

# Study on the Analysis Method for Ship Maintenance Safety

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**ABSTRACT:** Considering the characteristics of ship maintenance, the causes for accident are further analyzed based on the theories of accident causation and hazard, so as to propose a concept of safety accident causation factor. A ship maintenance safety analysis framework is created as the basis for traceability analysis to unearth the root causes for accident, in order to develop effective preventive strategies and corrective actions, further reduce the risks of maintenance and prevent safety accident.

**KEYWORD:** Traceability analysis; causation factor; root cause; ship; maintenance

## 1 INTRODUCTION

Nowadays, safety accidents occur frequently during ship maintenance, resulting in economic losses and personal injury. Most of the existing safety analysis methods focus on hazard identification and causation of faults, errors or accidents, etc. to ascertain what causes safety incidents. However, ship is featured by long service life and increasingly complicated equipment, so these methods cannot be well applied in the safety analysis of ship maintenance or achieve very noticeable effect. Based on the characteristics of ship maintenance, this paper puts forward a safety analysis method to further improve the safety management of ship maintenance and effectively reduce the occurrence of safety accidents.

## 2 FRAMEWORK DESIGN FOR SAFETY ANALYSIS OF SHIP MAINTENANCE

As revealed in the analysis on accident causation theory [1], an accident is caused by multiple factors, which can be categorized into the motions of people and objects. When the orbits of people and objects intersect with each other, an accident may occur. Also, the motions of people and objects happen under a certain environment. Therefore, it is necessary, for the safety management of ship maintenance, track the unsafe behaviors of people and the unsafe states of objects, and combine it with the analysis of environment, in order to study the motion characteristics of people and objects and

analyze the impacts of environment on the unsafe behaviors of people and the unsafe states of objects.

In the meanwhile, the occurrence of safety incident results from the joint effect of three hazards based on the analysis of hazard theory[2-3]. The first hazard is energy carrier or energy source; the second hazard is the fault and physical environmental factors of objects (including safety facilities) and the mistakes in the behaviors of individuals; the third hazard is the organizational factors that do not comply with safety requirements (organizational procedure, organizational culture, rules and systems, etc.), including organizer's unsafe behaviors and mistakes, etc. During the occurrence and expansion of safety incident, these three hazards depend on and foster each other to jointly cause a hazard accident.

Therefore, the safety incident of ship maintenance is actually caused by human factor, object factor and environmental factor. Human factor refers to the factor that causes the safety incident of ship maintenance and relates to people. Object factor refers to the unsafe state of object that causes the safety incident of ship maintenance. The unsafe state of object is a state of fault. The fault of object may cause the failure of measures for constraining or restricting energy or dangerous matters, e.g. any electric leakage caused by damaged insulation of electric wire and damage to machine as a result of pipe rupture, etc. Environmental factor refers to the factor that causes the safety incident of ship maintenance in the environment.

There are not only various relations among human, object and environmental factors, but also the causal relations among causation factors. Hence,

safety incident is caused for multiple reasons. In other words, the causation analysis on the safety incident of ship maintenance should not simply blame “violation of rules” or “carelessness”, but delve into the nature of phenomenon and trace the causes at deeper level based on superficial causes, so as to find out the complicated logical and causal relations among causation factors till the root cause is exposed. Only in this way, it is possible to thoroughly identify hazardous factors and discover the effective ways to control dangers.

Based on the above analysis, the safety analysis framework of ship maintenance can be obtained. In other words, a cause is selected as the effect after analyzing the possible general causes and specific causes in the “cause list of causation model”. The possible cause is discovered through analyzing the “effect-cause linked list” for the taxonomic group containing the said cause, and it may be taken as the effect to analyze and discover the possible cause. In this way, the root cause can be discovered through the analysis in the end. The outcome of traceability analysis is an effect-cause link for each branch. The last cause of link is the possible root cause of the safety incident. Therefore, the logical and causal relations at deeper level among causation factors can be obtained through analysis. The specific analysis framework is presented in Fig. 1.

Table 1. Margin settings for A4 size paper and letter size paper.

Causation Model		Definition/Interpretation
Human Factor Causation Model	Negligence	Lose attention; be disturbed; overlook warnings, etc.
	Omission	Operate with omitted item, forget operation, etc.
	Wrongness	Wrong understanding, wrong objective, wrong operation and improper operation, etc.
	Violation	Maintain against procedures and related provisions, etc.
Object Factor Causation Model	Equipment Defects	Safety incident due to the problems of equipment, machine and software in use
	Tool Defects	Safety incident due to the problems of tool in use
	Energy Transfer	Energy transfer of dangerous matters due to radiation, explosion, electric strike, combustion and high temperature, etc.
Environmental Factor Causation Model	Hostile Environment	Poor natural environment or working environment, and abrupt environmental changes, etc.
	Organizational Impacts	Improper organizational management; wrong decision; defect in team building; lack of safety culture, etc.
	Defective Information	No or unreasonable supporting information including procedures and systems, etc.

### 3.2 Classification of Causes

The basic reason for safety incident is called cause. In the work of ship maintenance, the reasons for safety incident are classified into people-related causes, object-related causes and environment-related causes. Among them, people-related causes include: A. State of hardware, B. Psychological factors and C. Quality factors. Object-related causes include: D. Equipment defects, E. Tool defects and F. Energy transfer; environment-related causes are

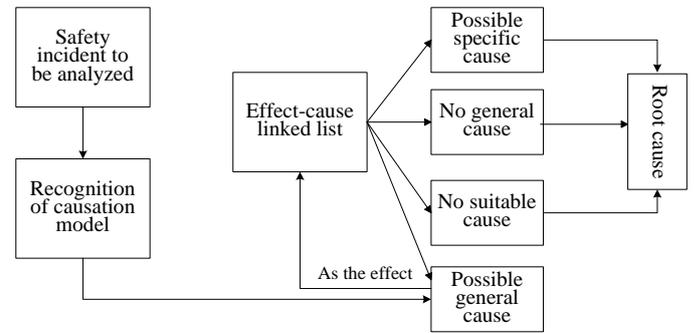


Fig. 1 Safety Analysis Framework of Ship Maintenance

## 3 CLASSIFICATION OF CAUSATION MODELS AND CAUSES

### 3.1 Classification of Causation Models

The external appearance of safety incident is defined as the causation model. The causation models for human factor, object factor and environmental factor are defined as human factor causation model, object factor causation model and environmental factor causation model respectively. Based on the analysis of the factors affecting ship maintenance, such three causation models are classified and defined as presented in Table 1.

classified into ten types, namely, G. Working environment unsuitable for maintenance, H. Improper arrangement of tasks, I. Safety culture, J. Training, K. Supervision management, L. Leadership, M. Decision-making, N. Team building. The 16 types of causes are regarded as the taxonomic groups, which are represented alphabetically. Each group is further segmented into several causes. The names and codes of causes are shown in Table 2.

Table 2. Classification of Causes.

Code	Name	Description
A1	Improper physiological factors	Diseases, psychological or mental disorder, alcohol poisoning, taking drugs, and other factors affecting the level of consciousness
A2	Poor physical conditions	Poor health conditions, tiredness and other poor physical conditions
B1	Negative psychological factors	Negative motive of work, poor psychological bearing ability, nerve, ignorance, blind pursuit, conformity, rebellion and other psychological conditions
C1	Lack of knowledge and skills	Lack of professional knowledge, operating skills and work experience, etc.
C2	Bad attitude toward work and habits	Lack of sense of responsibility, bad habits and lack of safety quality, etc.
D1	Fatal equipment fault	Equipment cannot function normally due to fatal fault
D2	Equipment aging	Delay in equipment maintenance, low working efficiency and other potential safety hazards
E1	Insufficient protection	Insufficient or defective protective devices
E2	Improper use of tools	Mainly include aging, expiration or delayed replacement of tools for maintenance, etc.
F1	Energy transfer	Dangers caused by radiation, explosion, electric strike and pollution, etc.
G1	Poor environmental quality	Temperature, humidity, dust, noise, vibration, radiation and poisonous substances, etc.
G2	Lack of safety warnings	No, obscure, unclear or misleading signs including safety operating procedures and warnings, etc.
H1	Improper arrangement of task/operation	Excessive workload, long-term operation, change of operation or start of new operation and shift change, etc.
I1	Lack of safety culture	Leaders lack the knowledge of and attitude toward safety culture, people's weak awareness of and attitude toward safety, lack of continual improvement in safety culture, etc.
J1	Lack of training about knowledge and skills	Lack of training about professional knowledge and operating skills; lack of training after equipment change
J2	Lack of safety training	No cultivation of people's awareness of and attitude toward safety and no good team safety culture
K1	Loose supervision and management	Insufficient fairness and completeness of supervision system; poor execution of supervision and management
L1	Defective organizational structure	Unreasonable organizational structure; unclear scope of authority; unclear responsibility, etc.
M1	Decision-making mistakes	Unreasonable allocation of tasks and unscientific management methods, etc.
N1	Weak team building	Unclear objectives or tasks; inappropriate structure of team members, etc.

#### 4 TRACEABILITY ANALYSIS ON SAFETY ACCIDENT OF SHIP MAINTENANCE

Based on the safety analysis framework in Fig. 1, after classifying causation models and causes, it is necessary to carry out the traceability analysis of "effect-cause", analyze and find out the possible causes and prepare the "effect-cause traceability list", in order to repeatedly analyze and search for the possible causes and finally determine the root cause. In Table 3, each line takes a cause category as the effect, in order to list the possible general causes (indicated by code in the 3<sup>rd</sup> column) and specific causes (in the 4<sup>th</sup> column) and present the effect-cause linked groups. The specific cause can be taken as root cause, while the general cause can be regarded as effect. The corresponding column is discovered in the table and then connected to the next effect-cause linked group. By tracing in this way, a series of effect-cause links are obtained. The causes represented by A1, D2, F1, G1 and L1 in the table are the effects without specific causes. Table 4 gives the possible basic causes for each causation model. Table 3 and Table 4 become the basis for the

traceability analysis of root case, which is started from causation model.

If an accident has happened during ship maintenance, experts are responsible for surveying and analyzing the accident and concluding the expansion process of such accident. One or several safety incidents may exist in the expansion process of an accident. To find out the root cause for a safety incident, traceability analysis can be carried out by employing "effect-cause traceability list" and "basic cause list of causation model". The specific procedure is as follows:

Step1: Determine the category of error model based on the appearance of safety incident;

Step2: Allow experts to select several possible causes as the start of traceability analysis based on the basic cause list of causation model in Table 4 and the basic condition of the incident;

Step3: Take each branch cause as the effect, identify a line in the effect-cause traceability list (see Table 3), allow experts to select the possible general causes and specific causes based on the specific condition of the incident, and stop the analysis if no reasonable cause can be found;

Table 3. Effect-Cause Traceability List

Code	Effect	General Cause	Specific Cause
A2	Poor physical conditions	G1, H1	Poor health condition, tiredness and other poor physical conditions
B1	Negative psychological factors	G1,H1, J1, J2, K1, N1	Negative environment or motive of work, nerve, blind pursuit, conformity and other psychological conditions due to personal issues
C1	Lack of knowledge and skills	J1	Insufficient experience, lack of training, knowledge and skills
C2	Bad attitude toward work and habits	B1, I1, K1, J2,	Poor personal quality, bad work habits or poor attitude toward work
D1	Fatal equipment fault	F1, G1,	Quality problems of equipment
E1	Insufficient protection	A4, C2	Incomplete or defective protective devices, insufficient or defective personal protection articles, e.g. protective clothes and gloves, etc.
E2	Improper use of tools	G1	aging, expiration or delayed replacement of tools
G2	Lack of safety warnings	I1	No, obscure, unclear or misleading signs including safety operating procedures and warnings, etc.
H1	Improper arrangement of task/operation	C1, K1, L1, M1, N1	Limited level of knowledge and experience, Excessive workload, long-term operation, change of operation or start of new operation and shift change, etc.
I1	Lack of safety culture	J2, L1	Leaders' lack of knowledge of and poor attitude toward safety, people's weak awareness of and poor attitude toward safety,
J1	Lack of training about skills	L1	No corresponding training mechanism and trainings within an organization
J2	Lack of safety training	I1, L1	Weak awareness of and poor attitude toward safety and low degree of team recognition
K1	Loose and unscientific supervision and management	B1, C2, I1, L1, N1	Insufficient fairness and completeness of supervision system; poor execution of supervision and management
M1	Decision-making mistakes	A1, A2, A3, A4, B1, C1, L1	Management personnel's improper arrangement of working hours and workers, unreasonable allocation of tasks and unscientific management methods, etc.
N1	Weak team building	I1, L1	Unclear objectives or tasks; inappropriate structure of team members; lack of understanding and trust among team members, etc.

Step4: Stop analyzing any branch of specific cause, return to step 3 for any branch of general cause and repeat steps 3 and 4. Through this cycle, a series of cause-effect links can be obtained. The last cause of each branch link will be a possible root cause of the safety incident.

Table 4. Basic Cause List of Causation Model

Causation Model		General Cause
Human Factor Causation Model	Negligence	A1, A2, B1, C1, C2, G1, G2, K1
	Omission	A2, C1, C2, G1, K1
	Wrongness	A1, A2, B1, M1
	Violation	A1, A2, B1, C1, C2, K1
Object Factor Causation Model	Equipment Defects	D1, D2,
	Tool Defects	E1, E2
	Energy Transfer	F1
Environmental Factor Causation Model	Hostile Environment	G1, G2
	Organizational Impacts	H1, I1, J1, J2, K1, L1, M1, N1

## 5 CONCLUSION

This paper straightens out and analyzes the causes for accident and their relations based on the theories of accident causation and hazard, and proposes a safety analysis method as a practical and effective tool for safety analysis during ship maintenance. The method is employed to analyze the shortcomings of the scenario based on the traceability analysis of the causes for safety accident and ascertain the root causes of the incident, in order to develop the effective preventive strategies and corrective actions and effectively prevent and reduce the occurrence of safety accident.

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