Evaluating the Effectiveness of Shoot-Look-Shoot Tactics using Discrete Event Modeling and Simulation

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Abstract. Modeling and Simulation (M&S) methods of analysis play an increasingly significant role in planning military operations and determining the optimal use of available defense forces to ensure that national security is maintained. M&S engineering enables the procurement of military equipment to become more efficient. This paper presents a case study that applies DEVS-based M&S technology to develop a simulation of shoot-look-shoot tactics. The developed simulation allows us to conduct a statistical evaluation of shoot-look-shoot tactics overall, and to provide an assessment of tactics development. In order to analyze the system effectiveness, we performed extensive combat experiments by varying certain parameters, including tactics and weapon performance. The experimental results show how these factors influence the effectiveness of the proposed system.

1 Introduction

Modeling and Simulation (M&S) methods of analysis play an increasingly significant role in planning military operations and determining the optimal use of available defense forces to ensure that national security is maintained [1]. These methods constitute a rational approach to exploring the different alternatives for force deployments, and to determining the best strategies and tactics in actual combat engagement. For the sake of enhancing the development of weapon systems, Modeling and Simulation (M&S) engineering has been widely employed for requirement analysis, development, test and evaluation, and weapon system training. M&S Engineering is a particularly appropriate approach for weapon systems in vehicles used for underwater warfare, such as torpedoes, decoys, or submarines, because the factors related to those vehicles have become more complicated and diverse. Applying M&S technique, simulation-based acquisition and development facilitates good decision-making about equipment procurements and tactics development.

This paper presents a case study that applies DEVS-based M&S technology to develop a simulation of shoot-look-shoot tactics. The purpose of this paper is to introduce and develop simulation models for simplified battlefield situations. The developed simulation allows us to conduct a statistical evaluation of these shoot-look-shoot tactics overall, and also to provide an assessment of tactics development. In order to analyze the system's effectiveness, we performed extensive combat experiments by varying certain parameters, such as tactics and weapon performance. The experimental results show how the factors influence the effectiveness of the proposed system.

This paper is organized as follows. Section 2 presents the simulation model and DEVS formalism. Section 3 explains the design of the overall model, while section 4 illustrates the effectiveness analysis using the experimental results from the shoot-look-shoot model. Finally, section 5 offers a conclusion.

2 Related Work

First, we introduce simulation modeling for underwater warfare combat. Second, we briefly introduce the DEVS formalism that we apply to modeling the underwater warfare system in this paper.

2.1 Simulation Modeling

Modeling is a way of solving problems that are encountered in the real world. It is applied whenever prototyping or experimenting with a real system is prohibitively expensive, or indeed impossible. Modeling allows us to optimize systems prior to their implementation. Modeling includes the process of mapping the problem from the real world to its model, model analysis and optimization, and mapping the solution back to the real-world system. We can distinguish between analytical and simulation models [2]. In an analytical model, the result functionally depends on the input (a number of parameters); it is possible to implement such a model in a spreadsheet. However, analytical solutions do not always exist, or may be very hard to find. In those instances, simulation modeling may be applied. A simulation model may be considered as a set of rules (e.g. flowcharts, state machines, cellular automata) that define how the system being modeled will change in the future, given its present state. Simulation is the process of model 'execution' that takes the model through state changes (either discrete or continuous) over time. In general, for complex problems where the time dynamics are important, simulation modeling is the superior option. In this paper, we employed simulation modeling rather than analytical modeling.

2.2 DEVS Formalism

The DEVS formalism is a general formalism for discrete event system modeling based on set theory, and it is one of the M&S theories that are applied to various military simulations [3]. The DEVS formalism supports the specification of discrete event models in a 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 a large system into its smaller components and identify the coupling scheme among them. There are two kinds of models in the formalism: the atomic model and the coupled model.

The atomic model is a specification of basic model behavior as a 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 $Q = \{(s,e) | s \in S, 0 \le e \le ta(s)\}$ 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.

A coupled model is a specification of a hierarchical model structure. It enables the method of assembling atomic and/or coupled models to build the hierarchy of a complex system. Formally, a coupled model is defined as follows:

$$DN = < X, Y, M, EIC, EOC, IC >,$$

Where

X: a set of input;

Y: a set of output events;

M: a set of all component models;

$EIC \subseteq DN.X \times \cup M.X$: external input coupling;

$EOC \subseteq \cup M.Y \times DN.Y$: external output coupling;

$IC \subseteq \cup M.Y \times \cup M.X$: internal coupling;

SELECT: $2^M - \Phi \rightarrow M$: tie-breaking selector.

3 Model Design

The exiting model is designed based on the DEVS formalism. In Section 3, we describe in simple terms the shoot-look-shoot tactics and the overall model design.

3.1 Shoot Look Shoot Tactics

The shoot-look-shoot assignment tactics for the attacker are based on the assumption that the command and control for the battle management has the ability to assess the consequences of each shot, i.e., whether the target was missed or destroyed, and to assign successive shots only to the surviving targets. This means that the kill assessment must be perfect [4]. A typical engagement for shoot-look-shoot tactics is illustrated in Figure 1. In spite of the precision of modern weaponry systems, shots fired at targets do occasionally miss or cause only partial damage. Consequently, a sequence of more than one shot may be directed at a particular target to increase the probability of a kill [5].

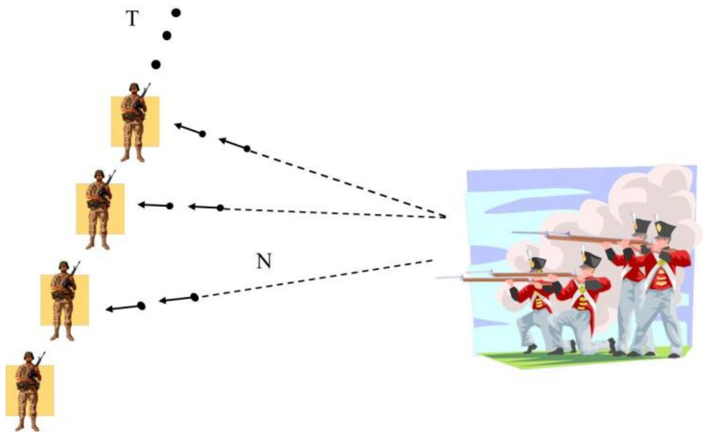


Figure 1 Attacker's shoot-look-shoot assignments

3.2 Model Design

A model of a typical engagement for shoot-look-shoot tactics is illustrated in Figure 2. The entire simulation model consists of a system model and an experimental frame. The overall model architecture that has been developed is described in Figure 2, and consists of two main models: a simulation model for the user's system, and an experimental frame model for analysis of the user's system. The simulation model consists of blue force and red force models: a hit, a damage and a killManage model.

The DEVS-coupled model describes the event message exchange relations among the DEVS atomic models. The following specification represents the DEVS-coupled model of the shoot-look-shoot model, and Figure 2 presents a diagram of the model.

Figure 3 and Figure 4 show the DEVS atomic model diagram for the maneuver model. In Figure **3**, the colored circle represents the initial state. Since the set-theoretic specification can be easily turned into the diagram, we will use this diagram to show the particular DEVS atomic model for this investigation.

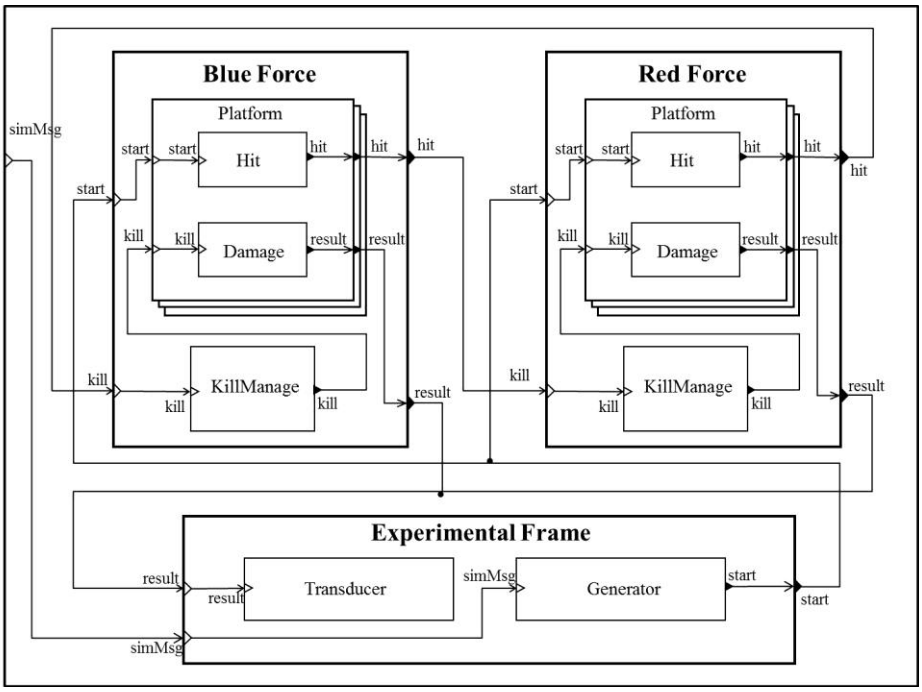
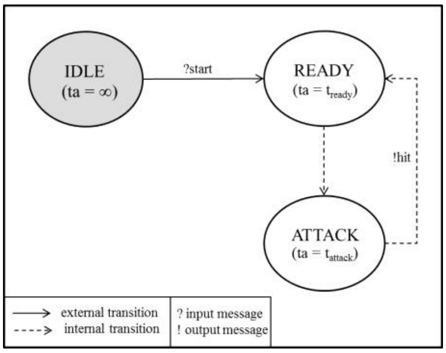
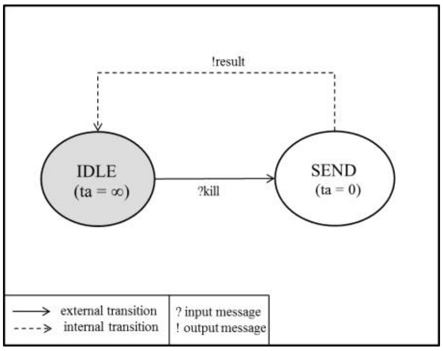


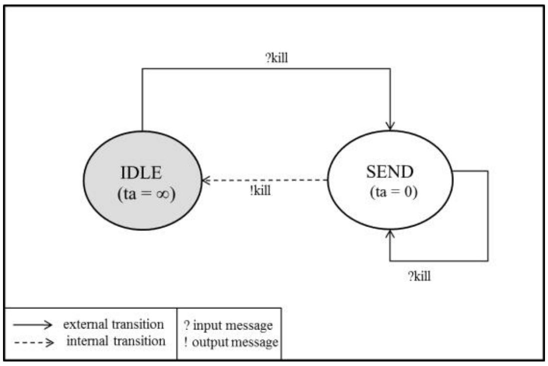
Figure 2 Overall model of shoot-look-shoot tactics



(a) Hit model



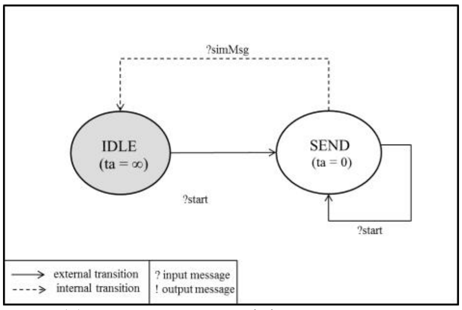
(b) Damage Model



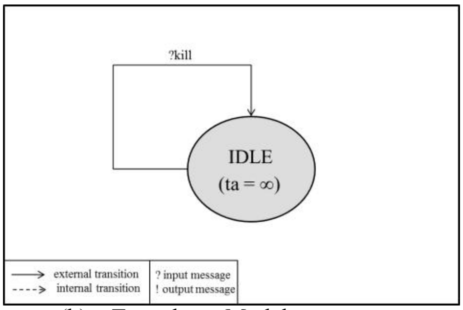
(c) HitManage Model

Figure 3 Atomic model of system model (blue force)

An experimental frame typically has three 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. In this paper, we design a generator and transducer model, as illustrated in Figure 4.



(a) Generator Model



(b) Transducer Model

Figure 4 Atomic model of experimental frame

A hit model assumes the role of attacking the enemy. The hit model transfers a 'hit' message to the hitManage model of the opponent's side. The hitManage model receives the message and decides whether its own model is killed or not. If its own model is killed, the hitManage model sends a 'kill' message to the damage model. The damage model receives the message and sends the result to the experimental frame.

4 Case Study – Shoot Look Shoot Tactics

All DEVS models and experimental frame models are implemented with the DEVSim++ library, which is a DEVS execution environment that uses C++ by SMSLab in KAIST [6]. This section illustrates the developed simulator, which is a shoot-look-shoot tactics simulator for effectiveness analysis. Analyzing the survivability of the blue force across diverse parameter values and tactics, we show how the simulator enables us to gather insights into equipment procurements and tactics development.

4.1 Model simulation of Shoot-Look-Shoot tactics

Now that we have completed the model implementation using C++, we will design the overall architecture of the shoot-look-shoot simulation.

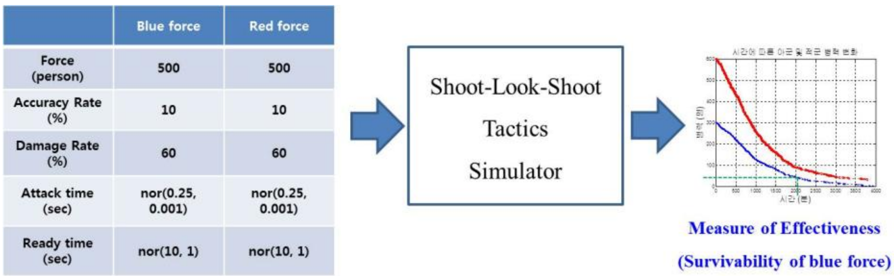


Figure 5 High-level view of shoot-look-shoot system

Figure 5 presents the high-level view of the discrete event simulation for underwater warfare. The underwater warfare simulation is not a live simulation, but a constructive simulation. Generally, a constructive simulation has various simulation parameters.

Table 1 Scenario input parameters

Parameter name	Default value	Implications
Troops	500	Blue and Red force
Accuracy Rate	10%	The probability of accuracy of weapon system
Damage Rate	60%	The probability of damage of weapon system
Attack Time	0.25 sec	The time for attacking
Ready Time	10 sec	Reloading time

We identify these parameters as the scenario parameters and enumerate the input parameters in Table 1. As our goal is to evaluate the simulation’s MOEs, such as the survivability of the blue force and the operational success rate for various situations, we will vary the input parameters in a later case study. In Table 1, “Troops” refers to the military strength of both armies, and "Accuracy Rate" of the weapon system refers to the percentage of target hits. "Attack Time" refers to the period in which the weapon flies toward the target, and finally, "Ready Time" refers to the time for reloading and aiming.

4.2 Experimental Results

We performed four experiments to analyze the MOE using this extended simulator. In each experiment, we varied the value of one input parameter, such as Troops, Accuracy Rate, Damage Rate, or Ready Time. We did not experiment by changing the Attack Time. The main purpose of these experiments was to evaluate the simulation's MOEs, such as the survivability of the blue force and the operational success rate in various situations.

Table 2 Scenario parameters for experiments

Parameter name	Blue Force	Red Force
Troops (persons)	700	500
Accuracy Rate (%)	10	10
Damage Rate (%)	60	60
Attack Time (sec)	nor(0.25, 0.001)	nor(0.25, 0.001)
Ready Time (sec)	nor(10,1)	nor(10,1)

(a) Experiment 1

Parameter name	Blue Force	Red Force
Troops (persons)	500	500
Accuracy Rate (%)	20	10
Damage Rate (%)	60	60
Attack Time (sec)	nor(0.25, 0.001)	nor(0.25, 0.001)
Ready Time (sec)	nor(10,1)	nor(10,1)

(b) Experiment 2

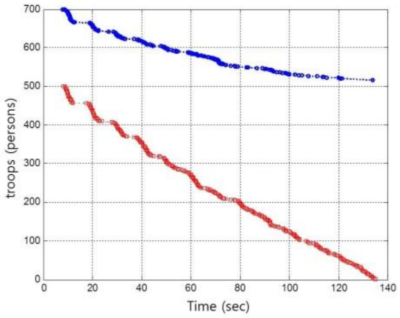
Parameter name	Blue Force	Red Force
Troops (persons)	500	500
Accuracy Rate (%)	10	10
Damage Rate (%)	80	60
Attack Time (sec)	nor(0.25, 0.001)	nor(0.25, 0.001)
Ready Time (sec)	nor(10,1)	nor(10,1)

(c) Experiment 3

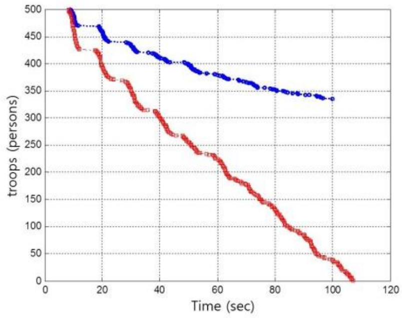
Parameter name	Blue Force	Red Force
Troops (persons)	500	500
Accuracy Rate (%)	10	10
Damage Rate (%)	60	60
Attack Time (sec)	nor(0.25, 0.001)	nor(0.25, 0.001)
Ready Time (sec)	nor(8,1)	nor(10,1)

(d) Experiment 4

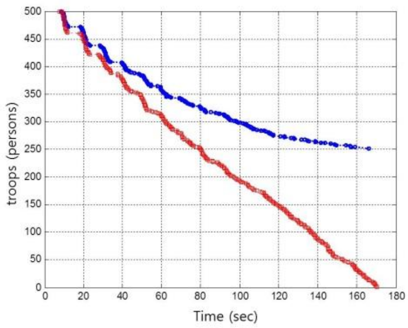
As depicted in Table 2, we performed four experiments to analyzing the MOE using this extended simulator. The main purpose of these experiments was to evaluate the simulation's MOEs, such as the survivability of the blue force and the operational success rate in various situations. Basically, the experimental results show that the military strength of both sides and the gap between both strengths decrease as time goes on.



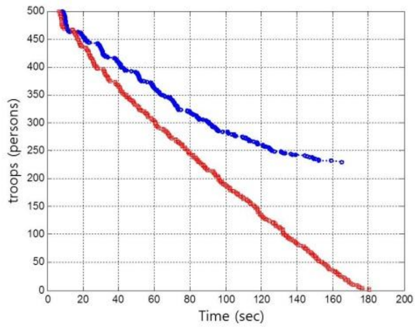
(a) Results of experiment 1



(b) Results of experiment 2



(c) Results of experiment 3



(d) Results of experiment 4

Figure 6 Experimental Results

The results of experiment 1 show, basically, that having more troops is superior to having fewer troops. Experiments 2 and 3 show the troops that survive according to the performance of the weapon system, such as the accuracy rate and damage rate. As shown in (b) and (c) of Figure 6, when the weapon system performance of the blue side is superior to the opponent's force, more troops survive than in the opponent force as the battle progressed. Finally, experiment 4 shows that well-trained troops are superior to troops that have inadequate training, because the reloading time is short when troops are well trained.

5 Conclusion

This paper presents a case study that applies DEVS-based M&S technology to the development of a simulation of shoot-look-shoot tactics. The developed simulation allows us to perform a statistical evaluation of the overall shoot-look-shoot tactics, and also to perform an assessment of tactics development. Using the proposed simulation, we can determine how various factors, such as military strength, performance of weapons and physical training, influence effectiveness of the system. Experimental results support assessment of system effectiveness. It requires much effort in modeling in detail and developing various input parameters, yet that is out goal for future works.

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