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AN APPLICATION OF 24MODEL TO ANALYSE CAPSIZING OF THE EASTERN STAR FERRY

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ABSTRACT

In the present study, the Eastern Star ferry accident was analyzed via 24Model. 24Model, as an accident causation model based on system thinking, holds that all causations of the accident are hazards and all hazards in the system need to be identified and comprehensively controlled in accident prevention. The result showed that five factors were the main causes of the accident. First, the direct causes: bad weather, the bad condition of the hull and the unsafe acts of the captain. Second, the indirect cause: the lack of safety awareness and safety knowledge of both the captain and the company's senior management. Third, there were loopholes in safety management system, including the training, supervision and execution of the company. Forth, the root cause: the company didn't establish a good safety culture. Last, the external causes: the severe market pressure, excessive regulatory authorities with puzzled relations and responsibilities—seriously hindered effective supervision. In order to prevent this kind of accident and to secure shipping system, the shipping companies and the relevant regulatory units should draw lessons from the five factors mentioned above, and take measures to identify and control those hazards.

Keywords: Eastern Star ferry accident; 24Model; Systematic accident causation model; Accident analysis; Hazards

INTRODUCTION

The capsizing of the Eastern Star ferry is the worst ship disasters in China in recent 60 years. The shipwreck caused 442 deaths (only 12 were rescued out of 454 people). The purposes of analysing the accident are to discover the causation, and to provide possible scheme for the prevention of such incidents. As a complex production system[1] the operating status is directly related to the safety of numerous passengers on board. In marine accident research, Özkan Uğurluet et al. employed the fault tree analysis to analyse the collision and grounding in oil tanker[2]. Also, Marine Accident Investigation Branch made a detailed study into bridge watchkeeping safety based on 65 collisions, near collisions, groundings and contacts, and offered specific recommendations[3]. Additionally, Jintta Ylitalo established marine accident frequency models to analyse the accident frequency in the Gulf of Finland[4]/c. System thinking [5, 6], which is helpful to the analysis of the systemic characteristics of emergence and components interaction, is an important theoretical guide to solve the limitation of classical analytical methods based on reduction theory. In order to draw lessons from this serious accident, the present study applied the systematic accident causation model and 24Model to conduct a comprehensive analysis of such faulty shipping system. The human, technical, organizational, and social factors[7] that caused the accident have been

analyzed, and the experiences of preventing such accidents and the corresponding countermeasures were proposed. The case studies mainly based on accident analysis report[8].

The remaining of the paper is organized as follows: In Section 2, we elaborated the process of accident and introduced 24Model. In Section 3, we conducted a case study based on 24Model. In Section 4, we discussed the results of the analysis. Finally, we conclude this work in Section 5.

MATERIAL AND METHODS

PROCESS OF THE ACCIDENT

13 o'clock on May 28th, 2015, Eastern Star ferry started its voyage from Wumadu Port in Nanjing, Jiangsu Province. The ship planned to arrive at its destination in Chongqing at 6:30, June 7th. The accident occurred at about 21:32 on June 1st – the detailed description is as follows:

21:03. Eastern Star ferry sailed to the "Buoy of Tianziyihao" (one of the middle reaches of the Yangtze River, mileage of about 297.5 km). Its speed was about 14 km/h. At this time, there was lightning, and then it began to rain.

21:18. Eastern Star ferry sailed to "No.3 Red Buoy of Damazhou" (Middle reach of the Yangtze River, mileage of 301.0 km). It encountered a squall line weather system, with the south wind turning to the northwest wind, and rainstorm began to increase.

21:19. The captain heard the rainstorm getting stronger, and he rushed into the cab. At this moment, the chief officer on duty was commanding driving behind the radar; helmsman was in the steering, and sailor was standing by the bell to give assistance. The captain took over the command after acquiring the basic situation from chief officer.

21:21. Rainstorm continued to increase: the instantaneous maximum wind speed was 24.6 m/s and visibility declined significantly. The captain ordered the chief officer to slow down to 12.0 km/h, rudder left slightly to the right bank and implement anchor.

21:22. Eastern Star ferry was at the speed of 7.5 km/h.

21:23. Eastern Star ferry gradually dropped to 2.2 km/h. Subsequently, the speed gradually decreased to 0 km/h.

21:24. Due to the strong wind, the ship gradually fell backwards to its right rear with the speed of 4.0 km/h. Subsequently, the retreat speed was at 5.6 km/h. The captain noticed the ship was falling backwards, and he ordered the chief officer to increase the engine speed.

21:26. The speed of retreat reduced to 5.0 km/h. At this point this water area was in downburst which caused a sudden strengthening of the wind, instantaneous maximum wind speed was at 32 to 38 m/s.

21:29. The retreat speed was slowed down to 4.0 km/h.

21:30. In the strong rainstorm, the ship is out of control with a deflection and the wind angle increased, the speed increased to 6 km/h at that point. Subsequently, the ship suddenly tilted to the right and water began to infuse.

21:31. The ship's main engine stopped, and the ship stated to tilt to the right heel quickly.

About 21:32. Eastern Star ferry capsized with AIS and GPS signals disappeared.

INTRODUCTION OF 24MODEL

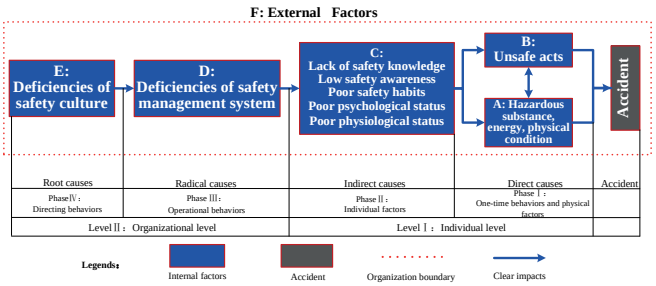

Fig. 1. 24Model[9-11].

24Model[9-11] as shown in Figure 1 is proposed and refined by the author's research team. 24model is put forward based on the Heinrich's[12], Reason's[1] accident causation model and the systematic thinking. The model redefines the individual and organizational dimensions and redefines the concept of hazards.

Safety is the emergence of the system from the viewpoint of system thinking[13]. Systematic accident causation model calls for dynamic and hierarchical characteristics. The hierarchical characteristics of 24Model are reflected in the two levels and four phases. Specifically, the two levels are individual level and organizational level; four phases are one-time behavior (acts), physical factors, safety management system and safety culture. In addition, the executors of unsafe acts in 24Model does not take the individual level into account—namely all the staff of the organization's unsafe acts are included. The organizational integrated behavior only contains the safety culture (philosophy, attitudes) and safety management system (files). The 24model redefines the individual and organizational behavior to make it easy to do statistical analysis of unsafe behavior of individuals and organization distinctly which reflecting the scale invariance[14]. Dynamic characteristic of 24Model is manifested on sustaining hazard identification and accident statistics continuously with the system changing. It can support the organization's daily safety management and continuous improvement and achieve the goal of accidents prevention through a hazards identification table and highly structured accident statistics formed based on the 24Model.

Fig. 2. Relationship of accidents and hazards

24moddel holds that the hazards are equivalent to the causations of the accident. From a systematic point of view, the system is a group of interconnected entities, which means that the accident is the consequence of the system migrating to the high risk status integrally. So that the failures and adverse interactions of all components in system are the causes of the accident, hazards contain human factors, physical factors, organization, organizational external factors.

As shown in Figure 2, an accident is incited by subset hazards of universe regarding all the hazards in the system as universe. This definition is consistent with the practice operating as well, such as ISO 45001 DIS[15] requiring taking the human factors, physical factors, organizational factors, organizational and external factors into fully consideration when hazards identification.

RESULTS

A Hazardous substance, energy and physical condition

A1 The squall line weather system.

The squall line system appeared "above the waters where Eastern Star" navigated accompanied by a downburst, tornadoes, other short-term local heavy rainfall as well as severe convective weather at the time of accident and therefore the ferry capsized suffering strong storms.

A2 The accident occurred between 9:00 p.m. and 10:00 p.m., when all the passengers were asleep or prepare to sleep. Therefore, it was difficult for them to escape.

A3 There was no side channel of the passengers' rooms that above the main deck.

A4 There were no weathertight covers or unfixed bunks on the cabin door and other related facilities.

A5 Wind pressure stability criterion was small.

A6 The ship veered rapidly leading the wind angle increasing.

A7 GPS signal were lost when the ship capsized but no one caught it in time.

B Unsafe acts

B1 The captain failed to make a decision in time to drop anchor in the bad weather. It was too late to drop anchor when the ship had been hit by the downburst and capsized. However, due to timely anchoring, the ships near the Easten Star ferry were safe.

B2 The captain and the crew failed to notice the receding of Eastern Star in time.

B3 In an emergency, the captain and chief officers failed to send out distress signal. Nor did they alarm the whole ship to arrange abandonment and evacuation of the ship.

B4 The management of the company let the designer dismantle the side channel when they remodeled the ship in 1997.

B5 The management of the company didn't notice that the cabin door, and other related facilities lacked the weathertight covers, and the bunks were unfixed.

B6 The management of the company cut the ship maintenance cost.

B7 Having been remodeled for three times, the stability criteria got smaller and smaller, although the value of it was still greater than 1. But the hull stability was getting worse; the specific changes of K value see Table 1. The ship remodeled in 1997. The ship remodeled in 2008. The company illegally hired the engineers who didn't acquire professional operating qualifications to transform the round bottom's ballast tank and water tank without submitting for approval in 2015.

Tab. 1. Changes of the stability criterion

Years	1994	1997	2008	2015
Ship stability (weather) criteria (K)	1.355	1.09	1.018	1.014

B8 The company safety supervision departments do not set up full-time vessels GPS monitoring personnel.

C Individual factors

C1 The captain and the chief officer lacked the safety knowledge of recognizing the seriousness of bad weather.

C2 Low safety consciousness led the captain and crew's failing to remain vigilant in a dangerous environment and find the receding of Eastern Star in time.

C3 Senior management of the company lacked the safety knowledge.

C31 Failed to realize risk posed by reduction of stability criteria after the transformation and inconvenience of escaping in emergency.

C32 Failed to realize the impact of weathertight and fixed bunks for the stability of the ship.

C33 Failed to realize the importance of GPS regulation.

C4 Poor safety habits of the senior management resulted in the long-term neglect of the ship's safety check and the assessment and training to the staff.

D Deficiencies of safety management system

D1 Chongqing Eastern Shipping Corporation did not develop the emergency treatment documents.

D2 Chongqing Eastern Shipping Corporation had loopholes in the crew's training system for ships, navigation and emergency knowledge. Besides, the company implemented assessment fraud which violates the "People's Republic

of China River Traffic Safety Management Regulations", Chapter II, Article IX.

D3 Chongqing Eastern Shipping Corporation did not establish a strict GPS regulatory system in management system.

E Deficiencies of safety culture

The table of Safety culture of the 32 elements See literature[16] for details.

E1 Lack of Safety Importance.
E4 Lack of Safety and Management Integration.
E6 Lack of Primary Responsibility for Workplace Safety.
E7 Lack of Safety Investment.
E8 Lack of Role of Safety Regulations.
E10 Lack of Safety Responsibility of Mangers.
E13 Lack of Demand of Safety Training.
E15 Lack of Role of Management System.
E32 Lack of Emergency Capability.

F External factors

F1 Market pressure made the senior management of the company cut the ship maintenance cost (Table 2 shows the Chongqing Eastern Shipping Corporation's financial status which depicts the company's poor profitability, higher debt in 2013 and 2014) and asked the trip must be completed original schedule on time.

Tab. 2. Chongqing Eastern Shipping Corporation's financial status[17]

	2013	2014		2013	2014
General assets	7,220 Million	8,975 Million	Total equities	-9,626 Million	-9,493 Million
Gross revenue	2,758 Million	3,315 Million	Total profit	-395 Million	133 Million
Prime operating revenue	2,519 Million	3,128 Million	Net margin	-395 Million	133 Million
Total tax	29 Million	184 Million	Total indebtedness	16,846 Million	18,468 Million

Unit: Chinese yuan

F2 Numerous management agencies with complex relationships and cross-functions.

The units that have supervisory responsibility for Chongqing Eastern Shipping Corporation include vertical supervision units of the Yangtze River Navigation Affairs Administration (Table 3) and the local government of Chongqing (Table 4).

Tab. 3. Ministry of Communications regulatory level (Vertical management)

1	2	3	4
Yangtze River Navigation Affairs Administration	Yangtze River MSA	Chongqing MSA	Wanzhou MSA
		Yueyang MSA	--

Yangtze River Navigation Affairs Administration had a poor supervision on Chongqing MSA and Wanzhou MSA. Wanzhou MSA as frontline law enforcement unit was not strict with the company's safety management system check. Neither did they find that the responsible person of the company's top management in charge of safety management did not have the corresponding qualifications nor they find the loopholes of GPS monitoring system, training and assessment, unfixed bunks, weather tight and so on. The control center of Yangtze River MSA ignored the affair of the control center of Yueyang MSA failed to perform duties seriously. Yueyang MSA did not constantly monitor the ship's status. When Eastern Star lost contact, they did not take measures to verify the status of the ship timely.

Table 4. Chongqing regulatory authorities level (Local government subordinate departments)

1	2	3	4
Chongqing municipal government	Chongqing transportation committee	Chongqing Navigational Affairs Administration	Wanzhou District Navigational Affairs Administration; Wanzhou shipping administration; Wanzhou Ship inspection Bureau
		Chongqing shipping administration	
		Chongqing Ship Inspection Bureau	
	Wanzhou municipal government	Wanzhou transportation committee	
	Chongqing SASAC	Wanzhou SASAC	

Wanzhou District Navigational Affairs Administration, as frontline law enforcement unit of local government, lacked strict inspection on Chongqing Eastern Shipping Corporation. The problems of illegal adjustment of ballast tanks and poor equipment in cabins were ignored and water transport permit was issued without careful inspection. SASAC of Wanzhou District was in charge of the Chongqing Eastern Shipping Corporation, but it did not carry out strict safety supervision and inspection of the company and did not find the fraud in training and assessment or the unhealthy management regime of the company.

F3 The imperfection of information sharing between China Meteorological Administration and maritime sector caused the maritime sector did not issue bad weather warnings to the Eastern Star.

DISCUSSION

The accident process is divided into two parts which are the capsizing and evacuating adversely. The specific path of the accident is shown in Figure 3 From the path of the accident can be seen that hazardous substance, energy and physical condition, unsafe acts, Individual factors, deficiencies of safety management system, deficiencies of safety culture and external factors interact and lead to mishap eventually.

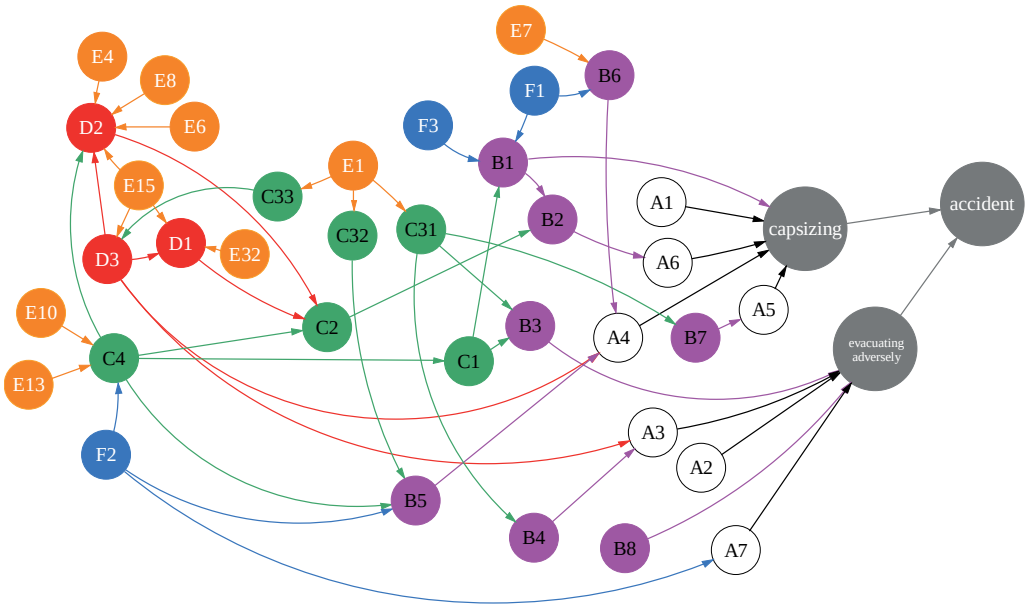

Fig. 3. The path of the Eastern Star ferry Accident

From the individual level of 24Model the direct cause of this inland waterways shipwreck was the ship met the squall line weather system which is a strong convective cloud formed by many monolithic thunderstorms and arranged side by side. What's more, the ferry was attacked by downburst (a strong sinking air flow in the local thunderstorm, after reaching the ground will produce a linear wind, the closer to the ground the faster wind speed it is, the maximum ground wind up to 15) at the same time. The hull stability was greatly challenged by the sudden strong convective weather. In addition, the hull was in a poor condition after the three times transformation (No side channel and stability significantly reduced). However, the captain yielded to market pressure and continued sailing in the bad weather, finally leading to capsize.

To analyze the deeper causes from the organizational level of 24Model, the corporation, as the main body of the responsibility, should ensure the provision of transport services and guarantee the safety of passengers at the same time. However, Chongqing Eastern Shipping Corporation, the Eastern Star belongs to, has laid the groundwork for the accident through day-to-day management and operation. Furthermore, the three times' reconstruction made the stability criteria getting smaller and smaller and the side channel was cancelled as well. In the meantime, there were no weathertight covers on the cabin door and other related facilities, and the bunks were unfixed. Additionally, the wrong operations of the captain and chief officer in emergency and sailing at night lead to the difficulty in escaping after capsizing. All these unsafe conditions have not been properly handled due to the unsound safety system and safety culture. The ship transportation organization should balance profits and safety and promote safety culture around deficiencies of safety culture mentioned earlier.

From the perspective of external organization factors, market pressure made the company in a poor business condition which led to catch up on travel schedule in a hurry and cut maintenance costs, so that the captain choose to continue sailing in such bad weather conditions.

The causes above are all belongs to subject responsibilities of the Chongqing Eastern Shipping Corporation. In external factors, oversight of Supervision department and insufficient early warning capabilities of China Meteorological Administration made contribution to the accident as well. Regulatory departments are divided into vertical departments of MSA and various departments of the local government, but still mismanagement. The functions of numerous regulatory authorities repeated in a way, may shift responsibility onto others. Due to this circumstance, it is recommended to simplify the shipping regulatory authorities, clear regulatory responsibilities and implement the implementation, so that the effective supervision of business enterprises.

It can be concluded that the mishap is the result of the overall deviation of the entire passenger transport system including hazards of human factors, physical factors, organizational factors and external factors. These hazards interact in the system and eventually led to overturning of the ship. The direct cause of the accident was the rarely bad weather and the unsafe acts of the captain. The countermeasure to the direct cause of the accident is to implement anchoring. Deep-seated causes were the safety management system of Chongqing Eastern Shipping Corporation confusion, deficiencies of safety culture, poor business conditions and regulatory supervision. The countermeasures to such causes above are: enterprises should establish a sound safety culture, and then develop a comprehensive safety management system. Moreover, the senior management and ship personnel need to implement the established rules of the system effectively to eliminate unsafe physical condition and unsafe acts. For the regulatory authorities, it's necessary to make clear the regulatory responsibilities and take effective supervision. To prevent accident, it is necessary to know well the path of accidents, and to improve the system comprehensively. If only implement rectification on one or several hazards, accidents cannot be prevented. For example, a sound safety management system and safety culture are established within the company, however, the flaws of the senior management implementation will generate the unsafe physical condition and unsafe acts of the ship personnel. Once the opportunity

is ripe, unsafe physical condition and unsafe acts will lead to the occurrence of the accident. In the case of preventing such accidents, it cannot be narrowed down to only identify and improve certain or several hazards. As elaborated in accident causation model based on system thinking 24Model, accident prevention should deploy the overall identification and control from viewpoint of the system level to achieve a good integration of system safety and functional achievement.

Additionally, it is also advisable for the customers and passengers to choose cruise companies with a good business operating status rather than a bad one, and to choose the ships with higher stability. Also, passengers should learn and remember how to use the escape facility in advance.

CONCLUSIONS

In the present study, a comprehensive analysis of the capsizing of the Eastern Star ferry was carried out via 24Model. Conclusions are as follows.

1. All the hazards that led to the accident have been analyzed and path of each hazard interaction has been mapped based on 24Model. The hazards contain all the components and the components interaction of the system. An accident is incited by subset hazards of universe, regarding all the hazards in the system as universe. For the daily safety management of shipping organizations, it is necessary to apply comprehensive hazards identification and control from the perspective of system so as to maintain the shipping system functions smooth and safe.

2. From the individual level of 24Model, the direct causes of the accident were the rarely bad weather and the unsafe decision-making of the captain. The countermeasure to prevent such direct causes is to anchor the ship.

3. From the organizational level of 24Model to analyze, the deep causes of the accident were the deficiencies of the management system and safety culture, the company's poor financial status and the misconduct of the regulatory authorities. The countermeasures to prevent such deep causes are forcing the enterprise to establish a sound safety culture, developing a comprehensive safety management system and implementing the effectively, and eliminating unsafe physical condition and unsafe acts. For regulators, it is necessary to simplify the organization structure, to confirm regulatory responsibility and implement effectively.

4. It is recommended that passengers should choose a cruise company with good financial condition when taking a cruise trip and understand the basic safety of the vessel before departure.

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