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Development of damage control training scenarios of naval ships based on simplified vulnerability analysis results

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Abstract

Given the growing interest in damage control training for the naval ships and their organizations, expectations for a new concept of training program have also increased. The existing training programs and its concept focus on training crew to be more proficient and skilled so that they can respond better to damage situations, i.e., fires and flooding. This paper suggests a development procedure of damage control training scenarios using the survivability analysis results as a new concept of damage control training programs employing advanced systems such as damage control console, automation system, and kill cards. This approach could help the decision maker not only enhance his or her capability but also improve the reacting capability of crew members for complex situations induced by a weapon hit.

Keywords: Naval ship survivability; Damage control training; Vulnerability analysis; Recoverability

1. Introduction

With increasing attention being paid to the survivability of a ship being deployed or in repair, continuous efforts have been made to refine the engineering design and maintenance process that considers the survivability of ship from the preliminary stage of the designing process. Some of the suggested means to improve the survivability of ship have primarily concentrated on the ship's possibility of being attacked, vulnerability, and recoverability. Studies have been repeatedly conducted to derive proper measures to improve the survivability of ship for the conduct of mission and safety of crew. Ships that are operational but had been transferred would solely have to rely on the capability of the entire ship's members; thus, the survivability of friendly forces depends heavily on skillful crew with a high level of readiness accumulated through regular training in the prevention of enemy attacks. To enhance survivability, the R.O.K Navy provides periodic trainings to the ship as well as war games that assign specific tasks to a damage control officer and the repair party.

To maintain the utmost readiness of naval ships, training assuming real-battle situations is important. Since it is fairly hard to reconfigure the actual battlefield, however, the damage control training needs to be periodic and continuous during peace time in order to minimize loss of men and to operate in war. Damage Control (DC) has been mentioned in many other references (Love and Williams, 1991; Miller et al., 2001; ROKN, 2007; USN, 2013). Nonetheless, few of them deal with training specifics that contain a high level of realistic elements. The content of damage training is often categorized as classified or for-internal-use only. In the case of survivability, many countries such as the United States, United Kingdom, and Netherlands have continuously devoted themselves to research on the survivability of ships under damage

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through the national research center (Qinetiq, TNO) or civilian defense companies (Alion S&T). Previous research studies on survivability tended to concentrate on analyzing attacks from a single weapon hit by the finite element method (Chung and Lee, 2001; Kwon et al., 2009; Parent, 2012); recently, the statistical approaches (Sajdak, 2007; Bradbeer and Andrews, 2009; Kim, 2011; Kong et al., 2011; Shin et al., 2013) have been published. Research studies related to the damage control system generally provide a viewpoint of platform development (Cosby et al., 2006; Kaminski et al., 2009) or its customization (Donnelly et al., 2003).

To ensure the effective conduct of such training and to simulate more realistic attack and damage situation, this study suggested hit scenarios based on the simplified vulnerability analysis results. In addition, it covered the development process of damage control training scenarios for the crew. This study conducted a simplified vulnerability analysis on targets with high vulnerability and, based on its result, evaluated the damages (or impairment) on the hull structure, accessibility, crew, major equipment, systems, etc.. With information accumulated in this process, this study finally elaborated on each phase of the development process of damage control training for the ship.

2. Current status of R.O.K Navy damage control training

2.1. Damage control organization of ROK Navy

To exercise an efficient damage control after being attacked, a C2 (Command & Control) system with proven effectiveness should be employed in advance. In a general DC (Damage Control) situation, i.e., damage prevention, rapid repairs of ships in war, the ROKN organization consists of DC (maintenance) center and repair party, as shown in Fig. 1. The number of men in the repair party is determined by the size of the ship, and this factor will determine whether one or more parties would be tasked to repair damages. The

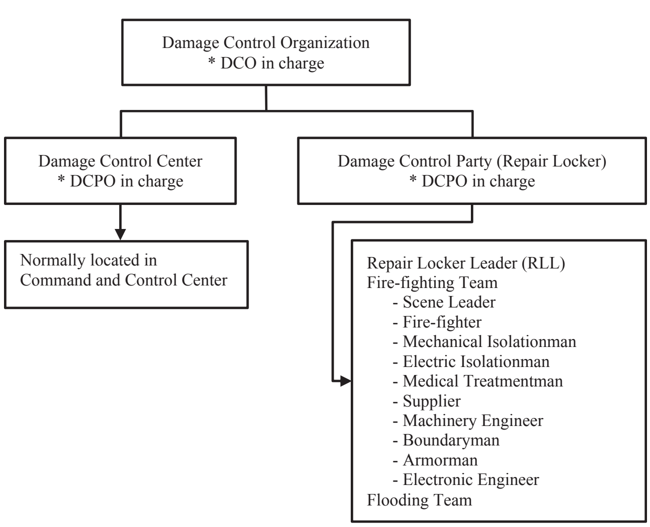


Fig. 1. ROKN damage control organization.

DC center is situated in the Central Control Center or a similar function in a mid-ship, and its primary function is to formulate a security plan to ensure recoverability, maneuverability, and safety; it also sends reports to the bridge as well as commands and communicates with the repair party. The repair party carries out rapid repairs when a damage such as fire occurs by dividing into two teams; firefighting and flooding control. Other than the above mentioned teams, the repair party would also be manned with damage control technician, electrician, medical personnel, propulsion technician, storekeeper, gunnery personnel, boatswain, electro-technician, etc.

2.2. Damage control and training of ROK Navy

ROKN DC measures vary from older/small ships to advanced up-to-date ones. As shown in Fig. 2, older/small vessels would respond to damages with handwritten casualty board using the code and rapid message blank as demonstrated below. The use of such casualty board helps demonstrate easy-to-read charts and diagrams for rapid communication of damages and also promotes a better C2 structure to respond to the damage.

Newly commissioned operational ships now employ a computerized DC system in Fig. 3, a version of the older board system that has evolved. To guarantee user-friendliness, a Windows-based software program has been developed and applied to the current system; its development is still ongoing with the aim of being compatible and controllable with most of the software programs related to the ship's damage control. Note, however, that such DC software is designed to fit foreign-based ships. Considering how difficult it is to apply it to our current system and doctrine, the development of local software should be expedited, and corresponding doctrines that consider digitalized elements should follow right after.

ROKN continues to provide periodic DC trainings for the ship under the supervision of the command element, damage control officers and petty officers (DCOs and DCPOs). As listed in Fig. 4, DC trainings are based on Class A−D firefighting and flooding control training scenarios that feature three stages of action (initial-action-endstate) to the bridge, on-scene commander, and back-up forces.

The objective of such DC training is familiarization with the entire process as well as studying firefighting and flooding control manuals; the expected outcome is to enhance the crew's capability to respond quickly.

3. Simplified vulnerability analysis

3.1. Concept of Simplified Vulnerability Analysis

Fig. 5 shows a typical damage volume by the hit from an explosive. By using Damage Ellipsoid Volume (DEV) for each threat within the hit scenario being tasked, SVA is aimed at analyzing potential damages on systems, components, crew, and hull structure for various operation capabilities. For maintenance purposes, SVA creates all hit scenarios under the

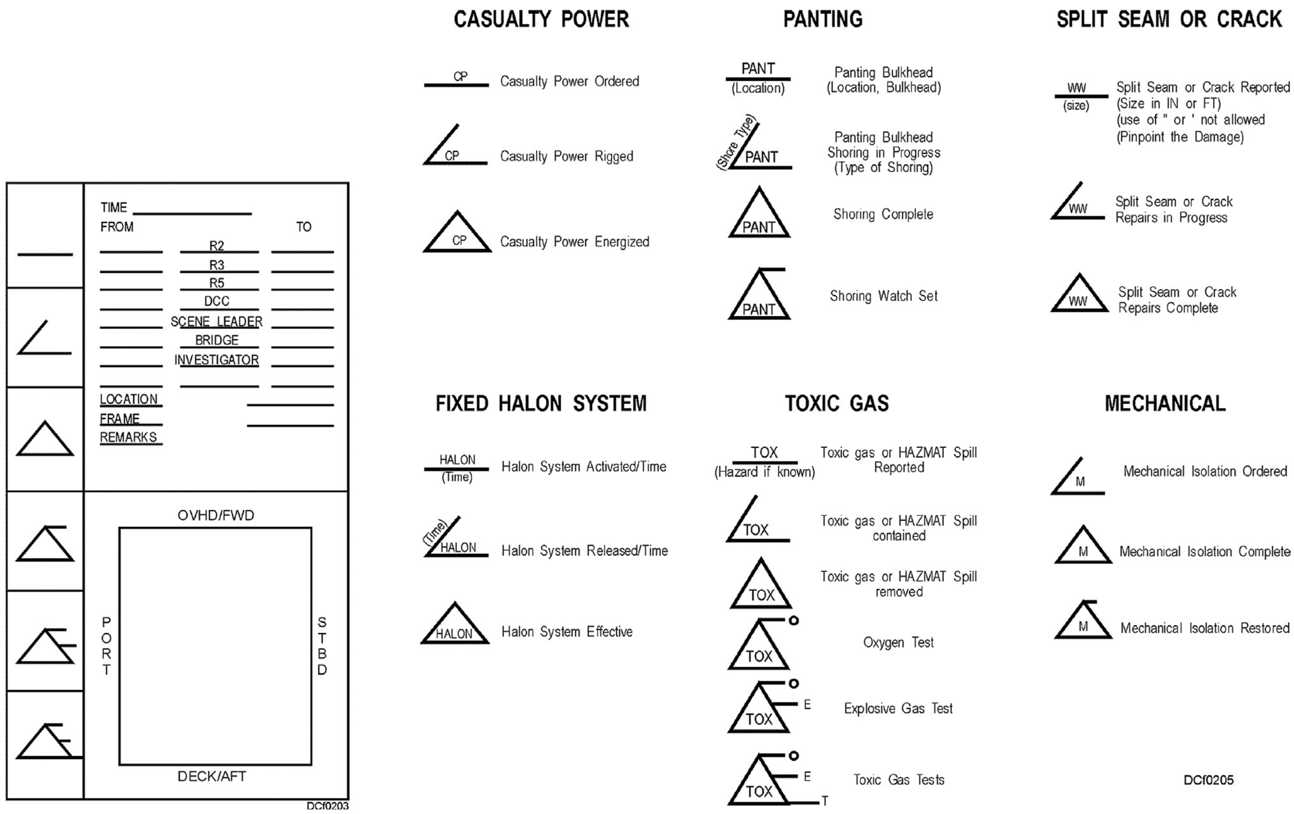


Fig. 2. Rapid message blank (ROKN, 2007).

assumption that compartments, components of compartments, systems and crew as well as one that the entire hull structure are being damaged.

For SVA, the modeling process of the compartments and equipment on the ship being assessed employed a rectangular box type that utilizes the equivalent volume concept, as seen in Fig. 6. This is one of the frequently used methods in SVA, and the simplicity of design makes it much easier to come up with the evaluation result in a prompt manner; note, however, that a model can be of any shape that can visualize any perspective. Fig. 7 shows the simplification process of a vital component by a box element.

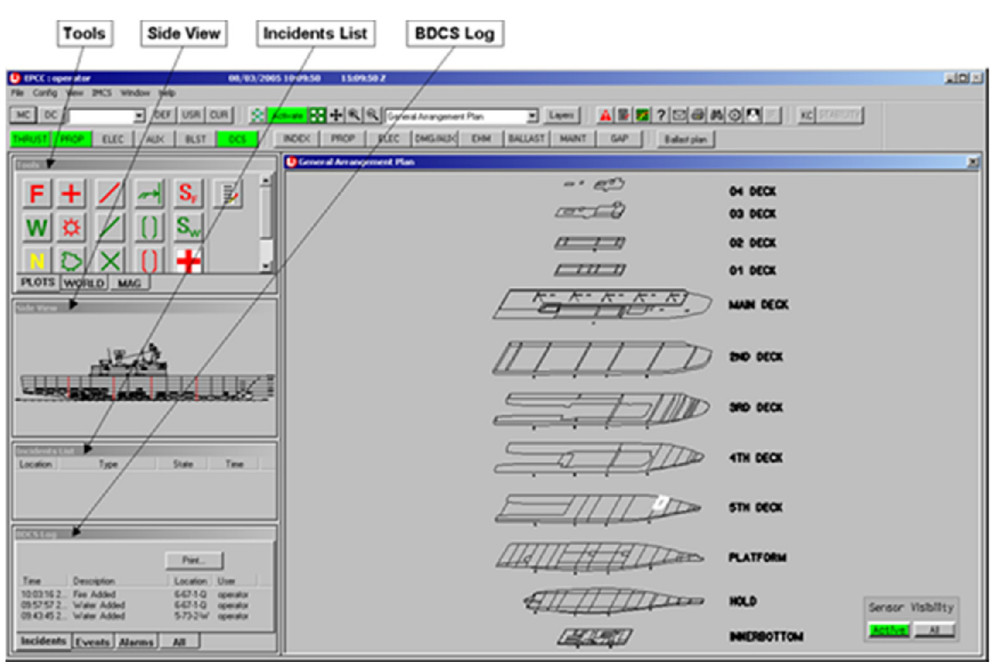


Fig. 3. An example screen of damage control console and software (L3-MAPPS, 2006).

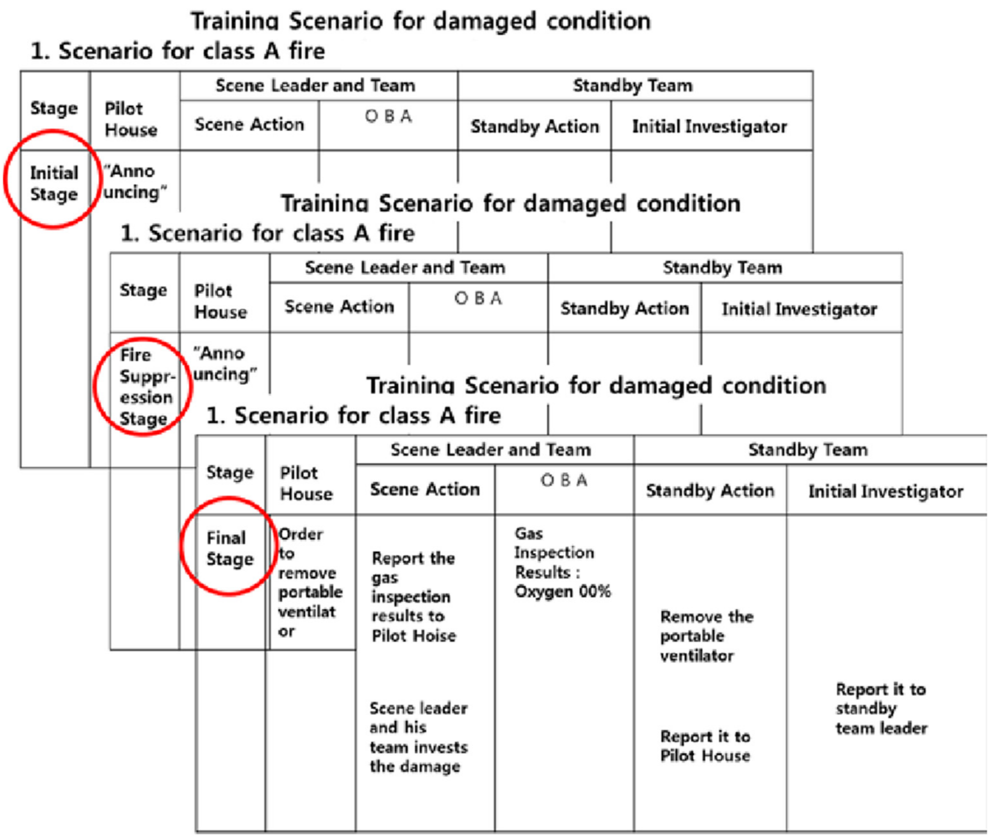


Fig. 4. An example of damage control scenario for class A fire (ROKN, 2007).

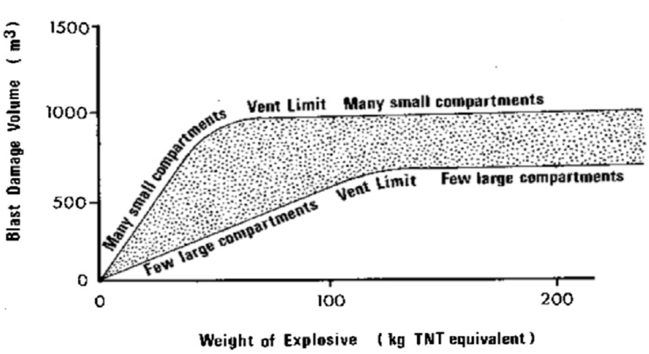


Fig. 5. Calculation of damage ellipsoid volume (Gates, 1987).

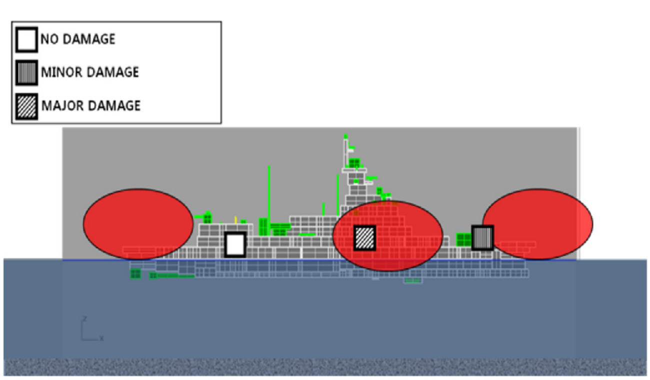


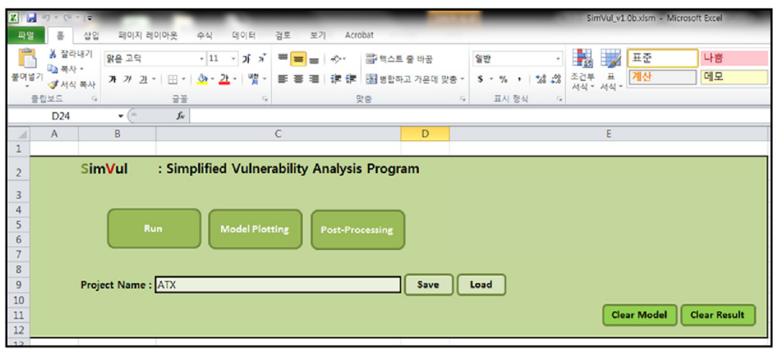
Fig. 6. Concept of simplified vulnerability analysis.

Fig. 7 is an example of modeling by assessment program "SimVul 1.0b," and its analysis result would determine damages on the hull, components, etc., caused by a threat.

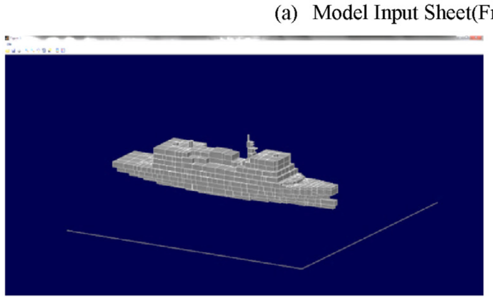
3.2. Simplified Vulnerability Analysis Program

As a Simplified vulnerability analysis program, SimVul 1.0b is used for analysis as shown in Fig. 8. The damage range of a ship is derived from the program, which is made with Microsoft Excel, Visual Basic, and MatLab languages; its configuration is presented in Fig. 9. The program consists of four parts: hit scenario generation, hull structure modeling, analysis and visualization, vital component modeling, analysis and visualization, and system network modeling and analysis. The hit scenario could be generated by the statistical data of a selected threat, such as average and variation, or by the user-defined location. The hull and vital components including equipment, crew, door, and distribution parts could be analyzed by the damage ellipsoid volume and hit location; from their failures, system network models could be evaluated. The system network model includes the mission capability of a target ship. The program was distributed to the R.O.K Navy, and related training was provided for the modeling of a naval ship model on their own within a week. The R.O.K Navy had made their own naval ship model for all types of naval ship in service for about three months including compartment, vital

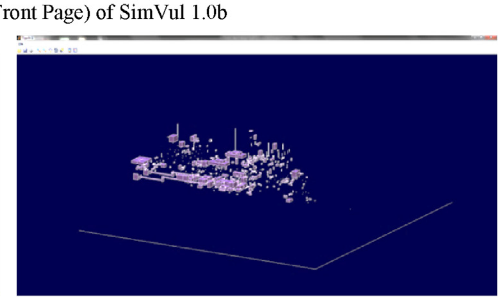
Fig. 7. Simplification of vital component by hexahedron element.



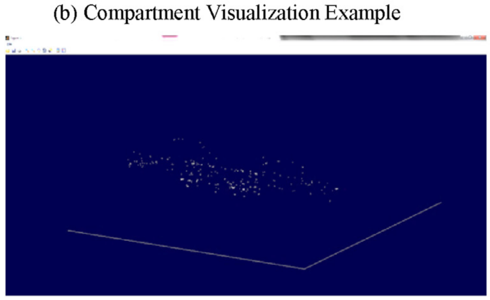
(a) Model Input Sheet(Front Page) of SimVul 1.0b



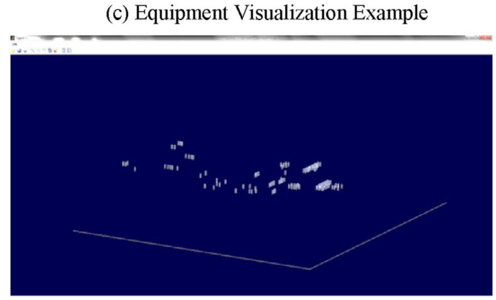
(b) Compartment Visualization Example



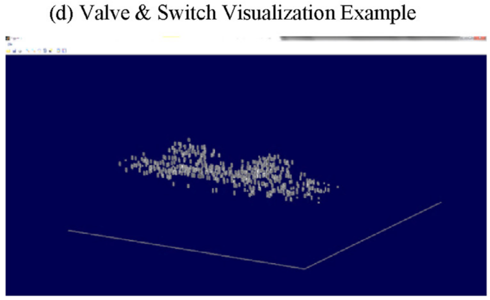
(c) Equipment Visualization Example



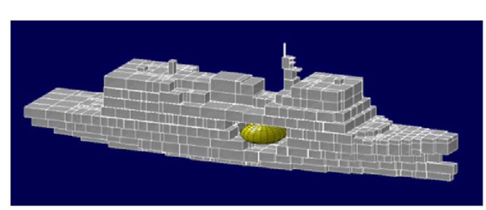
(d) Valve & Switch Visualization Example



(e) Crew Visualization Example



(f) Door & Hatch Visualization Example



(g) Threat Generation Example

Fig. 8. A sample run of the simplified vulnerability analysis program, *SimVul* 1.0b.

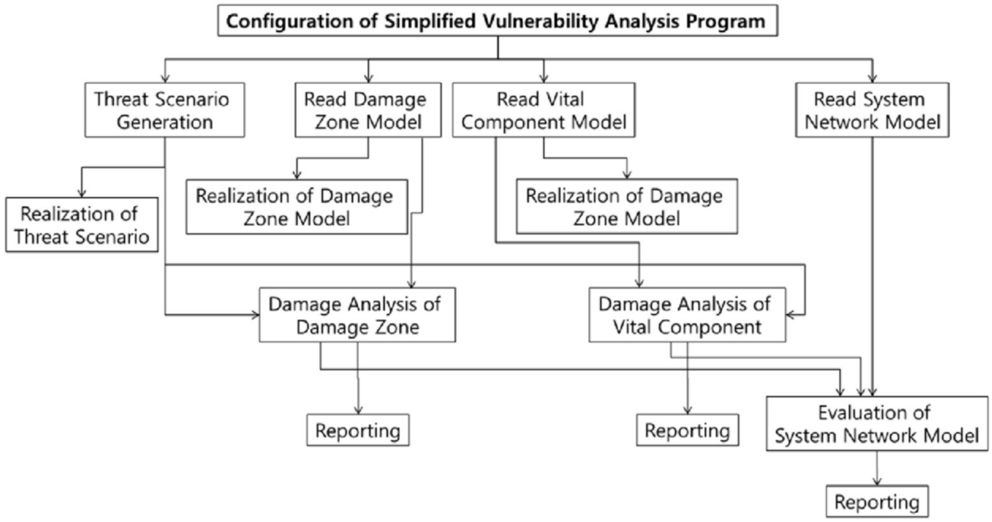


Fig. 9. The Procedural Configuration using the Simplified Vulnerability Analysis Program.

component, crew, valve & switch, and door & hatch, and they could execute it by themselves from hit location selection to post-processing such as classification of damaged area and components. The R.O.K Navy, especially all damage control officers or related officers who have been assigned to conduct damage control, could handle the damage control training program with proficiency.

3.3. Simplified vulnerability analysis results for a Sample Ship

As an example analysis, simplified vulnerability evaluation has been accomplished. The sample analysis for a combat ship, which is one of the R.O.K ships, is assumed to have been hit by a 100 mm round as shown in Fig. 10. The damage condition and circumstances are explained in Table 1, and the detailed list of damaged compartment, equipment, door, sensor, firefighting apparatus, and crew is presented in Table 2. Fig. 11 shows that radar equipment room#2 and EW equipment room had been attacked by a round; as a result, the equipment was damaged, and members of the crew inside the compartment were killed in action. Based on the results, the development of damage control training scenarios assuming multiple damages can be simulated.

4. Damage control training based on simplified vulnerability analysis

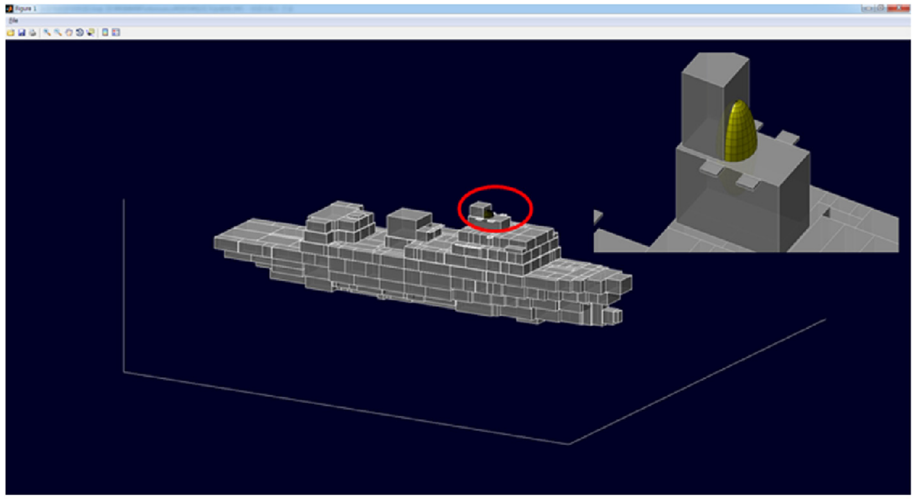
4.1. Objectives of damage control training

For DCOs and head of the repair party in the command element, it is necessary to task training drills simulating composite warfare situations that require them to make prompt decisions for active countermeasures instead of responding to the damage itself. Such training drills assume a hit situation caused by critical threats to friendly forces, i.e., surface missiles, gunfire, etc. It would be most ideal to begin with the initial damage evaluation and gradually increase the level of proficiency of decision making under such circumstances. To simulate a hit situation in a proper manner, this study proposed tasking training drills derived from Simplified vulnerability analysis results. For the in-depth development of training scenarios, this study recommended the integration of various case-by-case training drills. By undergoing such realistic training drill, the command element can predict casualties based on actual threats; this process is believed to be able to help minimize the time for decision making within the “golden time” and make correct decisions in accordance with various situations.

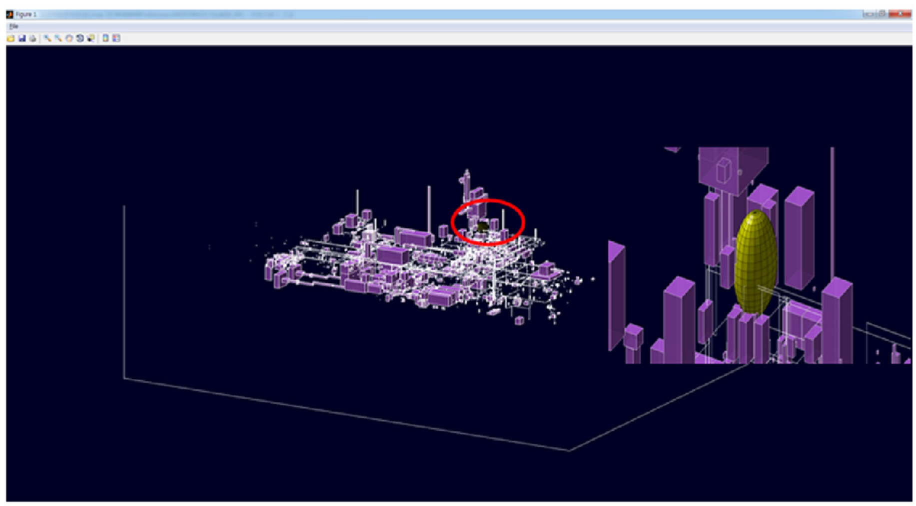
4.2. Development procedure of the damage control training scenario

A damage control training scenario could be developed using the damage range of an objective ship. Fig. 12 shows the development procedure of a damage control training scenario. The procedure consists of four categories: detection, establishment of internal communication, damage control action, and follow-up & recovery action. As the first stage of damage control, the patrol team or damage control officer grasps the damage from the sound of big impact or alarm of damage control console; the detailed damage range is then reported by RLL after establishing a hotline between the damage control center, repair locker, and scene. When the damage control team is dispatched, RLL and DCO continuously update the current status and decide whether an additional standby team should be deployed or not. As the final stage, gas inspection and ship's mission capability check are accomplished by the available team because the other crew still needs to prepare an additional attack or to keep the ship's mission.

The R.O.K Navy is currently setting up a framework for trainings including vulnerability analysis and the use of



(a) Compartment Model



(b) Vital Component Model

Fig. 10. Simplified vulnerability analysis results for a sample ship.

Table 1
Damage status explanation of the sample ship.

Status	Detailed descriptions
Hit	- Crew arrangement is assumed as General Quarter (GQ) condition - Fire occurs after hitting 100 mm shell from port side to No. 2 radar equipment room - 2 watertight hatches (05-58-1, 05-58-2) are damaged - 2 crew in No. 2 radar equipment room and EW equipment room are injured and unable to accomplish a mission - 2 valves (#1,#2) related with HVAC are damaged - After and forward repair lockers are maintained intactly - Radio communication system is partly damaged ○ Pilot house and Damage control center: SPT, FOCON ○ Damage control center and Repair locker: FOCON, SPT ○ Repair locker and Scene: Wireless communication system, SPT

Damage Casualty Isolation Instruction cards (DCII cards or kill cards); the general concept of training from analysis to action is shown in Fig. 13. The R.O.K Navy has also endeavored to complete the development of the damage control doctrine and damage control console with the software and to reorganize the damage control organization in accordance with the new training concept and upgraded equipment before 2020.

Table 2
Simplified vulnerability analysis results for the sample ship by *SimVul* 1.0b.

Classification	Damaged item	Remarks	Classification	Damaged item	Remarks
Compartment	Radar_Equip_Room_2	Compartment	Vital	CAU_User_Terminal_Radar_Equip_Rm_2_3_VC	Equipment
	EW_Equipment_Room	Compartment	Com-ponent	Tracking_Rad_Processing_Cab_VC	Equipment
Door/hatch	Radar_Equip_Room_2	Hatch		EW_Equip_Rtr/Distr_VC	Equipment
	EW_Equipment_Room	Hatch		Smoke_50C_NWT_Radar_Equip_Room_2_F_VC	Smoke sensor
Valve	HVAC_VLV_Radar_Equip_Room_2_No_1_VS	Valve		Smoke_50C_NWT_Radar_Equip_Room_2_A_VC	Smoke sensor
	HVAC_VLV_Radar_Equip_Room_2_No_2_VS	Valve		Smoke_50C_NWT_EW_Equip_Room_A_VC	Smoke sensor
Vital com-ponent	EA_EW_Equipment_Rack_Sec_02_VC	Equipment		Smoke_50C_NWT_EW_Equip_Room_F_VC	Smoke sensor
	EW_Equipment_Rack_2_Sec_02_VC	Equipment		Flood_Radar_Equip_Room_2_VC	Flooding sensor
	EA_EW_Equipment_Rack_Sec_01_VC	Equipment		FCU_1_04LVL_FR60_VC	Equipment
	EW_Equipment_Rack_2_Sec_01_VC	Equipment		CO2_Ext_1_VC	Portable fire extinguisher
	3D_Radar_Drive_Control_VC	Equipment	Crew	CREW_04_Electronic_Warfare_Equipment_Room	Crew
	3D_Radar_Environmental_Control_VC	Equipment		CREW_05_2nd_Radar_Equipment_Room	Crew

4.3. Generation of training scenarios based on the suggested procedure

Based on the suggested general procedure in 4.2, as the examples from the analysis results presented in Tables 1 and 2, the scenarios are developed and described in Tables 3 and 4. The scenario in Table 3 focuses on complete damage control as soon as possible without considering the reuse of electric equipment, so the damage control officer orders the use of seawater firefighting equipment for damage control. On the other hand, in Table 4, the damage control officer considers the recovery and reuse of electric equipment after damage control and consequently orders the application of CO_2 fire extinguishers. Both scenarios seem to be proper commands and actions when reviewed based on the damage control doctrine. The noticeable point here is that the scenario need

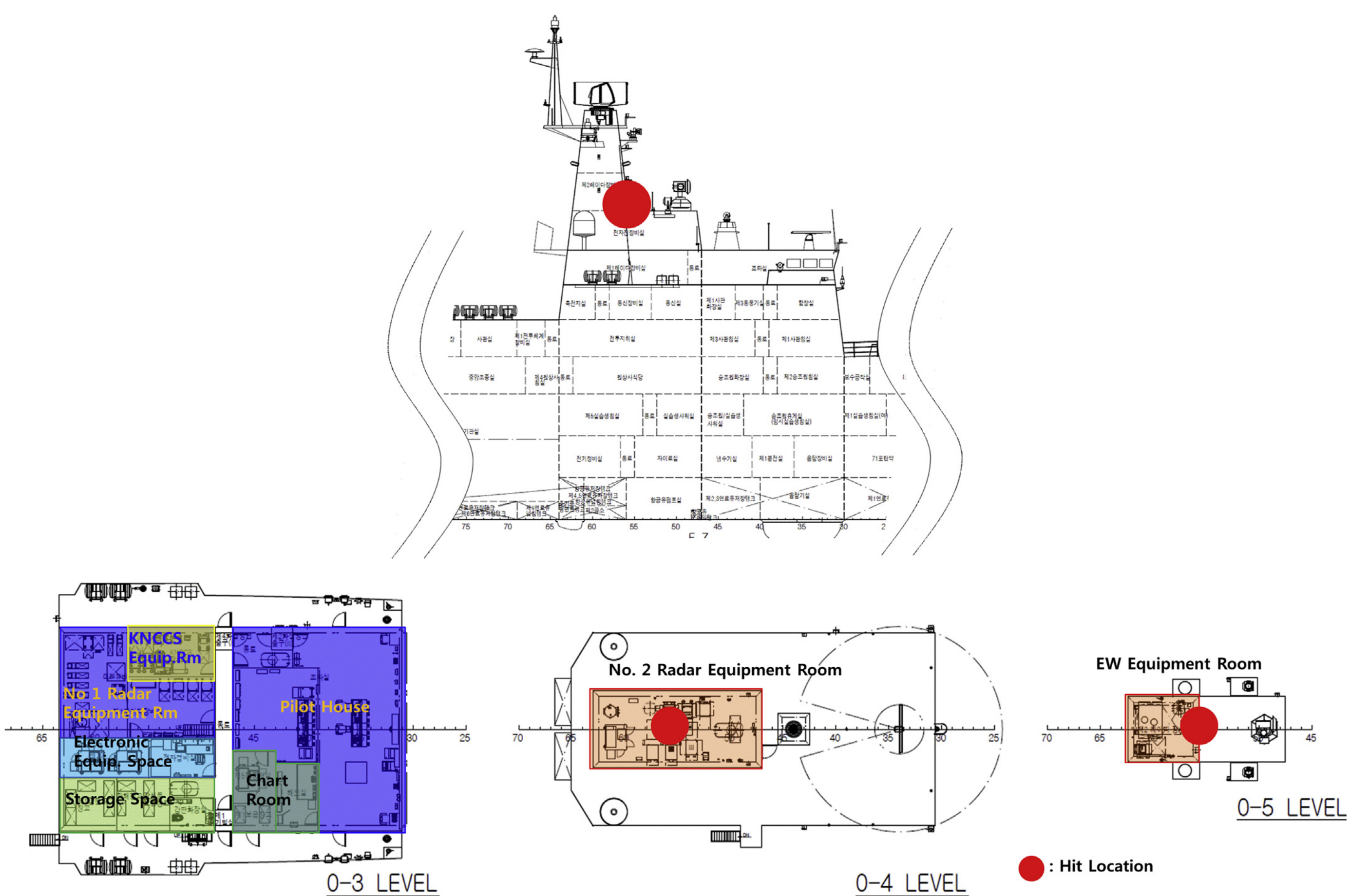


Fig. 11. Hit location of the sample ship.

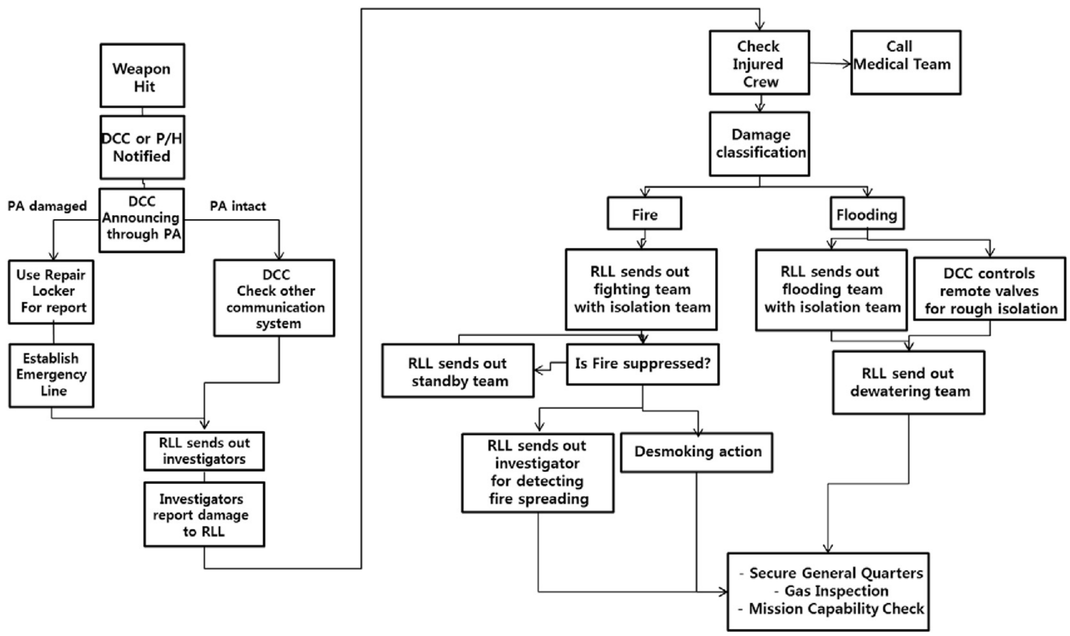


Fig. 12. Development procedure of damage control training scenario.

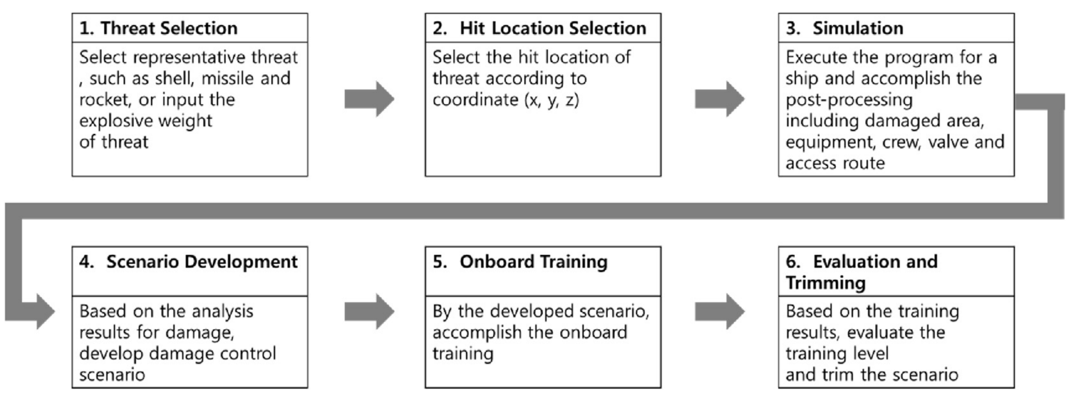


Fig. 13. Concept of training on battle damage control.

Table 3
Training scenario development results: Case 1.

Action	Action description and order of events
Hit	- All hands were at battle stations - A 100 mm round caused fire at the outer bulkheads of radar equipment room#2 at the port side - Two watertight hatches were damaged (05-58-1, 05-58-2) - Two were killed in action in radar equipment room#2 and EW equipment room - Two ventilation pipes were damaged (#1, 2) - There was nothing significant to report on the forward and stern repair party
Detection	- Heat and smoke detectors at radar room#2 were damaged by the attack - Being unable to receive alarm signals through DCC, sectors are likely to have sustained damages - DCC can verify fire and various matters related to ventilation equipment, but fire detectors are partially disabled and are unable to check the status in the compartment - Damage details will be reported through the repair party leader
Detection & internal communication	- All Networks are functional - All repair parties can use radios for disaster use - All COMMs are functional - Through communication at the bridge, evaluate damages to equipment and loss of men at each station - Order “Missile hit, missile hit, all stations report damages.” - Evaluate the estimated damages via reports from all stations

(continued on next page)

Table 3 (*continued*)

Action	Action description and order of events
Internal communication	- Prepare for searching in the damaged areas by the forward repair party and respond to the fire
Internal communication	- Send two search officers and an electrician specialist to patrol radar equipment room#2 - Tasks shall be accomplished with SCBA - The repair party leader and personnel on the scene communicate via radios - The forward and stern parties can have separate channels on the radio - Leader of the forward party input the damage situation on the console display
Internal communication	- The repair party evaluates the damage details via DCC and estimates the overall damages (water pressure, ventilation, closure settings, hatches, etc.) - Close radar equipment room#1 at the midship's NSF - Report damages to the leader of the forward repair party via FOCON - Check nearby compartments and report to the bridge - Pull out kill cards for damaged area and check the list for damage control action
Damage control	- Report after closing the NSF middle sector at radar equipment room#1 - Report to the repair party leader upon arriving at the EW room - The EW room had already been on fire - Attack on radar equipment room#2 led to hull damage and caused smoke outside - "Green on both hatch and door at the EW room, but there is still some fire remaining inside." - Report excessive heat on the compartment bulkheads at the EW equipment room - Conduct cooling and extinguish fire until the firefighting party arrives - Upon arriving, conduct patrolling in nearby compartments; "Although no smoke was found in radar equipment room#1, greater damage is expected due to the excessive heat."
Damage control	- Check the Kill Card and pressure of the fire main pipe - Check the operability of the deck washing station - If requested by OSC, then the repair party conducts cooling on the compartment bulkheads outside by operating the deck washing station
Damage control	- Upon arriving at the area, evaluate the damage details, select equipment and entry mode, and report to the repair party leader via radio - Prepare to give orders to enter the EW room on the 04 deck through the hatch (fire extinguisher 326) - Due to the smoke outside radar equipment room#2, firefighting should be carried out from outside the 05 deck using the applicator in the fire extinguisher - Assign the repair party to patrol nearby compartments - Request reports on whether power has been cut in the electric kit power system as well as any and all significant matters in relation to the system - Provide to the forward repair party leader updates on the scene and damage details - OSC will command and control the scene
Internal communication	- Report when power has shut down in the electronics kit EW room on the upper deck
Damage control	- The forward party leader controls the overall situation on the scene by using the casualty board. - The stern party leader directs the party that operates the fire extinguisher, multi-purpose nozzle, and applicator to provide support.
Damage control	- Wear personal protective gear to prevent additional support requests
Damage control	- Forward party leader to extinguish the fire in the EW equipment room by using fire detection camera and fire hydrant - Stern party leader to conduct fire extinguishing in radar room#2 by using an applicator
Internal communication	- Report the smoke caused by thermal conduction at the passageway of radar equipment room#1 on the upper deck
Damage control	- Request the aft repair party to man more firefighters in order to install a mobile ventilator in the passageway of radar equipment room#1 - Request the forward repair party to man more firefighters in order to conduct cooling in the passageway of radar equipment room#1
Damage control	- Forward party leader to request two additional firefighters to be stationed at radar equipment room#1 and conduct cooling - Stern party leader to request two additional firefighters to be stationed at radar equipment room#1 and install a mobile ventilator
Damage control	- When the thermal cooling team is in position, patrol nearby sectors and report to OSC
Damage control	- Report to OSC after installing a mobile ventilator on the port side outside radar equipment room#1 - Operate the ventilator when OSC is present
Internal communication	- Report to OSC after conducting surveillance of the compartment and bulkheads in the fire damage area
Damage control	- Fire in the EW room extinguished completely - Fire in radar equipment room#2 extinguished completely (inside detection required)
Follow-up & recovery	- Release smoke and check gas using the door outside the EW equipment room - Request the forward passageway clearance party to remove the bulkheads in the compartment of radar equipment room#2 - Release flooding water in radar equipment room#2
Follow-up & recovery	- Forward passageway clearance party to remove the bulkheads of the compartment in radar equipment room#2
Follow-up & recovery	- Request the passageway clearance party to open the upper hatch of the EW equipment room upon completion of flooding water release - Once the hatch is opened, conduct inside detection and report back - End of the scenario

Table 4
Training scenario development results: Case 2.

Action	Action description and order of events
Hit	- All hands were at battle stations - A 100 mm round attacked on the EW equipment room and the radar equipment room at the upper compartment caused fire and damage on the equipment - Two were killed in action in radar equipment room#2 and EW equipment room - The forward repair party conducts damage control, and the stern repair party supports the joint surveillance area - Communications were damaged • Bridge, repair party: Primary − sound power telephone, secondary − FOCON • Repair party, maintenance: Primary − FOCON, secondary − sound power telephone • Repair party, on-scene: Primary − radio for disaster use, secondary − sound power telephone
Detection	- On the FAS, using the two smoke detectors installed in radar equipment room#2 and EW equipment room, it was assumed that compartments were being destroyed, including partial fire damages caused by the missile attack - Some of the compartments adjacent to the EW equipment room and radar equipment room#1 can be monitored through FAS - Further investigation and damage details will be reported under the supervision of the forward repair party leader
Detection	- The forward repair party leader sent two firefighters to investigate further on the scene near the EW equipment room
Detection	- Evaluate the damage details via DCC and have a damage control assistant report the evaluation to the bridge - Two firefighters of the forward repair party sent to investigate the scene found two WIAs and requested medical support; carrying the injured out of the scene and handing them over to the medical team
Internal communication	- Two firefighters of the forward repair party reported to the forward party leader via radio; the forward party leader reported to the maintenance center via FOCON. • A torpedo infiltrated and was exploded inside; the fragments from the torpedo caused fire • Additional damages caused by the torpedo were found on the hull and door • The doors were damaged but are still functional • Two FCU supply and release valves in the air-conditioning system were being destroyed • Despite maintaining readiness, smoke in the compartment still remains - Pull out kill cards for damaged area and check the list for damage control action
Damage control	- The maintenance center remotely ceased FCU-1 on FCU - Send a medical team to report the status of patients once delivered to the battle aid station
Damage control	- Send firefighters of the forward repair party to extinguish fire by using the two fire extinguishers located in the KNCCS equipment room under the lower deck of the EW equipment room • If an engagement situation is assumed, keep power on and use CO_2 extinguisher to put out the fire - Forward repair party leader assigns more firefighters to mobilize more CO_2 extinguishers - Maintenance center assigns the stern repair party leader to transit to the scene with fine mist-spraying hose reels
Damage control	- Maintenance center assigns the stern repair party leader to open the outside entrance door for smoke release
Damage control	- The forward repair party has put out the fire using CO_2 extinguishers - Stern repair party checks for gas leaks after releasing smoke
Follow-up & recovery	- Upon checking the leaks, evaluate the damages on the compartment and equipment and conduct maintenance

not have only one solution. This is a very natural result and is the intention of this study. The damage control scenario could differ according to the characteristics and knowledge of the decision maker. Unless they violate the damage control doctrine, the scenario could be a solution, and a more effective action plan could be established from the comparison of the scenarios. One of the training purposes is the improvement of decision making skills and intuition for battle-damaged condition. More effective and faster decision making would be possible within a very short and limited time, so-called "Golden Time," by applying an unconventional training framework and assigning a more realistic damage situation.

5. Conclusions

This study suggested hit scenarios that consider the realistic casualties and damage situation based on the survivability analysis result. It also provided a description of the process to develop DC training scenarios for the ship. In addition, this study demonstrated the vulnerability analysis conducted for threats with high probability of attack and also evaluated damages to compartments, passageway, crew, major components, etc.. Based on this process, a detailed procedure for the development of DC training scenario for the ship was suggested. Finally, it is reasonable to conclude that such scenario development enables a more realistic DC training that assumes real-battle situations, provides opportunities to exercise firefighting and flooding control, and finally reinforces the capabilities of the command elements to make prompt and precise decisions under such circumstances. The suggested procedure has been instructed to petty officers and officers who are serving as damage control officers or assistants on a ship in the R.O.K Navy for a week. The officers who had attended the training were optimistic that such a training can help improve their decision making and help them understand better the duty of the repair party and onboard crew in such situation. A total of 25 officers responded in a debriefing with a positive feedback of 7.5 on the average in a 9-point scale with 1 being the least satisfied and 9 being the most satisfied. Although this study limits its scope to a single naval vessel, a further study is being planned to include multiple vessels.

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