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A concept study for the buoyancy support system based on the fixed fire-fighting system for damaged ships

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ABSTRACT

Although the number of marine accidents has gradually decreased, fatal ones continue to occur. To prevent huge losses of life, environment and property, there are sufficient laws, rules and regulations, which include many technical solutions. Notably, many solutions for damaged ships are suggested to prevent capsizing and sinking. However, many pioneering ideas for damaged ships remain at the conception level because of the lack of technical and economic feasibility. To have both technical and economic feasibility in the design process, in this study, a business-model-adopted design process has been considered. Using this design process, a new concept for buoyancy support systems is studied, which considers the technical and economic matters in the design process. In addition, a fixed fire-fighting system and 3d laser scan data basis 3-dimensional buoyancy support system are been studied. To convince the usability of the suggested concept, computational simulation was used at the abstract level. Because there can be thousands of damage scenarios for a ship, sampled catastrophic damage scenarios are used in the case study to confirm the possibility of the suggested concept of buoyancy support systems.

1. Introduction and background

Every ship is designed and built according to the rules and regulations to enable each ship to be prepared for various marine accidents. It is also furnished with the safety equipment and facilities required by Safety of Life at Sea (SOLAS) (IMO, 2009). IMO has continued to make concerted efforts to improve ship safety. In efforts to prevent a vessel from sinking due to flooding of accidents, very valuable results are now available including 'Guidelines for flooding detection system on passenger ship (IMO MSC, 2009)', 'Guidelines on safe return to port for passenger ships (IMO SDC, 2015)', 'Guidelines on harmonized aeronautical and maritime search and rescue procedures, including SAR training matters (IMO NCSR, 2016). With these meaningful efforts, the best way to ensure a safe voyage of vessels is to comply with relevant laws and regulations. Nevertheless, studies of technological alternatives to reduce human lives, the environment, and property damages in the event of an unexpected accident is still in progress. In cases of marine accidents such as collisions and groundings, excessive damage and flooding cause the ship to sink, capsize or impede the use of its essential navigation equipment. As ship has watertight bulkheads, doors, hatches and other means, the consequence of flooding accident usually can be mitigated in early phase of an accident. But in some excessive damaged case, the operation of the essential equipment that is crucial for sailing, such as the navigation radar or generator, can be becomes impossible (Kang et al., 2013). In addition, the progressive flooding after the excessive accident can cause sinking or capsizing of the ship. To counter these problems, many pioneering studies are in progress, such as research to avoid parametric roll (Bačkalov et al., 2016), studies of numerical prediction of damage ship stability (Papanikolaou and Spanos, 2004 and Papanikolaou, 2007), improvement of ship stability and safety in damaged condition through operational measures (Boulougouris et al., 2016) and onboard damage control system (DCS) and an incident management system (IMS) (Shafie-pour and Sajdak, 2015). In addition, several concepts of the buoyancy support system that is attached to the outer hull in the forms of sponson and ducktail for passenger vessel have been applied to fulfill SOLAS 95, which is called Stockholm Agreement (Vassalos and Papanikolaou, 2002). The inner ship structure that prevents the ship from losing its stability has also been introduced by research projects such as EU FP7 project SUSY (Surfacing System for Ship Recovery) for cargo vessels (Smith et al., 2011) and the foam resin based on damage stability recovery system (DSRS) (Vassalos et al., 2016). For an inner hull buoyancy support system, sharp bumps such as brackets with complicated geometrical shapes in the hull can damage the buoyancy chamber during inflation. For foam resin, reusability of essential equipment for safe

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Table 1
Initial requirements for the alternative design.

No.	Requirement
R1	Keeping the buoyancy in critical damage
R2	Improved inner ship operability
R3	Free from need of major made over (building cost)
R4	Minimized influence to ship performance (operation cost)

Table 2
MOE/KPP, MOP, and TPMs of the designing system.

Type		Item	Threshold	Indicator
MOE/KPP		Not to sinking and capsizing in critical damage	Cost and level of ship remodeling	Amount of compensated buoyancy
MOP		Ship behavior in certain damage	Not to sinking and capsizing	Heave, Roll, Pitch
TPM	TPM1	Ship stability	Risk of sinking and capsizing	Tine basis roll range transition
	TPM2	Inner ship workability	Damage control workability in damaged space	Space for entering, working, escaping
	TPM3	Level of ship remodeling	Not	Required No. of new equipment

Table 3
Configuration of the business model.

Task	Keeping compulsory buoyancy under critical damage(flooding)
Value	Preparatory buoyancy
Revenue	Enhanced safety under critical damage(flooding)
Infra	Existing equipment and facilities
Channel	Inner ship space
Stakeholder	Ship owner, crews, equipment manufacturers, rule makers and related organizations

Table 4
Function list for the alternative design.

No.	Required functions
F1	Stability keeping
F2	Workspace serving
F3	Ship inside foundation

return to port have to be considered. The additional requirements to install the gas (or foam resin) valves, nozzles and control systems such as sensors, power and data lines worsen the applicability of the concept. When the buoyancy support system is installed outside the ship, additional consideration for lack of lifetime maintainability should also be considered because the buoyancy support system is exposed to sunlight and salty sea breeze. To enhance damaged ships' safety, design alternatives for buoyancy support should be considered not only from technical but also economic feasibility. For this reason, in this paper, alternatives for buoyancy support system has studied more in detail from the initial concept which has been introduced as a proceeding at PRADS 2016 (Kang and Choi, 2016). Based on the buoyancy support function, an alternative has studied that could be used at an acceptable cost without degradation of the vessel's performance. Applicability to a variety of vessels and the life cycle maintenance were also considered.

2. Requirement analysis

The technology to be developed must be analyzed for technical and economic feasibility to put the previously proposed concepts into practical use and identify them as requirements of the new concept design. The system engineering basis design process applied for various meaningful requirement analyses. Because the buoyancy support systems of previous research have relatively simple configurations, the roll of the buoyancy support system has been reanalyzed as requirements for the new system, as shown in Table 1.

When we consider these requirements, for the practical use of the technical concepts for buoyancy support systems, the measure of effectiveness (MOE) can be set to secure the utility of the developed technology based on the results from requirement analysis, Measures of Performance (MOP) and Technical Performance Measures (TPMs) to determine and support the Key Performance Parameters (KPPs) in Table 2.

In the design process, the suggested TPMs of Table 2 must be obtained for MOE/KPP and MOP. To reach each goal of TPMs, through the design process, all technical, economic and other related matters should be consistently and intuitively considered. Thus, during the establishment of the development technology based on the identified TPM, a business model is used as a system analysis and control tool (Kang et al., 2014). Table 3 shows the business model for the designing system configuration.

3. Functional analysis and allocation

In terms of TPM1, which corresponded to R1, function F1 was set to maintain the stability of the ship by inflating the buoyancy chamber. To secure the operability of the essential sailing equipment such as the navigation radar, the ability of Function F1 to maintain stability must be controlled in the range that would not damage the operability of equipment, even when the roll angle is changed because of flooding because of its potential damage. In terms of TPM2, which corresponded to R2, function F2 was applied to secure the working space for damage control in flooding areas, even when the buoyancy chamber was unfolded. In terms of TPM3 for R3, F3 was set as the inner hull installation function. Table 4 shows the function list configuration to accept the requirement analysis results. The proposed required function list is

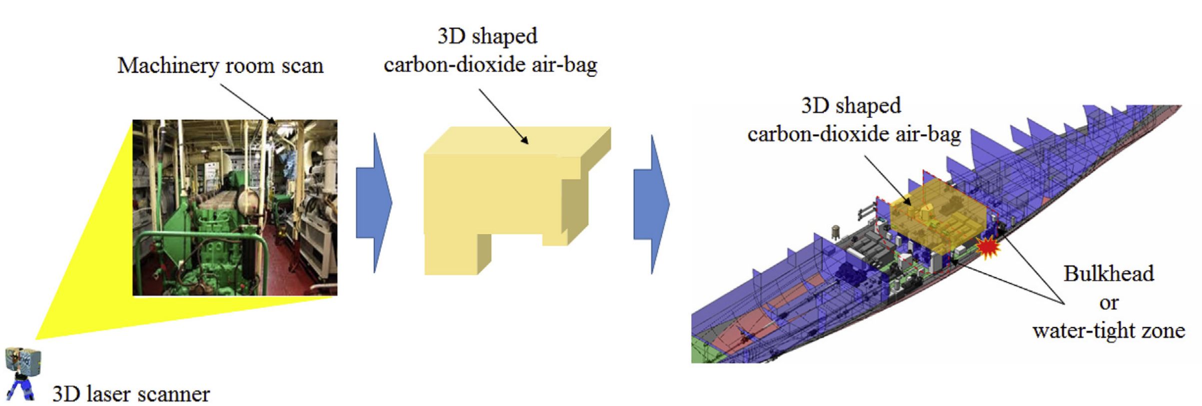

Fig. 1. Usage concept of 3D point cloud data to make the 3D shaped buoyancy chamber.