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A Case Study : Analysis on Effectiveness of Operation over Time Sensitive Target Using Modeling and Simulation

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요　약

시한성 표적(Time Sensitive Target : TST)이란 신속하게 움직이기 때문에 대응 가능시간이 제한되는 표적을 의미한다. 시한성 표적은 1991년 걸프전에서 이라크의 스커드 미사일 위협 이후 군사적으로 큰 고려사항이 되어왔다. 그 이후, 제한된 시간 안에서 시한성 표적을 효과적으로 공격하기 위한 여러 방법들이 연구되어 왔다. 시한성 표적 공격 작전에는 감시자산, 지휘통제 시스템, 공격자산 등의 다양한 수단들이 필요하며 이 수단들의 효율적인 협력이 중요하다.
본 논문에서는 모델링 및 시뮬레이션(M&S) 방법을 사용하여 시한성 표적 작전에 투입되는 자산들의 효율성을 분석하였다. 이 연구를 통하여, 시한성 표적에 성공적으로 대응할 수 있도록 투입 자산들의 효율성을 비교할 수 있는 방안을 제안하였다.

<핵심어>Time Sensitive Target, TST, Discrete Event, Simulation, DEVS

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M&S를 활용한 시한성 표적(TST) 공격 작전의 효율성 분석 사례

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Abstract

A time-sensitive target(TST) is a target that requires an immediate response because its vulnerability window is very limited like a fast-moving mobile target. TSTs have been a major concern of the military since SCUD missile threats in Operation Desert Storm in 1991. The military community has sought effective ways to destroy these targets within their vulnerability window. A TST operation requires a variety of assets such as a sensor, command & control, and a shooter to be engaged and working together in a timely manner. In this paper, we evaluate the effectiveness of the assets involved in a TST operation using the modeling and simulation method. The results can provide the military community with insights about ways to utilize TST assets to maximize the possibility of destroying TSTs.

<Key words> Time Sensitive Target, TST, Discrete Event, Simulation, DEVS

1. Introduction

A time-sensitive target(TST) is a target whose vulnerability window is significantly limited, and thus prompt action is required to eliminate or minimize the damage to friendly forces. JP 1-02(Department of Defense Dictionary of Military and Associated Terms) defines the time sensitive target as a target which requires an immediate response because it poses(or soon will pose) a clear and present danger to friendly forces, or is a highly lucrative, fleeting targets of opportunity[1]. Mobile targets like aircraft, cruise and ballistic missiles, mobile air defenses, fleeting forces operating in a small unit, and high-value military cargo are typical examples of TSTs. TSTs have been a major concern of the military community since SCUD missile threats in Operation Desert Storm in 1991[2]. For proper engagement with TSTs, timeliness is the most important factor. A delayed response to a TST could result in serious threats to friendly forces and enable the TST to safely conceal itself from a counter reaction by friendly forces.

TST operation requires a variety of resources such as *sensors, communication, command & control, and shooters* to be engaged and working together in a timely manner. The best performance of these resources should be exerted to achieve common objectives - such as destroying the TST before it exercises its threat. Although each resource is essential in a TST operation, one needs to identify some critical resources which play a pivotal role in dealing with a TST. For example, the person in charge of munition acquisition wants to efficiently use limited budget to enhance the critical resources to increase the military''s capability of destroying TSTs. However, identification of critical resources has been a challenge because of the dynamic and complicated characteristics of TST operations.

In this paper, we evaluate the effectiveness of these resources in engaging TSTs. To evaluate the contribution of resources for TST operations, we developed a test environment of TST operations where the resources involved in TST operations and battlefields were modeled with Discrete Event System Specification(DEVS) formalism and simulated with a DEVSim++ environment. For the initial study using this test environment, we performed an experiment to compare the effectiveness of a sensor and a shooter in a TST operation. The results can provide the military community with insights about how to utilize TST assets to maximize the possibility of destroying TSTs. Future work should further expand the overall evaluation of the effectiveness of resources involved in TST operations to reflect more complex, real-life battlefield conditions.

This paper is organized as follows. In section 2, we introduce Discrete Event System Specification(DEVS) formalism. Section 3 describes the modeling process and implementation of a TST operation environment. Section 4 shows an experiment to evaluate the effectiveness of TST resources. In section 5, we conclude this paper and suggest future work.

2. Background

A Discrete Event System Specification(DEVS) is a formalism proposed by Zeigler to model a discrete event system[3]. The DEVS formalism is defined as a 7 tuple.

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

- X is the set of input events
- S is the set of states
- Y is the set of output events
- $\delta_{int} : S \rightarrow S$ is the internal transition function
- $\delta_{ext} : Q \times X \rightarrow S$ is the external transition function where $Q = \{(s,e) | s \in S, 0 \leq e \leq ta(s)\}$
- $\lambda: S \rightarrow Y$ the output function
- $ta : S \rightarrow R^{+}_{0,\infty}$ is the time advanced function where $R^{+}_{0,\infty}$ is the set of positive real number from 0 to ∞

The interpretation of these elements is as follows. X and Y represent all input and output event sets of a system and S indicates all possible states of the system. When an external input event happens, a state transition is triggered by δ_{ext}. When a time expressed by ta elapses, a state transition is also triggered by δ_{int} and an output event is generated by λ. More detailed information about the formalism is available in [3]

3. Modeling of TCT Operational Environment

In this section, we describe the main scenario of TST engagement on the battlefield and explain the modeling process of all entities involved in this scenario. In the scenario, a TST is regarded as a projecting threat which should be neutralized by friendly forces before it demonstrates its threat. To deal with the TST in a timely manner, the friendly forces use their abilities to find, assess, track, target, and engage the TST.

3.1. Overview of TST Operation in Our Scenario

In our scenario, the enemy is planning to employ a Theater Ballistic Missile(TBM) to a friendly forces area. A Transporter-Erector-Launcher(TEL) is carrying the TBM and is moving along unknown roads in the enemy area. The objective is to neutralize the TBM before it is launched or to destroy the TEL before it conceals itself from friendly forces after the TBM is launched. Some friendly forces aircraft patrol along a preplanned route in the entire theater. Some of the aircraft are equipped with ground surveillance radar which can detect the ground target(called sensors, hereafter) while other aircraft are equipped with air-to-ground missiles to destroy the ground target(called shooters, hereafter). Other shooters on ground(air-bases) are ready to take-off within predefined time limits if they are ordered to do so. The Air Operation Center(AOC) performs Command and Control(C2) functions for the resources involved in the TST operation. The AOC has two main functions: (1) to decide whether a shooter is allocated to a TST depending on the credibility of information given by the sensors. (2) to determine which shooter is assigned to the TST among the airborne and ground shooters. If a sensor detects a target, it reports to the AOC using communication equipment which can be either a voice or data link type. The AOC evaluates the credibility of the information from the sensor, chooses a shooter, and orders the shooter to engage the target. The shooter then flies to the target via the shortest path, identifies the target, and finally fires an air-to-ground missile.

3.2. Assumptions

In this section, we explain the assumptions in our scenario.

■ **Air Superiority** : The friendly forces hold air superiority in the entire theater. Thus, the friendly forces do not need to escort the shooter that is engaging the TST.

■ **Physical Environment** : We do not explicitly consider the physical and environmental nature of the problem. For example, the operational characteristics of different types of aircraft and missiles, and terrain blockage of radar coverage are not considered. Since aircraft are assumed to have unlimited fuel, problems due to fuel shortage are also not considered. Finally, the weather conditions are not considered.

■ **The Number of TSTs** : Only one TST can be considered in our scenario. Seemingly, this assumption seems somewhat unrealistic when considering the dynamics and complexity in present warfare. However, since our objective in this scenario is to evaluate the time elapsed from a target occurrence to engagement(timeliness of a TST operation), we do not want to introduce these complexities into the planning phase of the scenario, such as the cooperation process and priority issues that are necessary to deal with multiple targets at the same time.

■ **TST Availability** : The maximum time window of TST vulnerability is 30 minutes. We assume if the proper action is not taken within 30 minutes after a TST is created, the TST will launch the TBM and conceal itself from friendly forces within that time frame.

3.3. Modeling of Entities in TST Battlefield

We determined the modeling of entities involved in a TST operation. Each entity in the model is modeled with its attributes and behaviors.

1) Target

In our scenario, the target is defined as a moving vehicle which should be engaged within a limited time window. The target is modeled with speed(max and min) and a radar cross section(RCS)(max and min). The RCS is a measure of how detectable an object is with a radar. A larger RCS indicates that an object is more easily detected. The target moves on a randomly selected path. The speed of the target can change linearly within a rate of 20KM/hour. In reality, the RCS of an object is dependent on several factors including size, material, incident angle, and reflected angle. However, we simplified the RCS measure of the target using the size of the target.

2) Airframe

An airframe is an object which can fly. In our scenario, an airframe can be either a shooter or a sensor, depending on the equipment of the airframe. If an airframe is equipped with a weapon(air-to-ground missile) or radar, it is regarded as a shooter or sensor, respectively. An airframe is modeled with several attributes: altitude, speed, location, type of weapon, type of radar, type of communication equipment, and current location(ground or airborne). An airframe also has different behaviors depending on its equipment and current location.

■ **Shooter in an air base** : If ordered from the AOC, the shooter takes off within the user defined time limit. It climbs to 20000 ft and heads for the target at the user defined speed(e,g., 450KTS). The shooter fires its weapon when the following conditions are satisfied.

- The target is located within the effective range of the weapon.
- The target is identified.

■ **Shooter in a holding point** : If ordered from the AOC, the shooter flies directly to the target and fires its weapon when the above conditions are fulfilled.

■ **Sensor** : The sensor is reconnoitering along a user defined route. There is no sensor on the ground. If the sensor finds the target, it tracks the target until the shooter engages the target.

3) Weapon

A weapon, which is an air-to-ground missile in our scenario, is installed in the airframe. It is modeled with speed, maximum effective range, lethal radius, reliability and CEP(Circular Error Probable). The CEP is a measure of missile accuracy. A missile''s CEP is the radius of a circle around the target in which 50% of the warheads aimed at that target will land. If fired, the weapon moves to the target at the predefined speed. The damage assessment of the target is then calculated using the following formula.

- Let u be a coordinate in a map where the target is located. Let v be a coordinate of a point which is randomly chosen within the range of the weapon''s CEP centered on the target coordinate(u). Let x be the lethal radius of the weapon and y be the distance between u and v.

- If u and v are identical(that is, $y = 0$), we assume the target damage is 100%.

- If v is located outside the lethal radius of the weapon(that is, $y > x$), we assume the target damage is 0%

- If v is located inside the lethal radius of the weapon(that is, $y < x$), the target damage is computed as follows.

$$target\ damage = (1-(y/x)^2)*100$$

4) Radar

Radar, which is ground surveillance radar, is installed in the airframe. It is modeled with the size of the coverage area(which is a rectangular shape), the detection probability of the target in the coverage area and the false alarm rate. The detection probability is provided by the user. For example, the user can define the detection probability of the target with respect to its RCS as shown in [Table 1]. The false alarm rate of the radar is the probability of the radar to falsely detect the target if that target does not exist in the coverage area. The radar can determine whether the target in the coverage area is detected or not depending on the RCS of the target and the user defined detection probability for RCS. When the radar detects the target, it reports the information to the AOC using communication equipment. The target detection of the radar might be a false alarm.

[Table 1] An example of detection probability based on RCS

RCS	1 - 25	26 - 50	51 - 75	76 - 100
Detection Probability	20%	40%	60%	80%

5) Communication Equipment

The communication equipment installed on the airframe and the AOC entities establishes a communication channel, which is modeled with the message type it can transmit. The voice equipment can transmit only the voice while data link type equipment can transmit both voice and digital data. The difference between these two types of equipment in our scenario is the communication capacity and latency. We assume that the communication capacity of the data link equipment is two times more than that of the voice communication equipment. The communication latency of the equipment can be defined by the user and by the default. The latency for the voice and data link communication is 1 minute and 2 minutes, respectively. Communication loss may occur in our scenario with 1% rate. The communication loss causes the communication latency to be twice as many as the normal communication latency since the communication needs to be reestablished.

6) AOC(Air Operation Center)

The AOC is a command and control entity for the TST operation in our scenario. The AOC is in charge of determining shooter allocation for TST engagement and choosing a specific shooter for the engagement. These processes require data analysis time and data process time. Thus, the AOC is modeled with shooter allocation time and shooter selection time. Whether the shooter is allocated or not depends on the false alarm rate and communication device type of the sensor. The probability of the shooter allocation is computed as follows. Let SAP be the shooter allocation probability for a target.

- SAP = (100 - false alarm rate) × 1, for voice communication equipment
- SAP = (100 - false alarm rate) × 0.5, for data link communication equipment

If target information is transmitted with data link communication equipment, the shooter allocation probability will be twice as high as when the voice communication equipment is used. This is justified because data link communication equipment can transmit higher quality information(for example, image and video) about the target, so the AOC can make a better decision based on high quality information for the target. The AOC chooses the shooter for the target based on the location of the shooter. The shooter that can reach the target within the shortest time is chosen to engage the target. The shooter allocation time and shooter selection time can be defined by the user.

7) Airbase and Holding Point

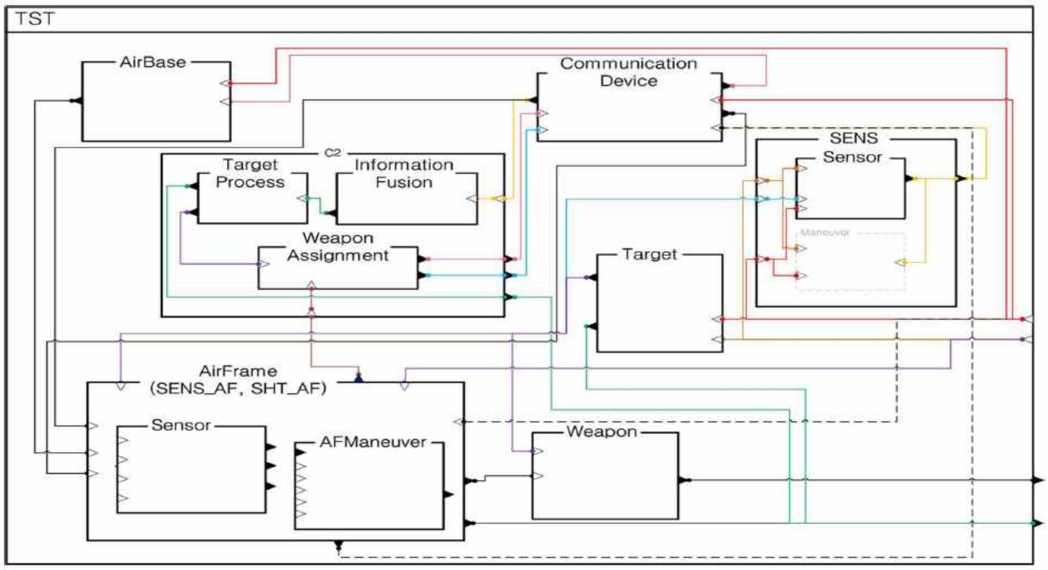
Airbases and holding points have shooters. Both entities are modeled with their location(coordinates) and shooters. As soon as an engagement order is received from the AOC, the shooter takes off from the airbase within the user defined time limit and flies to the target while the shooter in the holding point directly flies to the target.

3.4. Implementation

We modeled the TST operation entities involved in our scenario using DEVS formalism and implemented them using DEVSim++ environment[1] [4][5]. [Figure 1] shows the TST entities and their relations specified with DEVS formalism. We left

1) DEVSim++3.0 Manual; http://smslab.kaist.ac.kr.

out the explanation of each entity in the figure. [Figure 2] shows our implementation of the TST operation environment where the parameters for each entity can be set and behavior of each entity can be displayed during simulation.



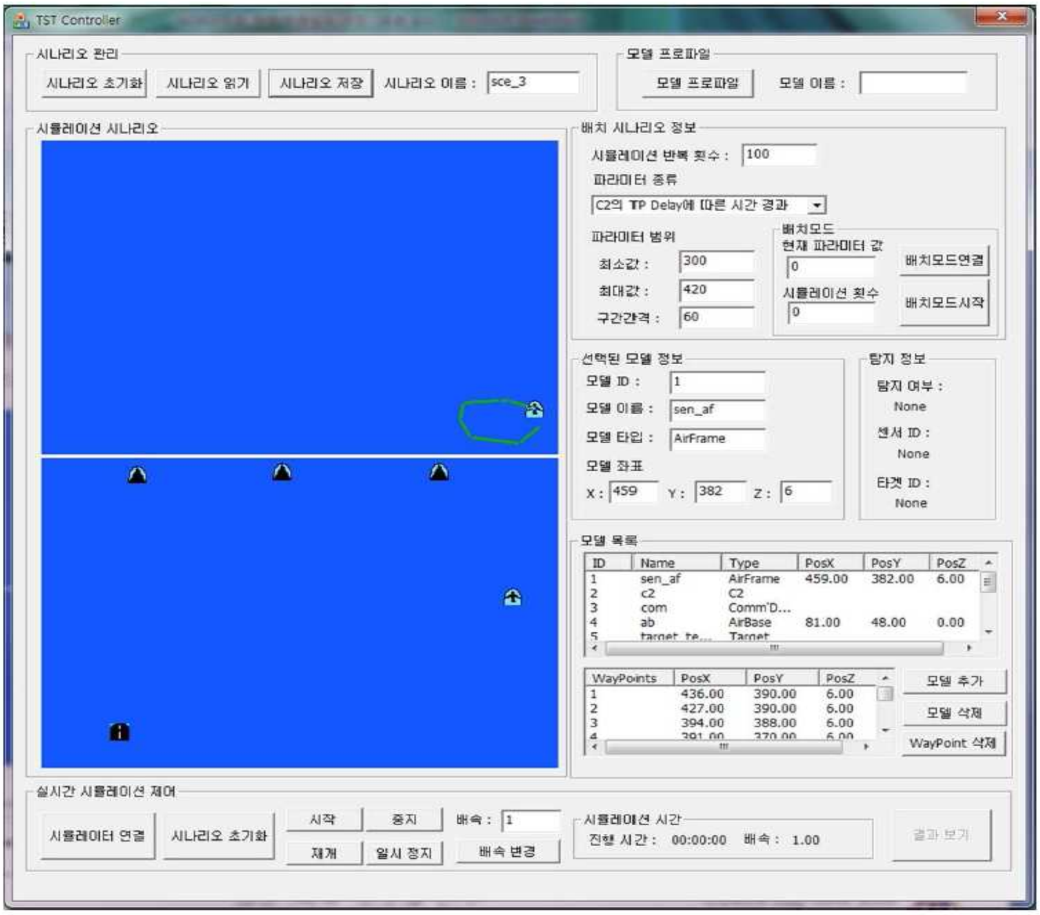
[Figure 1] The TST Entities modeled with DEVS formalism [4]

4. Simulation and Results

In this section, we present the experiment results for evaluating the effectiveness of TST operation entities in engaging a TST using our implementation. We designed our experiment to answer the following question:

- **Should we choose a weapon or a sensor to improve the effectiveness of destroying a TST in a timely manner if we can afford to upgrade only one of them?**

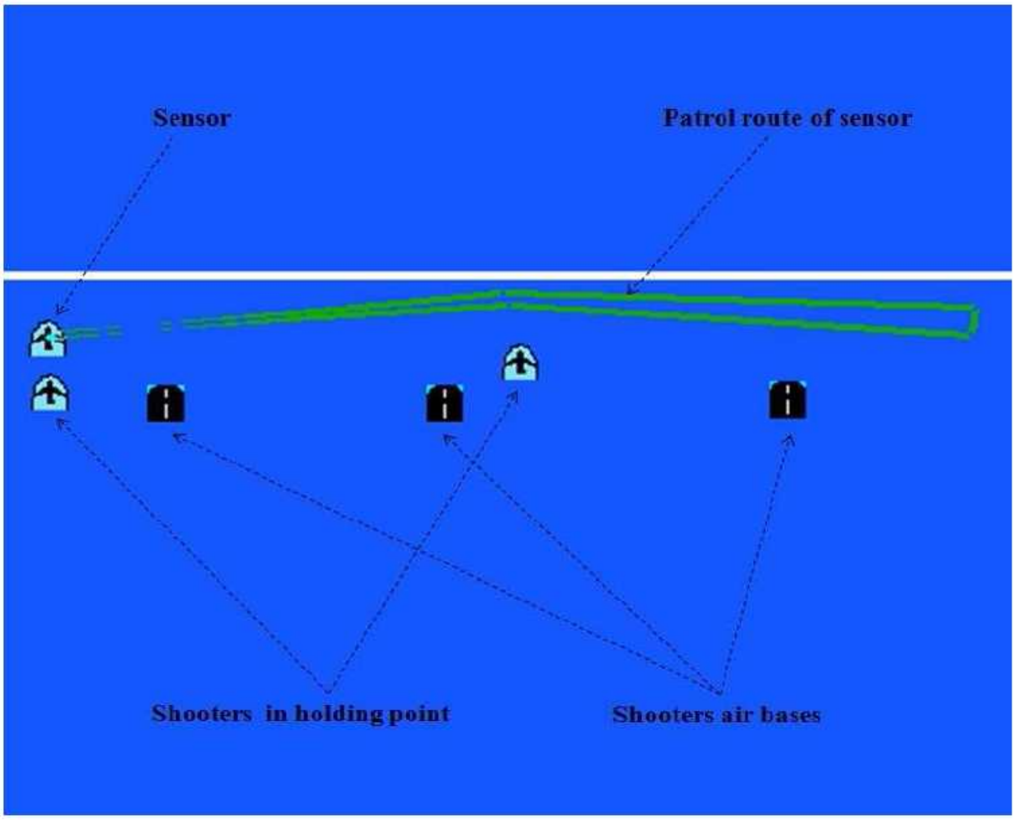
It is not an easy question to say which upgrade is more effective in engaging a TST. If we choose a weapon to upgrade accuracy and range, it would definitely be helpful to engage a TST. However, if we upgrade a sensor for its detection coverage, the sensor can detect a target at a longer distance and with a higher probability. Thus, it can also increase the effectiveness of a TST operation.



[Figure 2] The implementation of TST operation environment

4.1. Setting of the Battlefield

The battlefield in our scenario is shaped like a rectangle with the length 400km and the width 600km. In the [Figure 2], the blue area is the battlefield, which is split into the north(the hostile area) and the south(the friendly area). A target can only appear in the hostile area while airbases and holding points can be located in the friendly area. Sensors and shooters can move throughout the whole battlefield but the patrol route of sensors is limited to the friendly area. Only after a sensor detects a target, the sensor and shooter can cross the boundary between the friendly and hostile area and chase the target. [Figure 3] shows the initial placement of the friendly forces. A sensor is reconnoitering the battlefield along the patrol route in the friendly area. Two shooters are on airborne alert at each holding point while three shooters are on ground alert at each airbase, all of which are located in the friendly area.



[Figure 3] Battlefield setting

4.2. Setting of Entities in the TST Operation

The following is the setting of entities in the TST operation.

■ **Target** : The target in our scenario is a SCUD missile launcher like the MAZ543. The speed of the target has a maximum 60*km* per hour and minimum 0km per hour. The size of the target is 13*M*.

■ **AOC** : The shooter allocation time and shooter selection time of the AOC is 2:5 minutes, respectively.

■ **Communication Equipment** : The communication equipment type for the sensors and the AOC is data-link, which has 2-minute communication latency.

■ **Airframe** : The two different types of airframes are defined as follows.

1) Shooter Airframe : The speed of the shooter airframe is 450KTS with an altitude of 20000 ft

2) Sensor Airframe : The speed of the sensor airframe is 250KTS with an altitude of 20000 ft

■ **Weapon** : We modeled the two air-to-ground missiles in our experiment. The first(Weapon 1) is a GBU-10 smart bomb and the other(Weapon 2) is a AGM-84H(SLAM-ER). The specifications of these bombs are in [Table 2].

[Table 2] Parameters for air-to-ground missiles

Type	Range	Lethal Radius	CEP	Reliability
Weapon 1	13KM	10M	8M	95%
Weapon 2	270KM	10M	3M	95%

■ **Radar** : We modeled our scenario after two currently operational SAR radar systems. The first(Radar 1) is a SAR radar system which is operating with a Hawker-800 airframe in Korea and the other(Radar 2) is a SAR radar system which is operating with JSTARS. The specifications of these two types of radar are in [Table 3].

[Table 3] Parameters for radar

Name	Detection Range	Resolution	False Alarm Rate
Radar 1	180KM	3M	10%
Radar 2	300KM	3M	10%

4.3. Simulation

The goal of this experiment is to check the effectiveness between weapon enhancement(range and accuracy) and radar coverage enhancement to determine which one copes better with a TST. The experiment was performed using two different scenarios as follows.

■ **Scenario 1:** In this scenario, the friendly forces have no information about where a TST is likely to appear, so the sensor of the friendly forces has to reconnoiter the whole hostile area. During the simulation, a TST can appear anywhere in the entire hostile area.

■ **Scenario 2:** The friendly forces in this scenario have some information about the possible location of a TST. For example, a TST will appear only in some areas of the battlefield. In this scenario, a sensor can focus its radar on a relatively small area. During the simulation, a TST can occur in a user defined quarter area of the battlefield.

For each scenario, we performed experiments using the following steps.

To make our experiments statistically meaningful, we repeated each experiment 100 times for each scenario and took an average value of the experiment results.

- **For the baseline simulation:** we set up the friendly forces as shown in [Figure 3]. The shooters are equipped with Weapon 1 type and the sensor is installed with Radar 1 type. For Scenarios 1 and 2, we performed the simulation 100 times.
- **For the weapon enhancement simulation:** we used the same setting as the baseline simulation except for the weapon type. In this simulation, we used Weapon 2 type instead of Weapon 1 type.
- **For the radar enhancement simulation:** we used the same setting as the baseline simulation except for the radar type. In this simulation, we used Radar 2 type instead of Radar 1 type.

If one of following cases occurred during the simulation, the simulation was terminated and recorded as a mission failure.

- A target was not detected until 30 minutes from its generation
- The AOC decided not to allocate a shooter to a target

4.4. Experiment Results

In this section, we describe the experiment results and discuss the meaning of the results with respect to the effectiveness of force enhancement for TST engagement.

1) Scenario 1

In the Scenario 1 experiment, a sensor had to cover the entire hostile area, so the TST was more likely to be undetected. [Table 4] shows the simulation results for Scenario 1. In the baseline simulation, the mission failure rate which was caused by either target detection failure or resource allocation failure was 45%. The average engagement time was 1870 seconds. When we improved the weapon capability from Weapon 1 to Weapon 2, the detection failure rate of the TST did not show any meaningful distinction from those of the baseline simulation. However, the average engagement time was reduced to 369 seconds(about 6 minutes). When the capability of the radar was improved, the average engagement time did not change much from that of the baseline simulation while the detection failure rate was dramatically reduced from 45% to 8%. The result of this experiment show that if a vast area has to be reconnoitered to find TSTs, it is far more helpful to enhance the radar capability rather than to upgrade the weapon systems for engaging TSTs in a timely manner. In [table 4], the difference in failure rate between baseline and weapon enhancement, and the difference in engagement time between baseline and radar enhancement were attributed to randomness in the location of generated target and shooter location when a sensor detected the target. However, the differences were not statistically significant.

[Table 4] Simulation results for scenario 1

	Baseline	Weapon Enhancement	Radar Enhancement
Failure rate	45%	48%	8%
Engagement time	1870 Sec	1501 Sec	1910 Sec
TST damage	97%	98%	96.6%

2) Scenario 2

In the Scenario 2 experiment, a sensor needed to search for a TST in a quarter of the battlefield(200Km × 150Km). [Table 5] represents the simulation results in Scenario 2. In the baseline simulation, we noticed that the failure rate and engagement time was 3% and 1503 seconds, respectively, which were significantly less than those in Scenario 1. When the weapon was enhanced in Scenario 2, the failure rate and average engagement time was 0% and 1083 seconds respectively, while it was only 0% and 1300 seconds when the radar was upgraded. This result indicates that if the radar of a sensor airframe can cover the entire search area, improving the radar performance does not necessarily help to detect more TSTs. For the average engagement time, improving the weapon or the radar can both help to reduce the engagement time. However, weapon improvement reduces engagement time more compared to radar improvement.

[Table 5] Simulation results for scenario 2

	Baseline	Weapon Enhancement	Radar Enhancement
Failure rate	3%	0%	0%
Engagement time	1503 Sec	1083 Sec	1300 Sec
TST damage	91.9%	97%	95%

5. Conclusion

In this paper, we evaluated the effectiveness of resources in engaging time-sensitive targets. In particular, we were interested in what would be more beneficial for effectively destroying TSTs in a timely manner: improving weapon capability or enhancing radar performance. To test this comparison, we developed a simulation environment for a TST operation where entities in the TST operation were modeled by DEVS formalism, and we performed experiments with this environment. The experimental results showed the following conclusions.

- If the search area for a TST is vast, improving the radar performance would detect 6 times more TSTs at the expense of a 27% increase in engagement time with the TST compare to improving weapon capability.

- If the search area for a TST is relatively small, improving weapon capability would show a 27% reduction in engagement time without sacrificing the detection rate of the TST.

Our experiments have some limitations that need further considerations in future work. The TST operation in our simulation environment was too simplified to reflect complicated and dynamically changing modern warfare. For example, the existence of only one TST in the simulation and the assumption of perfect air superiority does not adequately reflect reality. In addition, some parameters used in the simulation were not derived from empirical or scientific data. For example, The time the AOC would spend and the communication latency time used in the simulation were based on our assumptions.

In the future, more experiments are needed to investigate the effectiveness of a variety of entities in the TST operations such as communication equipment, the AOC''s decision time, sensor patrol routes, and location of holding points. An improved simulation environment to reflect more complicated modern warfare is also needed.

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