INTERFACE FORM
FOR AN UNDERWATER WARFARE SIMULATION ENVIRONMENT

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ABSTRACT

The effectiveness analysis is influenced by the Measures of Effectiveness (MoEs), Measures of Performance (MoPs), alternatives, threats, scenarios, operation concepts, etc. For effectiveness analysis, modeling and simulation (M&S) technology is an important method, which is used to evaluate numerous designs and operational concepts for a real-world system. This paper proposes implementation of Interface Forms (I/Fs), which operates somewhat like experimental frame. Proposed illustrates how to design an experimental frame for appropriate modeling objectives. The experimental result shows that we can test alternative tactics and the behavior analysis was successful.

Keywords: Experimental frame, DEVS formalism, underwater warfare model

1. INTRODUCTION

The effectiveness analysis is designed to compare the effectiveness of the alternatives based on military worth (Office of Aerospace Studies 2008). It is influenced by the Measures of Effectiveness (MoEs), Measures of Performance (MoPs), alternatives, threats, scenarios, operation concepts, etc. From the simulation point of view, MoPs are typically a quantitative measure of a system characteristic. For example, the speed of a missile hitting its target is a performance measure. Such measures enter as factors into outcome measures, often called MoEs, that measure how well the overall system goals are being achieved (e.g., how many battles are actually won by a particular combination of weapons, platforms, personnel).

For effectiveness analysis, modeling and simulation (M&S) technology is an important method, which is used to evaluate numerous designs and operational concepts for a real-world system. M&S technology facilitates decisions about future equipment procurements such as a mobile decoy or a torpedo. In addition, assessment of submarine tactical development during an engagement against a torpedo can be conducted using M&S techniques.

A framework for M&S is divided into a system and an experimental frame. The system refers to a set of interacting or interdependent components that we are interested in modeling. It may be a real or virtual environment. An experimental frame is a specification of the conditions under which the system is observed or experimented with. Once the models are built, their effectiveness has to be analyzed. Therefore, various experiments need to be generated to evaluate various effectiveness analyses. The experimental frame is capable of generating different experiments needed to evaluate the system effectiveness. In the experimental frame, various scenarios can be set up and the MoEs, which are collected, can also be specified. In this case, simulations of flexible combinations are possible, such as alternatives scenarios with an experimental frame.

The objective of this paper is the implementation of Interface Forms (I/Fs) for an underwater warfare simulator. I/Fs operate somewhat like experimental frames, as described earlier. Proposed I/Fs provide the developed simulator platform information and tactical information, and we observe the simulation result and analyze the result with the proposed I/F. This paper contributes to the defense M&S community in two ways:

- It illustrates how to design an experimental frame for appropriate modeling objectives
- It provides flexible experimental frames to provide insights about how various factors, such as tactics and the performance of underwater weapons, influence the MOEs of the system.

The structure of this paper is as follows. Section 2 presents a framework for M&S and the DEVS formalism. Section 3 explains Interface Forms (I/Fs) for the DEVS-based underwater simulator, and Section 4 illustrates some case studies and experimental results. Finally, Section 5 concludes this research and proposes future extension for a more complete solution.

2. RELATED WORK

We first introduce a framework for M&S. We also introduce the DEVS formalism that we apply for modeling the underwater warfare system in this paper.

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2.1. Framework for modeling and simulation (M&S)

This subsection is devoted to establishing a framework for modeling and simulation (M&S). As can be seen in Figure 1, the basic entities of the framework are the source system, model, simulator, and experimental frame. The source system is the real or virtual environment that we are interested in modeling. It is viewed as a source of observable data. The data that has been gathered from observing or otherwise experimenting with a system is called the system behavior database. A model is a system specification that is a set of instructions, rules, and equations. In other words, we write a model with a state transition and output generation mechanisms to accept input trajectories and generate output trajectories, depending on its initial state setting. As a set of instructions, a model needs some agent capable of actually obeying the instructions and generating behavior. We call such an agent a simulator. Therefore, a simulator is any computation system capable of executing a model to generate its behavior.

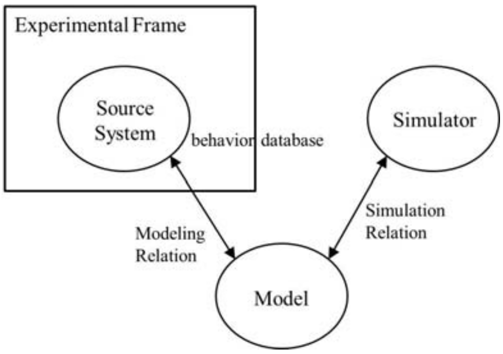


Figure 1: Basic entities in M&S and their relationships

Seo and Song(2011) proposed to design an underwater warfare modeling methodology using the DEVS formalism. For more efficient model development, they propose a generic three-part underwater platform model, which is flexible enough to be easily re-usable for developing different underwater platform models with different behaviors and structures. They developed a simulator using DEVSim++, which was developed by Park and Kim(1996) at KAIST in Korea. The developed simulation supports users in evaluating the effectiveness of underwater warfare systems through Monte Carlo simulation and assesses tactical development and anti-torpedo countermeasure effectiveness. In this paper, we use Seo and Song(2011)'s underwater warfare model and simulator and focus on how to develop I/Fs for an efficient experimental frame. In the subsection, we will describe an experimental frame in more detail.

2.1.1. Experimental Frame

An experimental frame is a specification of the conditions under which the system is observed or experimented with. As such, an experimental frame is the operational formulation of the objectives that motivate a modeling and simulation project.

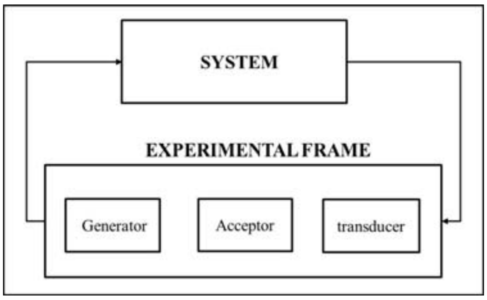


Figure 2: Experimental frame and its component

As described in Figure 2, an experimental frame typically has three types of components: a generator, which generates inputs to the system; an acceptor, which monitors an experiment to see that the desired experimental conditions are met; and a transducer, which observes and analyzes the system outputs. In practice, many experimental frames can be formulated for the same system. This means that we might have different objectives in modeling the same system. For example, in underwater warfare, we can evaluate the survival rate of our submarine according to various maneuver patterns for detour when opposing torpedoes are approaching. In this paper, we proposed two kinds of I/Fs for the experimental frame. The first I/F takes on the role of a generator and the second I/F performs the role of an acceptor and a transducer.

2.2. DEVS Formalism

The DEVS Formalism is general formalism for discrete event system modeling based on set theory, and it is one of the M&S theories which are applied in various military simulations (Zeigler, Praehofer, and Kim 2000). The DEVS Formalism supports to specify the discrete event models in hierarchical and modular manner. The DEVS Formalism exhibits the concepts of system theory and modeling, and with this formalism, the user can model the target system by decomposing large system into smaller components which coupling scheme among them. There are two kinds of models in the formalism: Atomic model and Coupled model.

The Atomic model is a specification of basic model behavior as timed state transition. Formally, an Atomic model can be defined by 7-tuples as follows:

$$M = < X, Y, S, \delta_{ext}, \delta_{int}, \lambda, ta >,$$

Where
X: a set of input;
Y: a set of output events;
S: a set of sequential states;
δ_{ext}: $Q \times X \rightarrow S$, an external transition function,
where $Q = \{(s,e)|s \in S, 0 \leq e \leq ta(s)\}$ is the total state set of M;
δ_{int} : $S \rightarrow S$, an internal transition function;
λ : $S \rightarrow Y$, an output function;
ta : $S \rightarrow$ Real, time advance function.

Coupled model is a specification of hierarchical model structure. It provides the method of assembly of atomic and/or coupled models to build the hierarchy of complex system. Formally, a Coupled model is defined as follow;

DN = < X, Y, M, EIC, EOC, IC>,
Where
X: a set of input;
Y: a set of output events;
M: a set of all component models;
EIC □ DN.X × □M.X: external input coupling;
EOC □ □M.Y × DN.Y: external output coupling;
IC □ □M.Y × □M.X: internal coupling;
SELECT: 2^M –□→ M: tie-breaking selector.

3. INTERFACE FORMS FOR DEVS BASED UNDERWATER WARFARE SIMULATOR

The underwater warfare model, which was developed by Seo and Song(2011), consists only of the core of the simulation software, so an experimental frame is needed to utilize the simulation model. I/Fs include an experimental frame and interface between the simulation software and an experimental frame. For example, a detailed human computer interaction interface will be needed in the use of simulation training, or a statistical result organizer will be needed to run a simulation experiment. These interfaces will provide the simulation results; we call this an experimental frame, as described earlier. In this section, we propose two kinds of I/Fs as an experimental frame for the DEVS-based underwater warfare simulator.

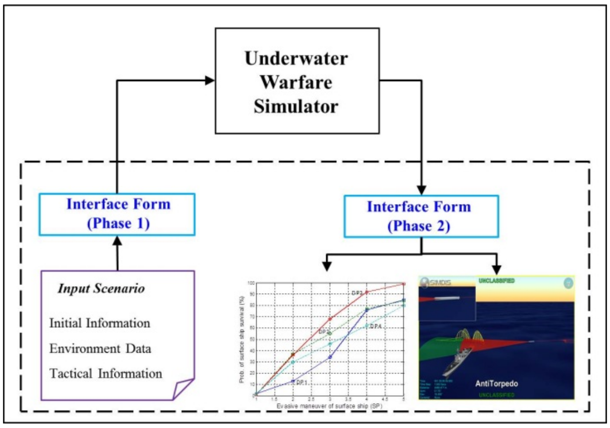


Figure 3: Interface Forms for Experimental Frame

Figure 3 illustrates the high-level view of the framework for underwater warfare M&S. We proposed two kinds of I/Fs: Phase I, which is the scenario identification I/F, and Phase II, which is for simulation analysis. The scenario identification I/F provides the underwater warfare simulator scenario information, such as the initial parameters for platforms and environmental and tactical information. Specifically, scenario identification I/F takes on the role of supporting the model to determine the manner of action dynamically, according to the predefined tactics in the I/F. This means that we can combine several tactical modules with this I/F to achieve the mission purpose when the simulator has these tactical modules and we know these modules. For example, suppose that the simulator provides several maneuver patterns, such as straight, snake, circular, or turn maneuvers. In this case, effectiveness, like the mission success rate, will vary depending on how well several maneuver patterns can be combined. Therefore, the scenario identification I/F enables users to assess alternative tactical deployments for maneuver patterns. In the case of the M&S framework without the proposed scenario identification I/F, there are problems, such as rewriting and modifying the model every time tactical information is changed, because tactics should be defined statically in the model. Scenario identification I/F does have a benefit, including the simulation of the various scenarios without modifying the model when tactics are changed; this is with the modifying scenario description I/F only.

The simulation analysis I/F takes the role of verifying the behavior analysis of simulation. This I/F provides the user graphical traces of the platform and Monte Carlo simulation. From a display perspective, simulation analysis I/F provides the common structure that can be shown in the simulation display tool. In this paper, we used SIMDIS for the display tool, which is a set of software tools that provide two- and three-dimensional interactive graphical and video displays of live and post-processing simulation, tests, and operational data (U.S. Naval Research Laboratory, 2006). We will describe the two I/Fs in more detail in the subsection.

3.1. Phase I : Scenario Identification

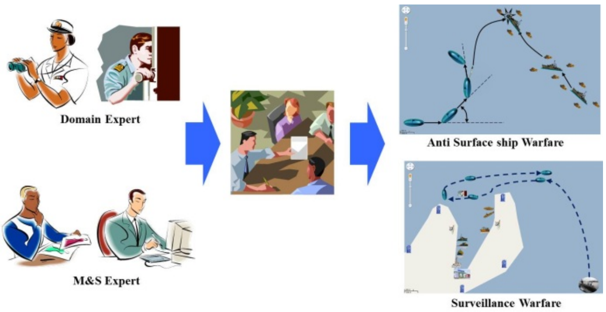
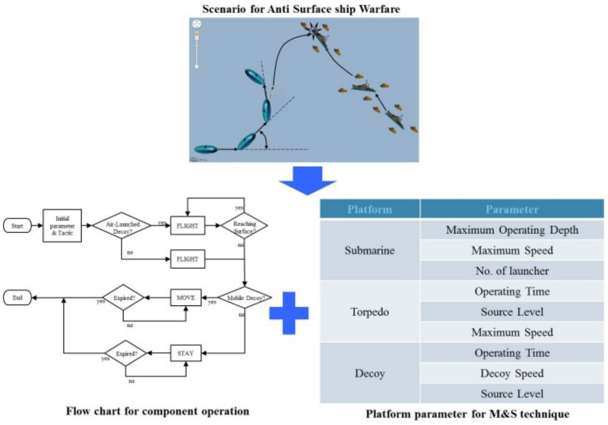


Figure 4: Collaborative Process between Domain and M&S Engineers

In order to identify scenario information in the domain specific system, it needs to cooperate with the domain and M&S engineers. In other words, a domain-specific model, such as a military model, is developed with the integration of domain knowledge and M&S methodology. A domain engineer is involved in performing the domain requirement analysis and design, and an M&S engineer is in charge of the overall process related to the M&S of discrete event systems satisfying the domain requirements. It would be difficult for the M&S engineer to identify scenario information to develop domain-specific models solely using his M&S

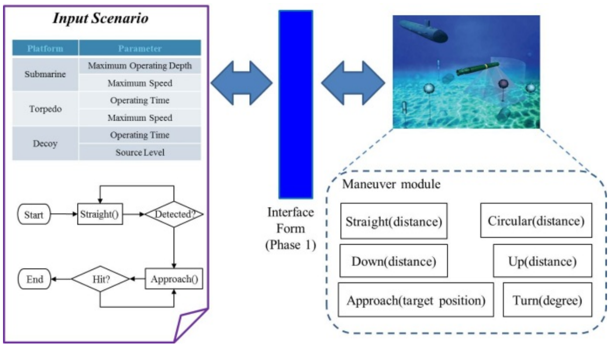
knowledge. We call this stage the requirement analysis (Sung, Moon, and Kim 2010). Figure 4 shows the collaborative process between the domain and M&S engineers for scenario identification. Requirement analysis will require the participation of the domain engineer and M&S engineer because the M&S engineer cannot develop detailed model design without the domain knowledge. Domain information is often gathered through questionnaires or direct interviews with domain engineers. Domain and M&S engineers define the M&S objectives and the overall functions of the simulation software by distilling the domain information. As a result of this stage, the domain engineers develop textual descriptions, called requirement specifications, of the software.



Platform	Parameter
Submarine	Maximum Operating Depth
	Maximum Speed
	No. of launcher
Torpedo	Operating Time
	Source Level
	Maximum Speed
Decoy	Operating Time
	Decoy Speed
	Source Level

Figure 5: Scenario Identification

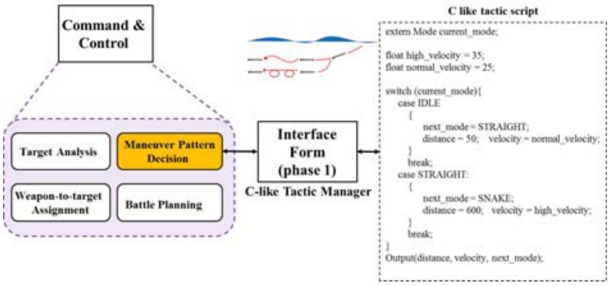
With these requirement specifications, the M&S engineer identifies platforms to be modeled, parameters to be used in each platform, and military tactical information. Figure 5 describes this process. This information is utilized for the input information of the scenario identification I/F.



Platform	Parameter
Submarine	Maximum Operating Depth
	Maximum Speed
Torpedo	Operating Time
	Maximum Speed
Decoy	Operating Time
	Source Level

Figure 6: I/F for Scenario Identification

Next, we identified inputs for scenario identification I/F, which are platform parameters and tactical information. Figure 6 shows the relationship among input scenario, I/F, and simulator. The underwater vehicle, in Figure 6, has six maneuver modules. We can composite several maneuver modules for the maneuver tactic. As described earlier, effectiveness, like the mission success rate, will vary depending on how well several maneuver patterns are combined.



```
extern Mode current_mode;

float high_velocity = 35;
float normal_velocity = 25;

switch (current_mode){
    case IDLE
        {
            next_mode = STRAIGHT;
            distance = 50;    velocity = normal_velocity;
        }
        break;
    case STRAIGHT:
        {
            next_mode = SNAKE;
            distance = 600;   velocity = high_velocity;
        }
        break;
}
Output(distance, velocity, next_mode);
```

Figure 7: Scenario Identification I/F using C-like Tactic Manager

Errore. L'origine riferimento non è stata trovata. shows implementation of I/F using a C-like tactic manager. The C-like tactic script is influenced by the simulator and the simulator simulates according to the C-like tactic script. A user can modify the script during simulation and the modified script is reflected immediately. Therefore, the user can test and evaluate various tactics during simulation. In the case of the simulation model without this I/F, there are problems, such as rewriting and modifying the model every time tactics are changed, because tactics should be defined statistically in the model.

3.2. Phase II : Simulation Analysis

In this subsection, we will describe the second I/F for simulation analysis. This I/F takes the role of verifying the behavior analysis of simulation. The I/F provides the user graphical traces of the platform and Monte Carlo simulation. After the I/F is established, the simulation software will be verified and validated

. As described in Figure 8, M&S engineers test the simulator to check the accuracy of converting a model representation into simulation software. We call this the simulation verification. After verifying that the model is implemented as designed, the statistical analysis will follow to compare the simulated data to the real-world data; this procedure is the simulation validation.

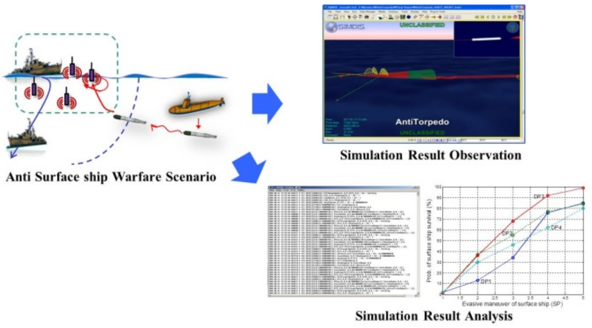


Figure 8: Simulation Result Analysis

In this I/F for simulation display, there are two steps. The first step is to register the platforms to be displayed, and the next step is to record simulation time and spatial information of the platform, such as position

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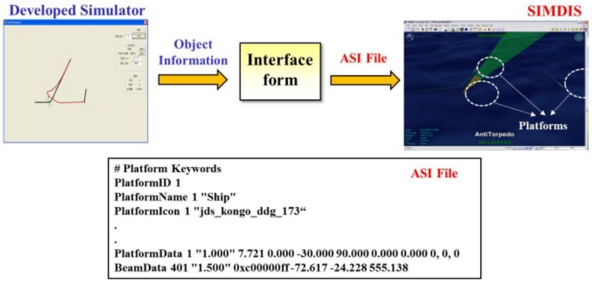
information, yaw, pitch and roll, and velocity. Therefore, the platform and environmental initialization for registration and platform input data are needed for simulation display.

Platform initialization consists of platform ID and platform name. For example, if we need one submarine, the object ID may be 1 and object name is “blue submarine.” Environmental initialization consists of wind speed, sea flow, etc.; however, this information is optional. As illustrated in the platform, input data consists of object ID, time, position, orientation, and velocity, as illustrated in Figure 9.

Object Name	Object ID	Time	Spatial Information	Yaw	Pitch	Roll	Velocity Vector

Figure 9: Platform Input Data for Phase II I/F

In this paper, we use SIMDIS for simulation display. SIMDIS provides support for high-fidelity analysis and display of test and training mission data to a growing user base of nearly 8,000 users. This highly specialized visualization tool provides unique capability for two- and three-dimensional interactive data display and analysis. Figure 10 shows the I/F for simulation analysis using SIMDIS format. Platform initial information and input data are converted to a file format suitable for SIMDIS.



```
# Platform Keywords
PlatformID 1
PlatformName 1 "Ship"
PlatformIcon 1 "jds_kongo_ddg_173“
.
.
PlatformData 1 "1.000" 7.721 0.000 -30.000 90.000 0.000 0.000 0, 0, 0
BeamData 401 "1.500" 0xc00000ff-72.617 -24.228 555.138
```

Figure 10: SIMDIS format for simulation analysis I/F

The I/F for simulation analysis also allows for a statistical evaluation of underwater warfare system effectiveness through Monte Carlo simulation. The feature of Monte Carlo simulation allows for random variations in certain platform parameters and simulated events to develop probabilistic assessments of system effectiveness. For example, the torpedo is launched randomly within the scenario guidelines and the reliability of the decoy is influenced by the normal random variable. These random variables are defined at the I/F for scenario identification.

4. CASE STUDY: COMPONENT OPERATION FOR SUBMARINE WARFARE

To demonstrate our contributions, this section illustrates two component operations for submarine warfare. We used the underwater warfare simulator developed by Seo and Song(2011), which is based on the DEVS formalism for underwater warfare.

4.1. Component operations for submarine warfare

A submarine performs various component operations such as anti-surface ship warfare (ASW), anti-submarine warfare (ASW), mine warfare (MW), surveillance warfare (SW), etc. In this paper, we consider two ASWs, and the brief scenario illustrated in Figure 11, as follows:

1. Enemies (submarine and surface ships) are approaching our submarine.
2. When the submarine detects the enemies during its barrier mission, it starts Target Motion Analysis (TMA) procedures to estimate the kinetic state, such as range, course, velocity, etc.
3. When enemies are located within attack range of the submarine, the submarine launches a torpedo toward the detected enemies.
4. After launching a torpedo, the submarine makes a detour for evasion.

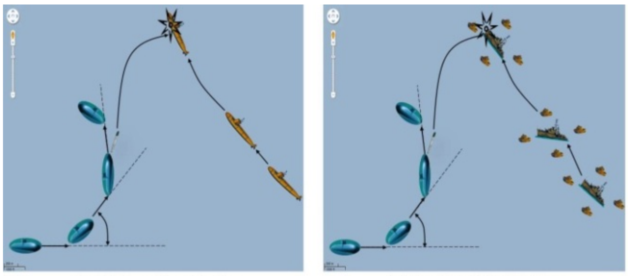

Anti Submarine Warfare
Anti Surface ship Warfare

Figure 11: Scenarios for Two Component Operations

4.2. Experimental Results

Figure 12 through Figure 14 show experimental results applied to proposed I/Fs. Experiment 1 is for anti-submarine warfare; its objective is to use interface forms and check the results. Experiment 2 is for anti-surface ship warfare; and its objective is to evaluate various maneuver tactics.

Experiment 1 : Anti-submarine warfare

Figure 12 shows the I/F for scenario identification. The left side of Figure 12 shows the tactic script to vary the torpedo’s maneuver pattern. The structure of the script is just like C-like code. When we decide the torpedo maneuver pattern from the tactic script, the underwater warfare simulator operates the maneuver pattern developed in the simulator. The right side of Figure 12 shows the I/F for scenario identification. The left side of Figure 12 shows platform parameters.

Figure 13 shows the simulation result of anti-submarine warfare. The I/F has a benefit, namely, the simulation of the various scenarios without modifying the model when tactics are changed, but with modifying scenario description I/F only. We can revise the tactic script at simulation run time.

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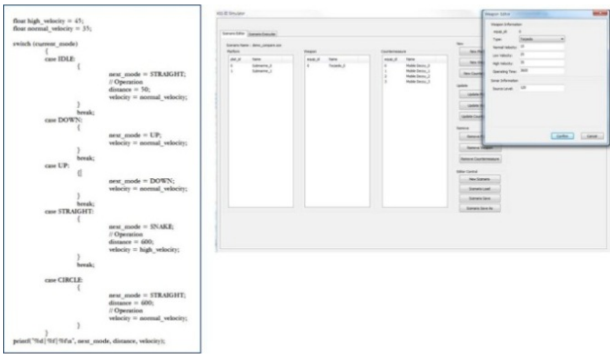

```
float high_velocity = 45;
float normal_velocity = 35;

switch (current_mode)
        {
        case IDLE:
                {
                        next_mode = STRAIGHT;
                        // Operation
                        distance = 50;
                        velocity = normal_velocity;
                }
                break;
        case DOWN:
                {
                        next_mode = UP;
                        velocity = normal_velocity;
                }
                break;
        case UP:
                {
                        next_mode = DOWN;
                        velocity = normal_velocity;
                }
                break;
        case STRAIGHT:
                {
                        next_mode = SNAKE;
                        // Operation
                        distance = 600;
                        velocity = high_velocity;
                }
                break;

        case CIRCLE:
                {
                        next_mode = STRAIGHT;
                        distance = 600;
                        // Operation
                        velocity = normal_velocity;
                }
        }
printf("%d|%f|%f\n", next_mode, distance, velocity);
```

Figure 12: Scenario Identification I/F for Anti-submarine Warfare

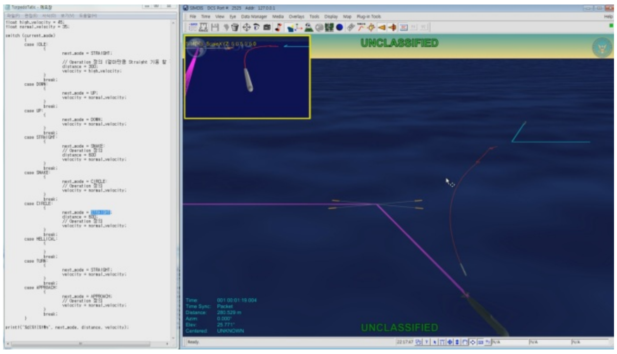

Figure 13: Simulation Result for Anti-submarine Warfare

Experiment 2 : Anti-surface ship warfare

The second experimental result depicted in Figure 14 shows the survival probability according to the search patterns of the torpedo. In this experiment, four different patterns, depicted in Table 1, are used. With the scenario description I/F, we can combine any maneuver patterns, which are designed in the simulator. The result shows that the combination of all three search patterns results in a higher probability of survival. The I/F enables users to assess alternative tactical deployments for torpedo maneuver patterns.

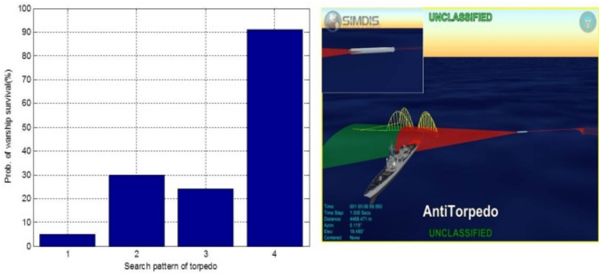

Figure 14: Simulation Result for Anti-Surface ship Warfare

Table 1: Maneuver Pattern Cases

Pattern	Description
1	Straight and snake maneuver patterns used
2	Straight and snake maneuver patterns used
3	Snake and circular maneuver patterns used
4	All of three patterns used

5. CONCLUSION

In this paper, we proposed implementation of Interface Forms (I/Fs) for underwater warfare simulator. I/Fs operate somewhat like experimental frames. Proposed I/Fs provide the developed simulator platform information and tactical information, and we observe the simulation result and analyze the result with the proposed I/F. Proposed I/F illustrates how to design an experimental frame for appropriate modeling objectives, and provides flexible experimental frames to provide insights about how various factors, such as tactics and the performance of underwater weapons, influence the MOEs of the system. The experimental result shows that we can test alternative tactics and that the behavior analysis was successful. Extension of the general concept should be considered in a future work.

ACKNOWLEDGEMENTS

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REFERENCES

Kim, T.G., Park, S.B., 1992. The DEVS formalism: Hierarchical modular systems specification in C++. *Proceedings of the European Simulation Multi-conference*, pp. 152-156, Jun., 1992, York, United Kingdom.

Office of Aerospace Studies, 2008. Analysis of Alternatives (AoA) Handbook. Available from: http://www.ndia.org

Seo, K.M., Song, H.S., Kwon, S.J., Kim, T.G., 2011. Measurement of Effectiveness for an Anti-Torpedo Combat System Using a Discrete Event System Specification-based Underwater Warfare Simulator. *The Journal of Defense Modeling and Simulation: Application, Methodology, Technology*. vol. 8, no. 3: pp. 157–171.

Sung, C.H., Moon, I.C., Kim, T.G., 2010. Collaborative Work in Domain-Specific Discrete Event Simulation Software Development: Fleet Anti-air Defense Simulation Software. *Proceedings of 2010 Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises*, pp. 160-165, Larisa, Greece.

U.S. Naval Research Laboratory, 2006. *SIMDIS User's Manual*. Available from: https://simdis.nrl.navy.mil.

Zeigler, B.P., Praehofer, H., Kim, T.G., 2000, Theory of Modeling and Simulation. United State: Academic Press.