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A Study on the Systematic Cause Analysis of Shipboard Fire Accident Case using STAMP Methodology

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[Abstract]

The ship system is complex and advanced, and the operation relationship between each element is very high. So it is necessary to approach it in terms of an overall and integrated system in addition to the traditional sequential approach of finding and removing the direct cause of the accident when analyzing the accident. In this study, it is analyzed the recent fire accidents on ships occurred the Korean terrestrial water using a STAMP methodology that is different from conventional accident analysis techniques. This analysis reviews a range of factors, including safety requirements to prevent fires in ships, inappropriate decisions and actions, situations, equipment defects, and recommendations derived from accident analysis results. Through a comprehensive approach to accident prevention using STAMP, alternative evaluations are presented at the component level within the entire system of ships, and they are systematically used for accident prevention and risk evaluation as well as simple accident analysis.

▸ **Key words**: Fire accident, STAMP, Accident analysis, System analysis, Ship system

[요 약]

선박 시스템은 복잡하고 고도화되어 있으며, 각 요소 간 업무연관성이 굉장히 높다 보니 관련된 사고를 예방하기 위해서는 사고를 분석할 때 사고의 직접적 원인을 찾아 제거하는 전통적인 순차적 접근방법에 더하여 전반적이고 통합적인 시스템의 측면에서 접근할 필요가 있다. 이에 본 연구에서는 전통적인 사고분석 기법과는 다른 STAMP 방법론을 사용하여 선박에서 발생한 화재 사고를 분석한다. 이 분석을 통해 선박 내 화재를 예방하기 위한 안전 요구 사항, 부적절한 결정과 조치, 상황, 장비 결함 및 사고분석 결과에서 도출된 권고 사항을 포함한 다양한 요소를 검토한다. STAMP를 이용한 사고 예방에 대한 종합적인 접근을 통해 선박이라는 전체 시스템 내에서 구성 요소 수준에서 대안 평가를 제시하고, 단순한 사고분석 뿐만 아니라 사고 예방 및 위험 평가에도 체계적으로 활용하고자 한다.

▸ **주제어**: 화재사고, STAMP, 사고 분석, 시스템 분석, 선박 시스템

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I. Introduction

Vessel assume a pivotal role in the realm of maritime transportation, serving as the primary ways and means responsible for the movement of goods and people. When ships set sail on the open sea, the paramount concern shifts from rapid arrival to prioritizing safety, owing to diverse array of risks inherent in shipping operation. Among these risks, onboard fires pose a particularity grave threat, given that a single occurrence can result in substantial damage to the vessel, its cargo, and the personnel like onboard passenger and crew. accidents involving fires during a voyage have persistently plagued the industry. According to maritime accident statistics complied by the Korean Statistics Information Services(KOSIS) over the past decade, commencing in 2013, as illustrated in FIg. 1, such accidents have demonstrated a consistent upward trend[1].

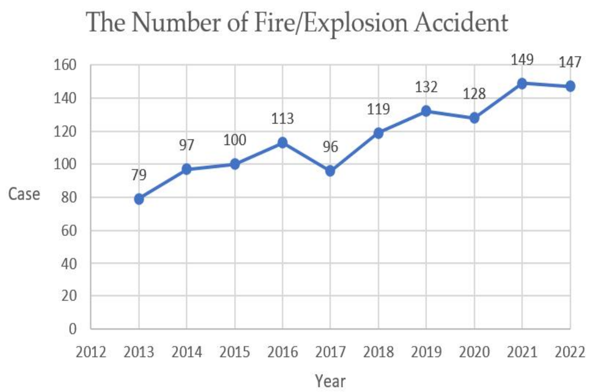

Fig. 1. The Number of Fire/Explosion Accidents

Furthermore, examining the maritime accident statistics categorized by accent type from 2016 to 2022, as reported by Korea Maritime Safety Tribunal, shipboard fire accident accounted for a total of 884 cases, constituting approximately 4.5% of all recorded accent. Looking at the damage caused by these accidents, a total of 78 individuals suffered casualties[2].

In the same vein, shipboard fire accidents continue to manifest on an annual basis, leading to substantial physical and human casualties. When delving into specific instances of recent shipboard fire accidents within domestic coastal areas, noteworthy cases include the M/V Auto Banner accident in Incheon Port on 2018, the M/V Platinum Ray accident in Ulsan Port, the Stolt Groenland accident in Yeompo Dock on 2019, the fire and sinking of the C/S Responder on 2020, and several others.

In recent shipboard fire accidents, the magnitude of damage has increased due to the modernization and scaling up of vessel systems, leading to greater structural complexity. Moreover, it has become increasingly challenging to categorize these accidents as the causes have grown more intricate. Rather than straightforwardly isolating a single ignition source, accidents often result from a complex interplay of multiple factors. Given this complexity and advancement, coupled with the multifaceted nature of these accidents, addressing them requires not only a sequential approach to identify and eliminate immediate causes but also a comprehensive system-oriented perspective.

Continuously, accidents have been occurring that cannot be adequately explained by solely relying on the concept of accident prevention through the removal of direct accident causes, under the assumption that no clear contributing factors remain. Hence, it is necessary to move beyond partial comprehension of the system and adopt a holistic perspective, considering internal relationships, when analyzing accident[3].

For these reasons, the systemic and integrated accident analysis method known as the STAMP(System Theoretic Accident Model and Processes) methodology has been adopted and applied to various accident analyzes internationally. However, it is challenging to find cases or research outcomes related to its application in the domestic industrial safety field as of now.

Therefore, it aims to apply the STAMP methodology to analyze a recent and prominent shipboard fire accident case in this study. Through this analysis, it is intended to provide a case study that not only identifies immediate accident causes but also derives overarching improvements for the system. The aim is to contribute to the prevention of maritime accidents and enhance safety in the future.

II. STAMP Methodology

2.1 The Methodology

The STAMP is an analytic approach and accident causality model derived by Leveson in 2004. It was created to address the shortcomings of conventional linear accident investigation method. This is because the conventional methods struggled to keep pace with the rapid advancements in science and technology, the ever-evolving characteristics of accidents, and the appearance of different types of hazards. The STAMP offers a structured framework for dissecting accidents that places significant emphasis on the broader context of the system under scrutiny. It delves into the intricate inter-plays among system components and their dynamic behaviors to uncover the root causes of accidents[4].

Within the framework of STAMP, accidents are viewed as outcomes stemming from the insufficient application of safety constraints within the interconnected components of a system, spanning its design, development, and operational phases. This approach underscores the idea that safety issues are not solely the result of failing to prevent accidents but are fundamentally linked to problems related to control. Safety constraints encompass a wide range of factors, such as consideration regarding environmental and financial conditions, regulatory compliance established procedures, technological aspects, and the overall system design[4].

In the context of STAMP, accidents are characterized as “the breakdown of the safety control framework”. This essentially implies situations where the mechanisms preventing the enforcement of safety constraints have faltered. Consequently, the primary goal of accident investigation within the STAMP framework is to pinpoint the underlying causes behind the breach of the safety contralto structure. It aims to discern what modifications or enhancements are necessarily within the control teamwork to avert future incidences and associated losses effectively[5].

The STAMP methodology incorporates a core control structure that encompasses both the development of system and operational phases, and this control structure is organized hierarchically. At the topmost level, it sets the overarching safety polices, standards and procedures, while the lower levels are tasked with executing and putting these policies and procedures into actions. Furthermore, the system is represented hierarchically with its components organized into various levels, and it showcases the interrelationship and feedback mechanisms between the high-level decision making processes and the lower-level system components. The most strength of the STAMP methodology is its adoption of a bottom-up(downward) approach which renders it suitable for analyzing complex systems. It comprehensively addresses a wide spectrum of factors that can contribute to accidents, including software, human factors, organizational dynamics, and safety culture. This integration eliminates the necessity of managing these aspects independently through distinct methods or approaches, streamlining the analysis process and providing a holistic vies of system safety[5].

2.2 Literature Survey

The analysis using STAMP methodology is being applied to a variety of fields such as aviation, chemical factories, maritime transportation, and railways. In the following Table 1[6][7][8][9], it shows the research report and papers where accidents were analyzed using STAMP as referred in the CAST HANDBOOK(2019) which is published

Table 1. The Research Record and Paper using STAMP Methodology

No	Title	Author	Field
1	A Study on the Improvement of Steering Command System through Accident Analysis of Azimuth thruster using STAMP Method, 2023	HyunDong Kim, SangHoon Lee, JeongMin Kim	Maritime
2	Risk Assessment of Actuators Uncertainty using STPA and SMC, 2023	Sohee Park, Ryeonggu Kwon, Gihwon Kwon	Railway
3	Analysis on Risk Factors of Platform Screen Door Failure Based on STPA, 2021	Sang Hun Lee, Sung-Min Shin	Automative
4	A Study on the Performing of Safety Analysis of ISO 26262 Development Phase Applying STPA Based on STAMP, 2019	Sungryong Do	Railway

by Prof. Leveson from MIT. These cases demonstrate the versatile application of STAMP in diverse domains, including aviation, chemical manufacturing, health-care, and more[5].

III. STAMP Analysis of the Accident Case

3.1 The Proximate Event

The vessel A set sail and was actively engaged in cable laying operations, while the vessel was operating, an F.O. leakage alarm was triggered due to leaks detected in cylinder no.5 to no.8 of the #1 and #2 main engines. Upon conducting an on-site inspection to assess the situation, the duty engineer confirmed substantial oil leakage from the high-pressure pipes of no.4 cylinders and no.6 of #2 main engine. Furthermore, oil was observed to be flowing from the exterior of the crankcase of no.8 cylinder in the #2 main engine, indicating a significant fuel leakage throughout the engine. Subsequently, the duty engineer reported the findings to the chief engineer who promptly came the scene to assess the situation firsthand. As a result, it was concluded that significant fractures, rather than mere cracks, had occurred. Consequently, the decision was made to halt these engines and initiate maintenance procedures. Following the shutdown of the #1 main engine, an assessment of the situation was conducted; however, the leakage issue persisted. To find and inspect the #2 main engine, an attempt was made to restart the #1 engine and press the ACB (Alternate Current Bus) button. Regrettably, the power switch-over did not occur as intended, and a fire alarm sounded suddenly. Subsequent, both the #1 and #2 main engines were brought to a halt, and the occurrence of a fire was recognized. An attempt was made to enter the engine room following the assembly of the fire emergency response team. However, it proved impossible to gain access due to the substantial smoke and the scale of the fire. The vessel promptly reported the fire accident to the Vessel Traffic Service(VTS) while simultaneously activating the fixed CO_2 fire fighting system. These efforts failed to contain the fire. With the fire escalating rapidly, the captain made the decision to abandon ship, and all crew safely disembarked onto the nearby assisting vessel B[10].

To conduct STAMP analysis for the accident, it has constructed a control structure for the ship and its operational system as depicted in Fig. 2.

3.2 Analysis of the Crew Level

In order to conduct an analysis of the accident, it is referenced accident reports obtained through surveys of the onboard crew. Initially, the officers and engineers who held responsible positions during the accident, were individuals with prior experience in similar vessel types within the company or had sufficient tenure experiences of specific vessel. Consequently, they possessed substantial information an out the operational performance and maintenance history of the ship involve in the accident. However, it is evident that this many experiences may have inadvertently influenced them towards a more pessimistic lookout, anticipating the

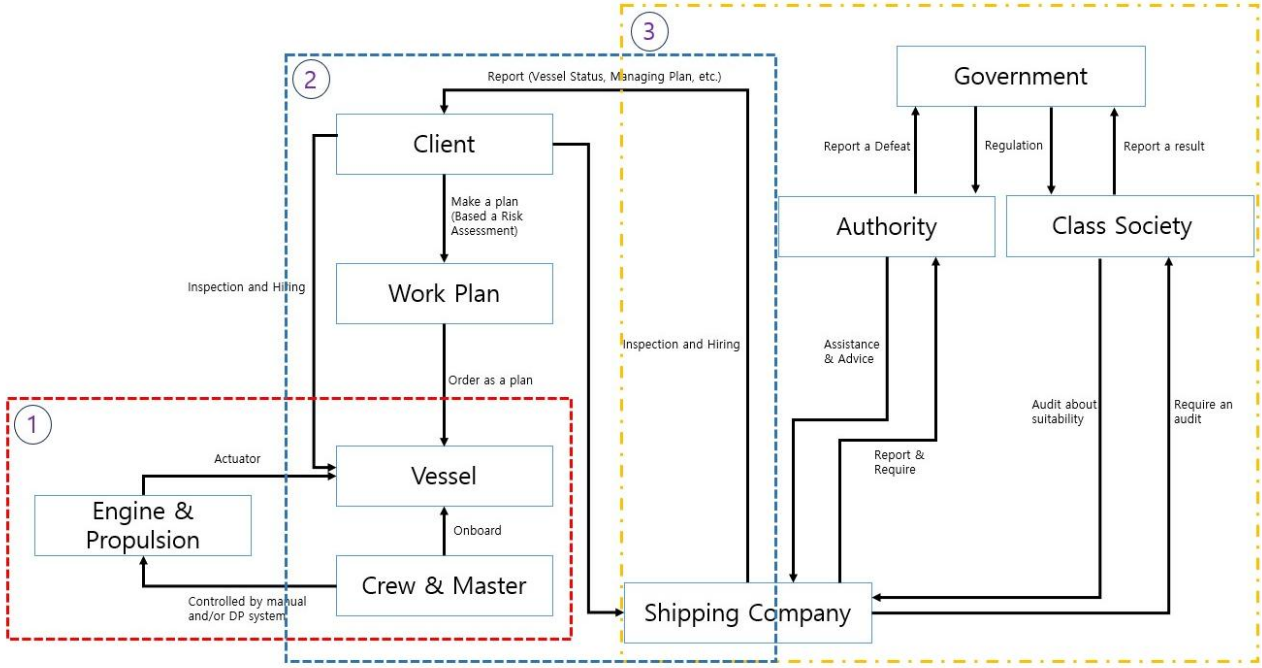

Fig. 2. Control Structure of Case Study

worst-case failure and accident.

This is because it appears that they prioritized repairing the leaking areas, even in a situation where oil leakage had occurred and a significant amount of vapor had been generated for at least 45 minutes. It suggests that they may not have considered the risks of fire or explosion. This could be attributed to the fact that the onboard crew had extensive experience with the particular vessel, leading to a cognitive bias where they believed that such an event would not escalate into the worst-case failure. In fact, the 1st engineer who had served on the vessel confirmed that they were aware of the fire risk associated with oil leakage on interview. However, they expressed that their initial decision was to prioritize containing the oil leakage as they believed it was sacrificial to prevent further leakage.

Furthermore, it is evident that the response to the oil leakage accident aboard the ship did not adhere to appropriate fire response and reporting procedures. Even though there should have been proactive reporting regarding the possibility of a fire when the oil leakage accident occurred, it was only reported when the fire broke out, and evacuation from the engine room was initiated. This highlights a failure in the fire response procedure and reporting protocols on ship. Additionally, it is observed that the effectiveness of monthly fire emergency response drills, as required by the International Convention for the Safety of Life at Sea(SOLAS), was not realized during the firefighting operations and situations. Particularly, according to the accident report, the fact that the fire emergency response drills were not actually conducted but were managed at a level of mere briefings represents a significant and critical issue[10]. This indicates a lack of awareness regarding the potential risks during normal operations and reveals deficiencies in safety consciousness. In the event of an actual emergency situation, this could imply a lack of preparedness and response capability.

3.3 Analysis of the Industry Association Level

According to the IMCA M 220 document “Guidelines for the vessels and units with dynamic positioning(DP) systems”, is utilized for regulating operational procedures concerning vessels and units equipped with DP systems. It represented that operational activities are carried out using ASOG(Activity Specific Operating Guidlines), which inlude CAM(Critical Activity Mode) and TAM(Task Appropriate Mode)[11].

However, the analysis of the accident report and interviews with relevant individuals suggest that there were no such operational procedures in place for the specific tasks related to the accident. Of course, having these operational procedures in place is not an absolute legal requirement. But, it is worth nothing that IMCA Guidance strongly emphasizes their necessity, and in the majority of the offshore industry, clients demand compliance with these regulations during the operation bidding phase. According to IMCA M 220 documents, the embellishment of an Operation Envelope serves as a safety mechanism to ensure that the operational activities on vessel always remain within a safe conduction, depending on the severity of the operational workload on vessel[12].

3.4 Analysis of the Government Authorities Level

According to SOLAS chapter III/Reg.19, all vessels are required to conduct fire drills with the entire crew participating once every month. Additionally, if more than 25% of the crew is changed, a fire drill must be conducted within 24 hours of departure. It is crucial that the records of these drills including in the ship's logbook[11]. Furthermore, such training records are among the foremost items checked and examined in various audits and inspections aimed at evaluating a operational fitness of certain vessel. Consequently, it was discovered that they maintained records without actually conducting the training in the case of this particular vessel.

In the accident, the fixed fire fighting system was activated when an actual fire occurred and it was deemed impossible to extinguish with manpower. Typically, fire fighting methods often involve blocking one of the three key elements of fire, commonly referred to as the “fire triangle”(heat, oxygen and fuel). Using a fixed fire fighting system entails primarily blocking the element of oxygen within this triangle. However, for this to be effective, it is imperative to first seal off openings and ventilation ducts leading from the engine room to the exterior, which was not carried out in this case. While attempts were made to seal off ventilation for fire fighting, the presence of toxic gases rendered it impossible to proceed with the operation. Generally, the personnel responsible for closing dampers and ventilation ducts leading to the engine room do not wear firefighting devices in standard fire fighting drill scenario in engine room. This can be regarded as an error resulting from conducting training without considering the actual fire environment. Furthermore, such scenarios are documented in the ship system documents indicating that this issue is not merely a problem with the ship but rather a systemic one. And, it is suggested that going beyond merely maintaining record video or photographs. These material could be widely regulated and overseen by government authorities and relevant institution. Such an approach would be highly beneficial to enhance knowledge for fire fighting.

Additionally, the alternative fire fighting methods should have been taken into account considering that this specific type of vessel possesses a different structure and configuration compared to conventional cargo ships. The individuals most knowledgeably about this information would likely be the onboard crew and the shipping company. Therefore, it is imperative that comprehensive information regarding the characteristics and particulars of vessel be actively provided to fire departments and relevant authorities, as they would be best equipped to understand these details even though abandoning ship.

IV. Change of Ship Operations Processes

In this chapter, the issues related to each component of the system which were previously identified and assessed, are briefly summarized. The content includes the safety-related responsibilities for each component of the control structure contributing factors to accidents(action, in-action, decisions), deficiencies in control structure components that lead to actions/decisions, and flaws in action/decision and process models along with situation factors. The recommendations are succinctly based on the information presented.

The identified issues at the crew level are shown in Table 2.

Table 2. Identified Issue at the Crew Level

Crew Level
1) Safety Requirements - Upon the activation of the engine room fire alarm, confirm the source and assess the current situation. - If there is a simultaneous fuel leakage, reduce the concentration of flammable gas below the explosive range. - Immediately share information related to the accident following the reporting procedure. - Implement appropriate initial response measures. 2) Inappropriate Decision and Actions - The focus was primarily on preventing fuel leakage, neglecting the consistent maintenance of ignition conditions. - Comprehensive information sharing did not take place immediately upon the accident. - Inadequate responses were executed. 3) Situation - Engine shutdown and high-pressure pipe condition verification were performed for fuel leakage prevention. - Ignition occurred during the restart phase. 4) Equipment Deficiencies - Conditions allowing back-flow existed in the drain tank. - Proper ventilation facilities were not installed. - Training was not conducted periodically. 5) Recommendation - Actual training must be conducted. - Adequate ventilation facilities should be installed. - Check valves or similar type of valves to prevent back-flow should be installed.

The identified issues at the industry association level are shown in Table 3.

Table 3. Identified Issue at the Industry Association Level

Industry Association Level
1) Safety Requirements - Must be operated following the procedure outlined in IMCA M 220 - Thorough verification procedures for compliance with regulations must be conducted beforehand. 2) Inappropriate Decision and Actions - Operating procedures according to the regulation have not been established. - Verification of operational procedures has not been carried out. 3) Situation - Work is typically performed and managed as part of routine operations. 4) Equipment Deficiencies - Lack of establishment and verification of operational procedures. 5) Recommendation - Guidelines should be established in accordance with the content of the Guidance, depending on the mode of operation. - Safety checks for the vessel should be conducted periodically.

The identified issues at the government authorities level are shown in Table 4.

Table 4. Identified Issue at the Government Authorities Level

Government Authorities Level
1) Safety Requirements - Submissions related to onboard training should be actively reviewed. - Training should be simulated real situation reflecting the actual conditions. - Firefighting methods should be considered, taking into account the various characteristics of vessel. 2) Inappropriate Decision and Actions - Failure to timely confirm the lack of proficiency in training on crew. - Actual situation occurrences were not adequately reflected. - Information regarding the particular and configuration of vessel was not shared promptly. 3) Situation - The task were performed according to the scenario, but in reality, the tasks could not be executed. - Information about the particular and configuration of vessel was not communicated during the firefighting stage. 4) Equipment Deficiencies - The example of scenario in system documents did not adequately reflect real situation. - Verification of training performance was inadequate. 5) Recommendation - Actual training should be well-documented and managed through various means. - Establishing standard fire scenarios with expert consultation is necessary. - Procedures should be established within the shipping

company for promptly reporting the particular and configuration of vessel to relevant authorities during firefighting operations.

V. Conclusions

To prevent accidents associated with complex and highly advanced operations such as shipboard fire accidents, it is essential to approach accident analysis not only by identifying and eliminating the immediate causes but also by considering the broader aspects of the system including societal, technological and organizational factors which are highly interrelated. In this study, it is conducted an analysis of fire accident using the STAMP methodology which differs from traditional accident analysis methods. Through this analysis, it is examined various elements including safety requirement, inappropriate decisions and actions, the situation, equipment deficiencies, and recommendation derived from the accident analysis results.

In STAMP, accident are introduced as the result of inadequte enforcement of safety constraints among interacting components within the system during design, development, and operational stages. STAMP views safety as a control problem rather than a failure prevention issue. And these constraints can encompass environmental, financial, rules, procedures, equipment, and technical design aspects. The fundamental control structure of the STAMP model includes both system development structure and system operational structure, each organized into hierarchical layers. In the upper structure, the safety policies, standards and procedures are determined. And lower structure is responsible for the actual execution of policies or procedures. Peritoneal procedures and control structures that operate in practice are also part of the lower structure. It follows a bottom-up approach rather than a top-down one, making it highly applicable to complex systems. It encompasses factors such as wetware, human elements, organizations, and safety culture that can serve as causes or contributors to accident or losses. This intimates the need to separately address these aspects through different methods, which is a notable advantage. However, a backward is its limited ability to explain the influence of external disruption or unexpected events[3]. Nevertheless, STAMP enables a holistic approach to accident prevention allowing for the presentation of alternative valuations at the component level within the entire system. It should be noted that the data related to accident investigation was collected based on accident reports, and some details may differ from actual factors.

It can be utilized not only for accident analysis but also for systematically preventing accidents and assessing risks. Therefore if there are more application cases of this systemic risk assessment technique, it can be used for safety diagnostics in real and, contribute to prevent accident.

REFERENCES

[1] Korean Statistics Information Service, The Status of marine accidents by accident type, 2023. https://kosis.kr/statHtml/

[2] Korea Maritime Safety tribunal, Statistics of marine accident, 2023. https://www.kmst.go.kr/web/

[3] C. C. Koo, D. H. Seo and P. H. Lee, "Analysis of Explosion Accidents in a Chemical Plant using STAMP, a Systematic Cause-and-effect Analysis Technique", Journal of Fire Science and Engineering, Vol. 35, No. 5, pp. 17-23, 2021. DOI : 10.7731/KIFSE.ff34dc1f

[4] N. G. Leveson, M. Daouk, N. Dulac and K. Marais, "Applying STAMP in accident analysis", In NASA Conference Publication, pp. 177-198, NASA: 1998, 2003

[5] Leveson N. G. and Thomas J. P., "CAST HANDBOOK", Massachusetts Institute of Chronology, 2019.

[6] H. D. Kim, S. H. Lee and J. M. Kim, "A Study on the Improvement of Steering Command System through Accident Analysis of Azimuth thruster using STAMP Method", Journal of the Korea Society of Computer and Information , vol. 28, no. 9, pp. 149-158, 2023. DOI: 10.9708/jksci.2023.28.09.149

[7] S. H. Park, R. G. Kwon and G. H. Kwon, "Risk Assessment of Actuators Uncertainty using STPA and SMC," The Journal of Korean Institute of Information Technology, vol. 21, no. 8, pp.

39-49, 2023, DOI: 10.14801/jkiit.2023.21.8.39

[8] S. H. Lee and S. M. Shin, "Analysis on Risk Factors of Platform Screen Door Failure Based on STPA," Journal of the Korean Society for Railway, vol. 24, no. 11, pp. 931-943, 2021, DOI: 10.7782/JKSR.2021.24.11.931

[9] S. R. Do, "A Study on the Performing of Safety Analysis of ISO 26262 Development Phase Applying STPA Based on STAMP", Transaction of the Korean Society of Automotive Engineers, vol. 27, no. 12, pp. 965-975, 2019, DOI: 10.7467/KSAE.2019.27.12.965

[10] Korea Maritime Safety Tribunal, Special investigation report on marine accident 'Fire accident of C/S Responder', 2021-006, 2021.

[11] International Marine Contractors Association, "Guidance on Operational Activity Planning", IMCA M 220, pp. 1-20, 2017. https://www.imca-int.com/

[12] International Maritime Organization, International Convention for Safety of Life at Sea, Chapter III, Regualtion 19: Emergency training and drills, 2020.

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