious documents and data.
- The communications watchstanders at the ROKCG Station Jindo-VTS did not know the sharp turn for the first 20 minutes.
- Only one watchstander was on duty while there should be two.
- The ROKCG Patrol Vessel-123 did not rescue effectively passengers stayed on the ferry.
- The ROKCG Patrol Vessel-123 rescued the crew including the Captain before passengers.

- The ROKCG District West did not notify the ROKCG SAR units "Passengers stay put in their cabins."
- The District West did not order the Patrol Vessel-123 to contact the Sewol-Ho.
- The District West and Group Mokpo did not order the Patrol Vessel-123 and Helicopter 511 to report the current status.

Both reports do not include a complete understanding of the reason why the accident occurred and why the people behaved the way they did with the information they had at the time. Therefore, most recommendations made without the understanding are limited mostly to prevent the human controllers from making the errors, which is inadequate, difficult and ultimately, impossible.

Analyzing the entire maritime transportation system's safety control structure and the roles of human controllers in the accident to understand why it made mentally sense for them to act the way they did in the context, the CAST provided a more complete understanding of the reason than the traditional Root Cause Analyses. The CAST analysis resulted in a holistic and top-down set of accident causal factors and recommendations, which is more extensive than those from the traditional Root Cause Analyses. The CAST also provided the safety control structure in a hierarchical framework developed at CAST Step 3 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:
  - No one monitored the ferry during the watchstanders shift. – The higher level at ROKCG has to update watchstander training process.
  - Three controllers (the Captain and the crewmembers on the bridge, ROKCG Station Jindo-VTS and the OSC) did not make the evacuation decision on time. – the ROKCG SAR policy needs to be updated and the OMR with the ROKCG SAR policy has to be undated.

- Three controllers (ROKCG District West, two commanders at Group Mokpo) did not brief "the SAR procedures including the on-scene assessment" to the Patrol Vessel-123. - The higher level at ROKCG has to update the SAR process.
- The Captain on the bridge was in panic and could not make critical decisions including "evacuation order." - ROKCG SAR manual or/and the OMR must have the procedure to determine the situation.

- No feedback
  - The communications on VHF FM channel 16 between ROKCG units on scene and the Sewol-Ho and between ROKCG units on scene were not possible because the new Advanced Maritime Surveillance System running at ROKCG Station Jindo-VTS and VHF FM channel 16 interfered. - The higher level at ROKCG has to update the Maintenance process for SAR-related equipment and devices.
- 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. - The management at the company has to update the OMR - Containers/vehicles Lashing review process.
- Appropriate control actions were provided but not followed
  - The KMOF relied on voluntary compliance with regulations, policies and guidelines, the KR, the KSA, the Liferafts Inspection Certified Company, and Chonghaejin Marine. - The KMOF should have stepped in to achieve the overall safety goals.

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