Fire and Explosion Safety Assessment of Container Line Supply Chain

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Abstract: Safety assessment is an essential element of maritime safety analysis and management as it can provide decision support to safety-based operations. In this paper, following a brief review of fire and explosion safety related regulations and assessment approaches, a hierarchical assessment framework is presented for evaluating safety level against fire and explosion hazards in container line supply chain (CLSC). The high-level factors influencing fire and explosion safety of containerships are investigated, and a safety modeling and synthesis method using the Evidential Reasoning (ER) approach is briefly discussed. The outcomes generated by the proposed assessment approach are highly consistent with "goal-setting" safety regulations.

Keywords: Fire and explosion, risk, safety assessment, container line supply chain

I. Introduction

Container line supply chain (CLSC), which transports cargo efficiently across seas and into ports throughout the world, has contributed significantly in facilitating global economic development and prosperity. Approximately 90 percent of world trade moves in shipping containers, and over 250 million containers are transported annually [8][10]. However, due to its characteristics of having complex physical and information flows, CLSC is also highly vulnerable to many possible undesirable accidents such as machinery failure, contact, collision, fire and explosion, grounding, etc. [1][7]. Among these "major accidents hazards", fire and explosion may be one of the most dangerous ones with potential to cause disastrous consequences [14]. For example, a 64,054 gt. Panama flag containership M.V. Hyundai Fortune was severely damaged in an accidental fire and explosion in aft on-deck container stacks and eventually abandoned after efforts to contain the fire failed. Moreover, MAIB statistics indicate that about 12% accidents of UK merchant vessels were incurred by fire and explosion hazards [7]. In response to the fact that CLSC is a dominant means to transport cargo but highly vulnerable to fire and explosion hazards, in past decades several regulations were issued by IMO (International Maritime Organization) and the UK HSE (Health & Safety Executive). Meanwhile, many safety assessment approaches, such as Formal Safety Analysis (FSA), have been widely used to assess the safety levels corresponding to various hazards in maritime transportation [13]. However, very limited work has been specifically carried out on fire and explosion safety assessment model of CLSC. In this paper, a well-structured assessment framework is proposed to assess safety level against fire and explosion hazards in CLSC.

The rest of this paper is organized as follows. A brief review of safety-related regulations and assessment approaches is provided in section 2. An assessment framework for evaluating safety level against fire and explosion hazards in CLSC is presented in section 3. Conclusions are drawn in Section 4.

II. Review of Safety-Related Regulations and Assessment Approaches

The safety of offshore installations against marine hazards has traditionally relied on IMO and classification society regulations [3]. These regulations are usually guided by expert judgments, responding to serious marine accident experience. Internationally, IMO SOLAS (International Convention for the Safety of Life at Sea) specifies detailed fire safety provisions for all ships and specific measures for cargo ships [5]. In the UK, PFEER (Offshore Installations - Prevention of Fire and Explosion and Emergency Response Regulations) provides general requirements for preventative and protective measures to manage fire and explosive hazards, to secure effective emergency response, and to ensure compliance with regulations [2]; UKOOA (Offshore Operators Association) Fire and Explosion Guidance provides an integrated approach to the management of fires and explosions [9].

On the basis of safety related regulations, many typical safety assessment approaches have also been widely applied to the evaluation of likelihood and consequences of hazards, such as Fault Tree Analysis (FTA), Failure Modes, Effects and Criticality Analysis (FMECA), Quantitative Risk Analysis (QRA) and FSA [3]. QRA is a complicated technique for risk assessment, and its methods of frequency analysis and consequence modeling have been successfully applied to the risk management of fire and explosions [11]. FSA is probably the most formal and comprehensive framework for general risk management in the field of maritime safety [4][13]. It was first developed by the UK Maritime and Coastguard Agency (MCA) and later incorporated into the IMO interim guidelines for safety assessment. The approach mainly consists of five steps: (1) hazard identification, (2) risk assessment, (3) risk control options, (4) cost-benefit analysis, and (5) decision making.

Despite the variety of safety assessment approaches, FSA and other conventional assessment techniques only provide the assessment process instead of well-structured assessment framework. Furthermore, these approaches are not designed to specifically address fire and explosion safety issues in CLSC.

III. Fire and explosion safety assessment

To maximize safety level against fire and explosion hazards in CLSC, safety assessment framework needs to be developed on the integral CLSC level. Generally, as shown in Fig. 1, CLSC can be characterized by the following physical stages: shipment consolidation, inland transportation, port of loading, maritime transportation, port of unloading, inland transportation, and shipment deconsolidation.

Figure 1 The physical flow of CSLC

At each stage, a hierarchical structure of assessment criteria is presented to assess safety level against fire and explosion hazards.

Assessment Criteria Hierarchy

In the framework, the safety level against hazard-based risks is modeled by three basic parameters, namely *occurrence likelihood*, *probability of occurrence of potential consequence*, and *potential consequence*. The evaluation of these three parameters can be further decomposed into the evaluation of contributing factors as shown in Fig. 2. To evaluate *occurrence likelihood* of fire and explosion event, we need assess the inherent features of cargo and containership and prevention measures. To evaluate *probability of occurrence of potential consequence*, we need assess detection, control, mitigation measures and recovery difficulty. The *potential consequence* can be evaluated by potential losses to people, property, environment and business systems.

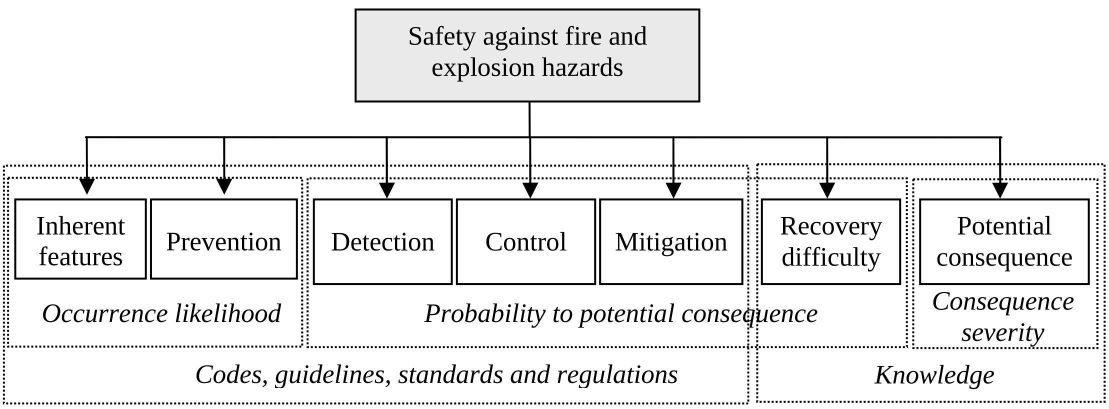

Figure 2 Hierarchical structure of fire and explosion safety assessment criteria

It worth noting that the performance standards of inherent features, prevention, detection, control and mitigation measures can be acquired from fire and explosion safety related codes, guidelines, standards and regulations, and recovery difficulty and potential consequence can be assessed by using experts' knowledge and historical accident data. As a case study, in the following we briefly discuss the factors influencing safety level of fire and explosion hazards on a containership.

(1) Occurrence likelihood

The occurrence likelihood defines the probability that a fire and explosion event occurs onboard the containership.

- Inherent features include flammable and explosive characteristics of cargos (particularly for dangerous goods and hazardous substances, e.g., oils, chemicals, acids, flammable solids, substances liable to spontaneous combustion, substances which can emit flammable gases on contact with water, etc.), and inherent fire and explosion safety of the containership (e.g., basic structure and layout of the ship, ventilation system of machinery spaces, etc.).
- Preventative measures are the most effective means to minimize the occurrence likelihood of fire and explosion and its associated risks. The performance of preventative measures can be evaluated by design measures, procedural controls, and prevention and protection systems.

(2) Probability of occurrence of potential consequence

This basic parameter represents the probability that potential consequence happens, given the occurrence of a fire and explosion event. It is affected by detection, control, mitigation measures and recovery difficulty.

- Detection measures can reduce undesired consequences of fire and explosion events by detecting and locating fires and alerting the navigation bridge and fire teams. Generally, the detection system is installed to transmit information to control points. Its performance is determined by automatic sprinklers, fire detection and alarm systems, and fire patrols.
- Control measures can limit the scale, intensity and duration of potential consequence. If a fire or explosion event happens, the containership has the capability of limiting the fire growth within every space by fire-extinguishing systems and fire brigade.
- Mitigation measures are deployed to mitigate the effects of fire and explosion events, including emergency training and drills, life-saving appliances, emergency instructions, and communication systems. For examples, it is required that at least one escape route must remain available during and after a fire and explosion event.
- Recovery difficulty is characterized by those activities that are needed to provide initial recovery and to provide the basis to facilitate long-term recovery activities, e.g., cargo replacement and ship repairment.

(3) Potential consequence

The potential consequence describes the magnitude of possible consequence. It can be assessed on the following dimensions:

- Human cost (e.g., physical and psychological harm to people, human death)
- Property damage (e.g., damage on cargo and containership, property losses)
- Environmental damage (e.g., environmental pollution, pollution on ecosystem)
- Losses to business systems (e.g., corporate image cost, economic losses to the community)

To assess the potential consequence of fire and explosion events, a fire and explosion scenario with a specific set of conditions usually need to be defined.

Subjective safety modeling and synthesis

In safety analysis, the evaluation of each factor can be described by subjective linguistic variables. For example, one may often use such variables as "*catastrophic*", "*critical*", "*marginal*", and "*negligible*" to evaluate the severity of *Potential Consequence (PC)*. In addition, uncertainties are always associated with maritime safety assessment due to lack of reliable safety data and lack of confidence. As such, a belief structure [15] can be applied to model the subjective safety assessment with uncertainty. For example, the subjective severity description *S*(*PC*) of *PC* can be expressed in the following form:

$$S(PC)=\{(\beta_{PC}^{1},\text{"catastrophic"}),(\beta_{PC}^{2},\text{"critical"}),(\beta_{PC}^{3},\text{"marginal"}),(\beta_{PC}^{4},\text{"negligible"})\} \quad (1)$$

where $\beta_{PC}^{i}(i=1,2,3\text{ or }4)$ represents the extent to which *PC* belongs to the *i*th subjective expression.

In the hierarchical structure of assessment criteria, safety assessment at higher levels is based on the information assessed at lower levels. It is therefore important to synthesize the safety evaluations of lower level factors in a rational way so as to obtain the safety evaluations of the higher level factors or the whole CLSC. The Evidential Reasoning (ER) approach can be employed to synthesize the subjective assessment information represented by belief structures [6][12].

VI. Conclusion

In this paper, an assessment framework is presented for assessing safety level against fire and explosion hazards in CLSC. The factors influencing fire and explosion safety of containerships are investigated, and a safety modelling and synthesis method using the ER approach is briefly discussed. The assessment approach has been validated by experts in the Port of Liverpool, and the generated outcomes are effective and highly consistent with "goal-setting" safety regulations.

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