JOURNAL OF AERONAUTICS AND SPACE TECHNOLOGIES
JANUARY 2010 VOLUME 4 NUMBER 3 (7-17)

ANALYSIS OF COOPERATIVE BEHAVIOR FOR AUTONOMOUS WIDE AREA SEARCH MUNITIONS

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Received: *01st November 2009,* ***Accepted:*** *28th January 2010*

ABSTRACT
This research investigates the effectiveness of autonomous wide area search munitions using cooperative and non-cooperative behavior algorithms under various scenarios. The scenarios involve multiple autonomous munitions searching for an unknown number of targets with different priorities at unknown locations. For the cooperative cases, communications are allowed between the munitions to help locate, identify, and decide to pursue an attack on a target or to continue searching the rest of the battlefield. For non cooperative cases, munitions independently search, detect, identify and decide to attack an identified target or continue to search. Performance of the cooperative munitions depends on numerous parameters such as target types, number, mobility, battlefield characteristics, warhead lethality, decision objectives, and variability in the battlefield. The results were examined under characteristics of warhead lethality, ATR capability, false target attack rate, number of munitions deployed in the simulation, and search weight.
Keywords**:** *Autonomous Wide Area Search Munitions, Cooperative Behavior.*

OTONOM GENIŞ ALAN ARAMA MÜHİMMATI İÇİN KOOPERATİF DAVRANIŞIN ANALİZİ

ÖZET
Bu makalede otonom geniş alan arama mühimmatının kooperatif ve kooperatif olmayan davranış algoritmalarının altındaki etkinliği incelenmektedir. Senaryolar yeri ve sayısı bilinmeyen değişik önceliklere sahip hedefleri arayan çoklu otonom mühimmatı içermektedir. Kooperatif durumlar için, hedefin yerinin tespiti ve tanımlanması ile savaş alanının diğer bölgelerinde aramaya devam edilmesi veya hedef üzerine bir saldırı gerçekleştirmesine karar verilebilmesi için iletişim serbest bırakılmıştır. Kooperatif olmayan durumlar için ise mühimmatlar hedefi aramak, tespit etmek teşhis etmek ve tanımlanan hedeflere hucum etmeye veya aramaya devam etme işlevlerinibirbirinden bağımsız olarak yerine getirmektedirler. Kooperatif mühimmatın performansı, hedef tipi ,sayısı hareketliliği, savaşalanı karekteristikleri başlık gücü, karar hedefleri ve savaş alanındaki değişkenlik gibi birçok etkene bağlıdır. Sonuçlar başlık gücü, ATR etkinliği, yanlış hedefe hucum oranı , arama ağırlığı ve simülasyonda kullanılan mühimmat sayısı altında incelenmiştir.

Anahtar Kelimeler: *Otonom Geniş Alan Arama Mühimmatı, Kooperatif Davranış.*

1. INTRODUCTION

Due to the changing military objectives and diminishing budgets the Air Force has begun to decline the size of its combat forces. Mission efficiency has become as important as mission effectiveness, and this has led to interest in small, autonomous cost efficient weapons [1,2].

It is very difficult to achieve high lethality with smaller weapons. In order to get desired lethality an alternative way is to use cooperative behavior to bring multiple munitions to bear on critical targets.

A RAND study examined rationale for cooperative behavior between Proliferated Autonomous Weapons (PRAWNS) equipped with near-term automatic target recognition systems [2]. A swarming algorithm was used to implement the desired cooperative behavior. Their study showed that communications, Automatic Target Recognition (ATR) and sensors and navigation system are required to implement the swarming munition concept. This study showed that by allowing communications between swarm weapons, a group of individually less capable weapons may show capabilities that can exceed those conventional systems with no communication. The munitions in their study have no possibility of encountering false targets. According to Jacques, false target attacks need to be taken into consideration when evaluating the effectiveness of autonomous wide area search munitions [3]. Some false target attacks are inevitable due to the stochastic nature of the ATR process. Therefore, false target attacks must be considered as a degrading parameter for effectiveness in autonomous wide area search munitions.

Gillen developed a decision methodology for cooperative behavior and evaluated the effectiveness of it against a baseline of non-cooperative munitions [4,5]. His study showed that loss of lethality due to a smaller warhead can be overcome by applying cooperative engagement to the wide area search munitions.

In his study, Dunkel showed that cooperative behavior does not always improve the effectiveness of the wide area search munitions [1]. The amount of improvement or degradation depends on the form of cooperative behavior and the specific scenario. Park studied the validity of simulations for wide area search munitions [6]. His study show that a properly designed wide area search munition simulation can be effectively used to predict the performance of these munitions under prescribed conditions.

The Primary objective of this study is to investigate and compare the effectiveness of wide-area search munitions using cooperative and non cooperative behavior algorithms under various scenarios.

For this research a computer simulation is used to model multiple autonomous wide area search munitions that search, classify and attack targets. Within the search area both real and false targets are uniformly distributed. For predetermined battlefield characteristics both non-cooperative and cooperative cases are examined. In the non-cooperative cases autonomous munitions are not allowed to communicate with each other. Hence each individual munition needs to independently search, classify and decide either to attack the classified target or continue to search for new targets.

In the cooperative cases communication between the munitions are allowed. Individual munitions broadcast information regarding classification and attacks to the other agents of the group so every munition can be informed as to the progress of the all munitions. By using this shared information munitions cooperatively classify and decide whether an attack should be made on the target. Cooperative decision logic can also be used to determine which munitions attack classified targets and which continue to search. In this research all targets and non-targets are modeled as stationary. Various cooperative and non-cooperative scenarios are studied using 4 and 8 munition groups.

2. AUTONOMOUS WIDE AREA SEARCH MUNITIONS

Wide area search munitions can be described as autonomous vehicles which have the ability to carry warheads, relatively small onboard sensors to detect and classify targets, navigation systems (INS/GPS) to navigate through the search area, and communication systems to communicate with each other. In this research the munitions carry a single warhead that destroys the munition once detonated; they do not have the ability to drop individual bombs on targets. The Low Cost Autonomous Attack System (LOCAAS) is a very good example of wide area search vehicles that are under development.[7].

The most significant factors for overall performance of cooperative wide area search munitions are the communication, Automatic Target Recognition (ATR), and warhead lethality. According to Jacques [8] False Target Attack Rate (FTAR) and probability of target report (P_{TR}) are the most important measures of ATR performance. FTAR can be defined as the average rate (/km^2) at which munitions would falsely declare targets if the seeker were flown in a non-commit mode. P_{TR} is the probability of a correct Target Report given that a valid target is encountered in the search area. Some classical work in the area of optimal search has been done by Koopman [9] and Washburn [10]. Probabilities for successful search and attack will be examined in detail for single munition/single target, single munition/multi-target, and multi-munition/multi-target cases based on Jacques' studies [3,11]. Prior to defining the probabilities of mission success it is necessary to discuss the ATR algorithm in greater detail.

2.1.ATR Algorithm

The performance of an ATR system is determined by its' ability to make the right decision when verifying the type of object (target or non-target) that has been encountered. The process of making the right decision given target encounter is quantified by the probability of target report (P_{TR}). Jacques described the relationship of these probabilities and other ATR measures using a confusion matrix [11]. A confusion matrix expresses *a priori* probabilities for discriminating between targets and non targets. A binary confusion matrix is shown in Table 1 for the single target case [1].

Table 1 shows only a single target type. In addition to P_{TR}, the confusion matrix requires the specification of $P_{FTA|E}$, the probability of false target attack given encounter.

Table 1. Binary Confusion Matrix(1).

DECLARED OBJECT	ENCOUNTERED OBJECT	
	Target	Non-Target
Target	P_{TR}	$P_{FTA\|E}$
Non-Target	$1-P_{TR}$	$1-P_{FTA\|E}$

2.2 Probabilities for Successful Search and Attack
2.2.1 Single Munition Single Target Case
When a munition searches an area it is only able to see the part of the search area under its sensor footprint, assumed to be constant width in this research. A sample search pattern for the single munition/single target case is shown in Figure 1. For the simplest case, the search area, A_S, contains a single target. Targets are considered as uniformly distributed within the search area in a Poisson field of false targets.

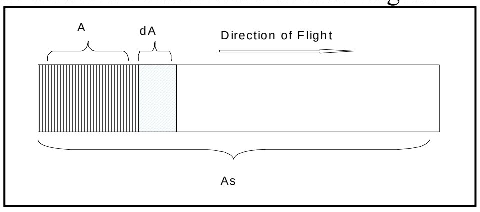

Figure 1. Sample Search Pattern

The probability of mission success for the single munition, single target case can be expressed as:

$$P_{MS} = P_K \cdot P_{TR} \cdot P_E \quad (2.1)$$

where

P_K = the probability of target kill given that the target is classified as a valid target.

P_{TR} = probability of target report given the target is in the sensor footprint.

P_E = the probability the target will be encountered in the search area.

In order to obtain the probability of mission success P_K, P_{TR}, and P_E values have to be determined. P_K, can be expressed as single numerical values depending on the warhead lethality, and P_{TR} can be derived from the confusion matrix tables.

The probability that the munition will encounter the target given that the target is in the search area, P_E, can be determined from an integral formulation using the probabilities that the munition has not made previous false target declarations in the already searched area, $P_{\overline{FA}}$, and the probability that the target is contained in the area dA.

$$P_{\overline{FA}} = e^{-\alpha A} \quad (2.2)$$

$$P_c(dA) = \eta_t \cdot dA \quad (2.3)$$

where α is the false target attack rate and the η_t is the average target density for the search area. For the single target case, $\eta_t = 1/A_S$. False target attack rate is the expected rate of false target declarations for the Sensor/ATR algorithm. It can be formulated as the product of the probability that the munition will attack a false target given that it has been encountered, ($P_{FTA|E}$), and the expected probability density of false targets (η_{FT}).

$$\alpha = \eta_{FT} \cdot P_{FTA|E} \quad (2.4)$$

Therefore, the incremental probability that the munition will encounter the target in area dA can be expressed as:

$$\Delta P_E(A) = \frac{e^{-\alpha A}}{A_s} . dA \quad (2.5)$$

The probability that the munition will encounter the target in the total search area can be obtained by integrating equation 2.5 over the search area A_S yielding:

$$P_E(A_s) = \frac{1 - e^{-\alpha A_s}}{\alpha \cdot A_s} \quad (2.6)$$

2.2.2 Outcome Trees. An outcome tree for the single munition/single target scenario showing the possible outcomes and their likelihoods is shown in Figure 2 [1]. Solid lines represent desired outcomes, and dashed lines are the negative outcomes.

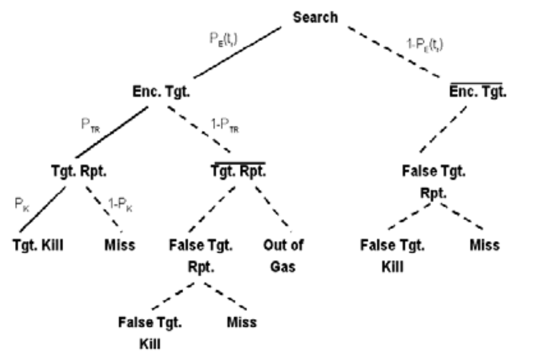

Figure 2. Outcome Tree for Autonomous Search (1).

The likelihood of any specific outcome can be determined by simply taking the product of the possibilities along the path of that branch. The probability of successful search is the left branch of the outcome tree. Analytically it can be shown as:

$$P_{SS} = P_K . P_{TR}. P_E = P_{MS} = P_K . P_{TR}. \frac{1-e^{-\alpha A_s}}{\alpha . A_s} \quad (2.7)$$

When a target is reported by the ATR of a different munition it may be a real target or a false target. The probability that a second attack on the declared object will result in a successful target kill can be determined by looking at the outcome tree for the attack Figure 3 [3].

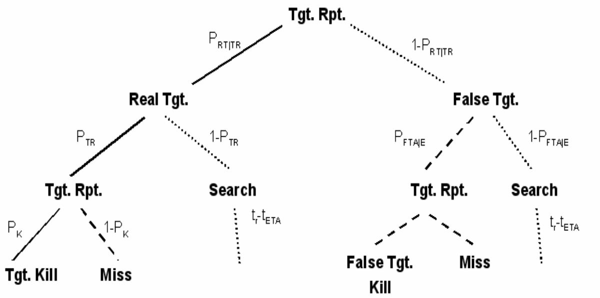

Figure 3. Outcome Tree for Cooperative Attack [1].

The probability of a successful attack, lethal attack on a real target, is the most left branch of the Figure 3.

$$P_{SS} = P_{RT|TR} . P_{TR} . P_K \quad (2.8)$$

where $P_{RT|TR}$ is the probability that a declared target is actually a real target given that it is reported. $P_{RT|TR}$ can be expressed as the ratio of the true target attack rate to total attack rate.

$$P_{RT|TR} = \frac{P_{TR} \cdot \eta_T}{P_{TR} \cdot \eta_T + P_{FTA|E} \cdot \eta_{FT}} \quad (2.9)$$

In the search area there is only one target and once it is not recognized by munition's ATR system, the probability of continuing to search for the target will be zero resulting outcomes of all the other branches to be zero as well.

2.2.3 Single Munition Multi-Target Case

In the case of a single munition searching for different types of targets, all target types are considered valid. Modifications must be made from the set up of the single munition/single target case to handle this scenario. For the single munition/single target case the incremental probability that the munition will encounter the target in area *dA* was shown to be the product of the probabilities that munition has had no false alarms in the already searched area, $P_{\overline{FA}}$, and the target is contained in the area *dA*. For the multi target scenario there are other valid targets in the search area and the incremental probability of target encounter also depends on the probability of not attacking a target within the already search area. This probability can be expressed as:

$$P_{\overline{RT}} = e^{-\eta_t P_{TR} A} \quad (2.10)$$

Thus the incremental probability for target encounter in *dA* is the product of the probability that the munition has had no false alarms in the already searched area, $P_{\overline{FA}}$, the probability that the target is contained in the area *dA*, and the probability of not having a previously declared target within the already search area.

$$\Delta P_E(A) = e^{-(\eta_t P_{TR}+\alpha)A} \cdot \eta_t \cdot dA \quad (2.11)$$

Finally 2.11 can be integrated over the entire area to obtain the total probability of target encounter for the entire search area:

$$P_E(A_S) = \frac{\eta_t}{\eta_t P_{TR} + \alpha} \cdot (1 - e^{-(\eta_t P_{TR}+\alpha)A_s}) \quad (2.12)$$

The probability of target report can be determined by using the confusion matrix. However, since a target encountered by the munition can be classified as *any* type, it cannot be taken directly from the confusion matrix as it was for the single target type case. The probability that an encountered target of type *i* will be declared as a target of any type can be defined as:

$$P_{TRi} = \sum_j P_{TRj|Type\_i} \quad (2.13)$$

where j ranges from one to the number of target types being considered in the ATR algorithm. When a munition encounters a target, the probability that this encountered target will be type *i* can be defined as:

$$P_{Ei} = \frac{\eta_{ti}}{\eta_{total\_tgts}} \quad (2.14)$$

By using equations 2.13 and 2.14 a combined P_{TR} weighted by the average densities of the various target types can then be stated as:

$$P_{TR} = \sum_i P_{TRi} \cdot P_{Ei} \quad (2.15)$$

2.2.4 Multi-Munition Multi-Target Case

The analytical studies for the single munition single/target case can still be applicable to the multi munition/multi target cases. Jacques showed the analytical tools for the multi-munition case with single targets and extension of these to the multi-munition/multi-target case [3]. For the multi-munition/multi-target case, munitions may still search the area individually, so these searches can be considered independently. Probability of successful search is the same as the single munition/single target case. However, munitions can also execute attacks on targets declared by other munitions. By using the outcome tree shown at Figure 3, the probability of a successful attack can be shown as [3]:

$$P_{sa} = P_K \cdot P_{TR} \cdot P_{RT|TR} + P_{SS}(t_r - t_{ETA}) \cdot (1 - P_{TR}) \cdot P_{RT|TR} + P_{SS}(t_r - t_{ETA}) \cdot (1 - P_{FTA|FTE}) \cdot (1 - P_{RT|TR}) \quad (2.16)$$

3. SIMULATION PROGRAM AND MODIFICATIONS

3.1 Original Simulation

The MultiUAV simulation used in this research was developed by AFRL/VACA as a development tool for their research on cooperative vehicles. The original MultiUAV simulation developed by AFRL/VACA was capable of simulating eight vehicles searching an area that contains a maximum of ten targets. Simulated vehicles have embedded flight software (EFS) that can be used to implement cooperative control algorithms and vehicle dynamics. [12].

Simulation begins by the random placement of the targets in the search area and the placement of the autonomous vehicles at their initial positions. The vehicles then fly specified routes to search the area for possible targets. When an object enters a vehicle's field of regard it is detected by the sensor of the vehicle and a classification is made as a real target or a non target. A confidence of correct classification for the object is assigned depending on the angle from which the target is viewed by the vehicle. This confidence level has an effect on the task assignment for cooperative munitions because a specified level of confidence must be attained before any attack can occur.

There are certain tasks that a vehicle can perform after classification of the object. These tasks are assigned in a way to maximize the overall benefit [12,13].

1. Continue searching
2. Attack
3. Reclassify
4. Verify (Battle Damage Assessment (BDA)).

Vehicles continue to perform these assigned tasks until the total simulation time is expired, at which time the simulation terminates. For this research, a total simulation time of 1200 seconds was used.

Currently the simulation uses a Capacitated Transshipment Problem (CTP), a special case of linear programming, to perform the task allocation routine. Tasks are assigned to the munitions in a way that maximizes the overall benefits to the multi-munition system. The capacitated transshipment problem is solved every time when a change occurs in a target state, or when specified time intervals are reached

How Automatic Target Recognition Algorithm works is described in following paragraphs. When a vehicle encounters an object in the original Simulation, it classifies the object based on truth information. It then calculates a confidence level for the classification that has been made depending on the view angle for the object. Vehicles are not allowed to misclassify the objects, thus eliminating any possibility for false target attack. Although we would certainly like to minimize the number of false targets attacks, it is unreasonable to expect that we can entirely eliminate the possibility of occurrence.

Once classified, a calculated confidence level is compared with the predetermined threshold. If the confidence level is less than the threshold another vehicle may be assigned to classify the object depending on the benefit calculation results. Confidence levels for individual vehicles are then combined into a single value and this new metric will be compared to the threshold. The object stays detected but not classified until the confidence becomes greater than the threshold.

It is not possible to have a perfect ATR algorithm. There will be some errors in the ATR system of a real munition and this error should be modeled within the simulation.

When a vehicle executes an attack on a target, the target is considered as dead if the bomb drops within a predetermined radius from the target.

In the original simulation communications are global and reliable. Information is available to all vehicles and there are no errors, loss or bad information broadcasted between the vehicles.

3.2 Simulation Modifications

In order to adapt the simulation program to the objective of this research there were several required modifications. The modifications are listed below:

1. Adding logic to separate sensed information from truth information
2. ATR algorithm modifications
3. Adding warhead lethality options
4. Benefit and task assignment calculations
5. Battle damage assessment
6. Obtaining the desired statistical data

3.2.1 Modifying Maximum Number of Targets.

For the purposes of this research targets are uniformly distributed in a uniform field of false targets. While the analytical results assumed a Poisson field of false targets, this research fixed the number of non-target objects, and uniformly distributed them on the battlefield. In order to employ false targets as well as real targets the maximum number of the targets needed to be increased. The maximum number of targets increased from 10 to 32 to accommodate the desired number of the real targets and false targets.

Distinguishing between the target types and target priorities is also considered an important factor that should be used to evaluate the effectiveness of cooperative behavior. Therefore two high priority and four low priority targets are employed along with 26 false targets, resulting $\eta_{FT} = 0.1$.

3.2.2 Separation of Truth and Sensed Information. In the original simulation truth information is broadcast between vehicles.

In real life it is not certain that truth information will be obtained. There are sometimes errors in identification or loss of information. Dunkel [1] made some modifications; as an extension to this work logic was added to the simulation to further distinguish between truth and sensed information. The simulation keeps track of the sensed information generated by the vehicles as well as the truth information. For the purposes of this research, benefit calculations, task assignments and decisions are made according to sensed information.

3.2.3 Automatic Target Recognition Algorithm Modifications

While evaluating the effectiveness of cooperative behavior in wide area search munitions false target attacks due to the misidentification of objects must be considered as a major performance measure [8]. False target attacks cause the loss of valuable munitions and result in collateral damage, hence raising political and moral implications. ATR errors enter into the simulation program through the confusion matrices as defined in the simulation.

When a vehicle encounters an object, the object will be classified based on the result of a function call which uses true target types, a random number draw and probability entries in the confusion matrix. This final classification is used for benefit calculation and task allocation. By adjusting the probabilities in the confusion matrix different ATR performance levels can be modeled. By letting vehicles misidentify objects the ATR algorithm is more realistic to actual battlefield characteristics.

3.2.4 Warhead Lethality

Modifications were made to implement various low lethality warheads. Fifty percent and eighty percent numbers for warhead lethality are used in both no cooperation and cooperative classification and engagement scenarios. The attack outcome is determined using a random draw and the warhead lethality figure, P_K. P_K represents a probability of kill given initiation of attack, and it includes a composite of guidance accuracy, warhead reliability, and lethality given hit on the target.

When a munition executes an attack on a target, a random draw is made and is compared to the P_K value that is hard coded depending on the scenario. If the random number is less than the probability of kill, then the target is considered as killed. However this information is not passed to the other vehicles since the attacking vehicle is already dead.

3.2.5 Battle Damage Assessment

For the scope of this research the BDA task is eliminated by setting the task value of performing BDA to zero.

3.2.6 Benefit and Task Assignment Calculations

The original simulation uses heuristics benefit calculations. In this research a new benefit calculation method proposed by Dunkel is used [1]. This approach bases the task benefits on the probabilities of successful attack and search. A formula for the calculation of search benefit can be expressed as:

$$\textit{Search Benefit} = \xi \cdot P_{ss} \qquad (3.1)$$

where P_{ss} is the probability of successful search and ξ is a weighting factor. The weighting parameter ξ is the relative advantage of continuing to search for new targets over executing an attack on an already known target, and can vary between 0 and 1. When ξ is 0 the search benefit will be zero and it will never be beneficial to search for additional targets. On the other hand, vehicles will always continue to search for additional targets rather than attacking the known ones when ξ is 1. Dunkel used this weighting function to fine-tune the performance of the cooperative multi-munition system [1].

Various factors affect the task value and probability of a successful attack such as; probability of the target being alive, time needed by the vehicle to reach the target, the probability that the target classification is correct, and different types of targets and target priorities. While the outcomes of previous attacks are known within the simulation, this information is not passed to the other vehicles since the attacking vehicle is already dead. Therefore, the other vehicles only know that an attack has been made on that particular target. One vehicle can execute an attack on a target that has already been attacked by another vehicle, but the probability of a target being alive after *n* previous attack is used as a degrading factor in the benefit calculation. This prevents an excessive number of attacks on already attacked targets. Assuming independent events the probability that a target is still alive after *n* attacks have been made on the target can be expressed as:

$$P_{alive|n\ attacks} = (1 - P_K)^n \qquad (3.2)$$

Varying target priorities is also an important factor that should be considered for attack benefit calculations. For this research two types of real targets are assumed to exist on the battlefield. Target Type 1 is considered a high priority target and Target Type 2 is considered a low priority target. A weighting parameter, β is used in benefit calculations to reflect the value of low priority targets relative to that of high priority targets. When β equals 1 low priority targets will be as valuable as high priority targets, and the benefits of attacking either target will be the same. For this research a fixed value of 0.5 is used for the weighting parameter β. Attack benefit formulas can be expressed as:

Target Type 1:

$$Attack\ Benefit = (1 - \xi) \cdot (1 - P_K)^n \cdot P_{sa} \quad (3.3)$$

Target Type 2:

$$Attack\ Benefit = (1 - \xi) \cdot \beta \cdot (1 - P_K)^n \cdot P_{sa} \quad (3.4)$$

Non-Target (False Target): $Attack\ Benefit = 0$ (3.5)

where $(1 - \xi)$ is the weighting parameter associated with attacking a target rather than continuing to search for additional targets.

3.2.7 Obtaining the Desired Statistical Data and Other Modifications

In order to obtain the desired statistical data some modifications were made. For the purposes of this study, the number of real targets kills, number of false targets kills, number of attacks executed on real and false targets and number of total attacks (including multiple attacks on a target or false target) were gathered. And other modifications were made to reach the desired information.

4. SIMULATION RESULTS AND ANALYSIS

In this research the effectiveness of autonomous wide area search munitions is investigated by applying cooperative and non-cooperative behavior algorithms under various scenarios. These scenarios are defined by several parameters:

1. Warhead lethality
2. ATR performance
3. Search weight
4. Number of munitions and targets
5. False target attack rate (FTAR)

Other parameters such as search rate and search patterns are held constant in this research. While warhead lethality, and ATR capability depend on the munition's technical features, the number of munitions and search weight are determined by the operational concepts and tactics.

Two other characteristics related to the search area (battlefield) specifications are the target and false target densities. These densities are kept constant with six real targets (two Type 1, four Type 2) and 26 false targets in the search area. The specific parameters that are varied in the simulation are shown in Table 2.

Table 2. Specific Simulation Parameters

P_K	Probability of kill	0.5, 0.8
P_{TR}	Probability of target report	0.8, 0.95
FTAR	False target attack rate	0.002, 0.02
N_M	Number of munitions	4, 8
ξ	Search weight	0.25, 0.42

The number of attacks made by munitions on real or false targets and the lethality of those attacks are the key elements for mission success and effectiveness, and subsequently the performance of cooperative and non-cooperative wide area search munitions. The specific responses selected are number of killed targets, total number of attacks on false targets, total number of attacks, number of false targets attacked, number of real targets attacked, and the number of attacks executed on high and low priority targets.

Cooperative cases and non-cooperative cases are considered under the same conditions and parameters through various scenarios.

4.1 Warhead Lethality Effects

Warhead lethality is one of the most important factors in determining the performance of the munitions. Table 3 shows the performance of cooperative and non-cooperative behavior for a low warhead lethality ($P_K = 0.5$). Except in three of the scenarios, non-cooperative behavior resulted in more real target kills than the cooperative behavior. Cooperative behavior did not improve the number of killed targets; actually there is a decrease in number of kills between 2 to 57 percent through the different scenarios. These results are similar to those of Dunkel [1].

Table 3. Number of Killed Targets/False Target Attacks at Low Warhead Lethality

					No-cooperation		Cooperation		# of Kills	False Target
P_K	FTAR	#Munition	P_{TR}	Weight ξ	# of Kills	# of FTA	# of Kills	# of FTA	Improvement	Attack Decrease
0.5	0.002	4	0.8	0.42	0.5500	0.1000	0.2833	0	-48.5%	-100.0%
				0.25	1.2333	0.2000	0.7333	0	-40.5%	-100.0%
			0.95	0.42	0.6500	0.0667	0.4500	0	-30.8%	-100.0%
				0.25	1.3667	0.1833	1.0833	0	-20.7%	-100.0%
		8	0.8	0.42	0.8667	0.2500	0.4500	0	-48.1%	-100.0%
				0.25	2.2167	0.5333	1.4500	0	-34.6%	-100.0%
			0.95	0.42	0.9500	0.2833	0.6167	0	-35.1%	-100.0%
				0.25	2.5833	0.4333	2.1333	0	-17.4%	-100.0%
	0.02	4	0.8	0.42	0.5000	1.0667	0.2167	0.1667	-56.7%	-84.4%
				0.25	0.8000	1.7667	0.6667	0.2667	-16.7%	-84.9%
			0.95	0.42	0.6333	1.0000	0.2833	0.1500	-55.3%	-85.0%
				0.25	0.9333	1.6500	0.9500	0.2833	1.8%	-82.8%
		8	0.8	0.42	0.8500	2.4000	0.4167	0.3000	-51.0%	-87.5%
				0.25	1.6000	3.5667	1.6667	0.5167	4.2%	-85.5%
			0.95	0.42	0.8667	2.3833	0.5167	0.2167	-40.4%	-90.9%
				0.25	1.8333	3.2500	1.8667	0.6333	1.8%	-80.5%
OVERALL PREFORMANCE					1.152083	1.195833	0.861458333	0.15833333	-25.2%	-86.8%

Cooperative behavior has significantly decreased the number of False Target Attacks (FTA). While non-cooperative munitions attack significant numbers of false targets, the cooperative munitions execute very few attacks on false targets. Since cooperative munitions classify targets cooperatively, the effective false target attack rate is reduced. There is an 86.8% decrease in the false target attacks as a result of cooperative behavior. This is a promising improvement for wide area search munitions.

Table 4 shows the performance of cooperative and non-cooperative behavior for high warhead lethality ($P_K = 0.8$). Cooperative behavior was less beneficial in high warhead lethality cases than it was for low lethality cases.

Table 4 Number of Killed Targets/False Target Attacks at High Warhead Lethality

					No-cooperation		Cooperation		# of Kills	False Target
P_K	FTAR	#Munition	P_{TR}	Weight ξ	# of Kills	# of FTA	# of Kills	# of FTA	Improvement	Attack Decrease
0.8	0.002	4	0.8	0.42	0.8167	0.1000	0.4333	0	-46.9%	-100.0%
				0.25	2.0167	0.2167	1.1833	0	-41.3%	-100.0%
			0.95	0.42	1.0333	0.0667	0.6600	0	-37.1%	-100.0%
				0.25	2.2833	0.2000	1.6167	0	-29.2%	-100.0%
		8	0.8	0.42	1.2333	0.2500	0.7167	0	-41.9%	-100.0%
				0.25	3.1667	0.4333	2.2500	0	-28.9%	-100.0%
			0.95	0.42	1.4333	0.2833	0.9667	0	-32.6%	-100.0%
				0.25	3.8833	0.3667	3.0333	0	-21.9%	-100.0%
	0.02	4	0.8	0.42	0.7167	1.0667	0.3667	0.1667	-48.8%	-84.4%
				0.25	1.4667	1.8167	1.0500	0.2667	-28.4%	-85.3%
			0.95	0.42	0.9167	1.0000	0.4833	0.1500	-47.3%	-85.0%
				0.25	1.7000	1.6833	1.4500	0.2333	-14.7%	-86.1%
		8	0.8	0.42	1.1667	2.4000	0.6833	0.3000	-41.4%	-87.5%
				0.25	2.7667	3.5667	2.2000	0.5667	-20.5%	-84.1%
			0.95	0.42	1.3000	2.3833	0.8833	0.2167	-32.1%	-90.9%
				0.25	3.0833	3.1833	2.5333	0.4667	-17.8%	-85.3%
OVERALL PREFORMANCE					1.811458	1.188542	1.28125	0.14791667	-29.3%	-87.6%

4.2 ATR Capability Effects

The automatic target recognition system is used by munitions to identify the object they encounter while searching the battlefield for valid targets. The ability of a munition to correctly identify the objects is defined by the probability of target report (P_{TR}). The effects of P_{TR} on the performance of the cooperative and non-cooperative munitions will be discussed.

The performance of cooperative and non-cooperative behavior for low ATR capability ($P_{TR} = 0.8$) is shown in Table 5, and high ATR capability ($P_{TR} = 0.95$) is shown in Table 6.

Table 5. Number of Killed Targets/False Target Attacks at Low ATR Capability

					No-cooperation		Cooperation		# of Kills	False Target
P_{TR}	P_K	FTAR	#Munition	Weight ξ	# of Kills	# of FTA	# of Kills	# of FTA	Improvement	Attack Decrease
0.8	0.5	0.002	4	0.42	0.5500	0.1000	0.2833	0	-48.5%	-100.0%
				0.25	1.2333	0.2000	0.7333	0	-40.5%	-100.0%
			8	0.42	0.8667	0.2500	0.4500	0	-48.1%	-100.0%
				0.25	2.2167	0.5333	1.4500	0	-34.6%	-100.0%
		0.02	4	0.42	0.8167	0.1000	0.4333	0	-46.9%	-100.0%
				0.25	2.0167	0.2167	1.1833	0	-41.3%	-100.0%
			8	0.42	1.2333	0.2500	0.7167	0	-41.9%	-100.0%
				0.25	3.1667	0.4333	2.2500	0	-28.9%	-100.0%
	0.8	0.002	4	0.42	0.5000	1.0667	0.2167	0.1667	-56.7%	-84.4%
				0.25	0.8000	1.7667	0.6667	0.2667	-16.7%	-84.9%
			8	0.42	0.8500	2.4000	0.4167	0.3000	-51.0%	-87.5%
				0.25	1.6000	3.5667	1.6667	0.5167	4.2%	-85.5%
		0.02	4	0.42	0.7167	1.0667	0.3667	0.1667	-48.8%	-84.4%
				0.25	1.4667	1.8167	1.0500	0.2667	-28.4%	-85.3%
			8	0.42	1.1667	2.4000	0.6833	0.3000	-41.4%	-87.5%
				0.25	2.7667	3.5667	2.2000	0.5667	-20.5%	-84.1%
OVERALL PREFORMANCE					1.372917	1.233333	0.922916667	0.159375	-32.8%	-87.1%

Table 6. Number of Killed Targets/False Target Attacks at High ATR Capability

					No-cooperation		Cooperation		# of Kills	False Target
P_{TR}	P_K	FTAR	#Munition	Weight ξ	# of Kills	# of FTA	# of Kills	# of FTA	Improvement	Attack Decrease
0.95	0.5	0.002	4	0.42	0.6500	0.0667	0.4500	0	-30.8%	-100.0%
				0.25	1.3667	0.1833	1.0833	0	-20.7%	-100.0%
			8	0.42	0.9500	0.2833	0.6167	0	-35.1%	-100.0%
				0.25	2.5833	0.4333	2.1333	0	-17.4%	-100.0%
		0.02	4	0.42	1.0333	0.0667	0.6500	0	-37.1%	-100.0%
				0.25	2.2833	0.2000	1.6167	0	-29.2%	-100.0%
			8	0.42	1.4333	0.2833	0.9667	0	-32.6%	-100.0%
				0.25	3.8833	0.3667	3.0333	0	-21.9%	-100.0%
	0.8	0.002	4	0.42	0.6333	1.0000	0.2833	0.1500	-55.3%	-85.0%
				0.25	0.9333	1.6500	0.9500	0.2833	1.8%	-82.8%
			8	0.42	0.8667	2.3833	0.5167	0.2167	-40.4%	-90.9%
				0.25	1.8333	3.2500	1.8667	0.6333	1.8%	-80.5%
		0.02	4	0.42	0.9167	1.0000	0.4833	0.1500	-47.3%	-85.0%
				0.25	1.7000	1.6833	1.4500	0.2333	-14.7%	-86.1%
			8	0.42	1.3000	2.3833	0.8833	0.2167	-32.1%	-90.9%
				0.25	3.0833	3.1833	2.5333	0.4667	-17.8%	-85.3%
OVERALL PREFORMANCE					1.590625	1.151042	1.219791667	0.146875	-23.3%	-87.2%

The high ATR capability scenarios for both non-cooperative and cooperative munitions achieved better results as compared to the low ATR capability cases. ATR systems with high P_{TR} produce more certain classification of the objects leading to a reduction in missed targets. Of note, cooperative behavior was more beneficial for cases of high P_{TR} than it was for low P_{TR}.

4.3 Effects of Number of Munitions

The performance of cooperative and non-cooperative behavior for 4 and 8 munitions is examined. Simulation results for 4 munition scenarios are shown in Table 7, and the 8 munition results are shown in Table 8. It is seen that there is 32.5% percent decrease in number of targets killed and 86.2% less false targets attacks for 4 munitions scenarios and 24.9% percent decrease in number of targets and 87.6% less false targets attacks for 8 munitions scenarios.

Table 7. Number of Killed Targets/False Target Attacks for 4 Munitions

					No-cooperation		Cooperation		# of Kills	False Target
#Munition	FTAR	P_K	P_{TR}	Weight ξ	# of Kills	# of FTA	# of Kills	# of FTA	Improvement	Attack Decrease
4	0.002	0.5	0.8	0.42	0.5500	0.1000	0.283333	0	-48.5%	-100.0%
				0.25	1.2333	0.2000	0.733333	0	-40.5%	-100.0%
			0.95	0.42	0.6500	0.0667	0.45	0	-30.8%	-100.0%
				0.25	1.3667	0.1833	1.083333	0	-20.7%	-100.0%
		0.8	0.8	0.42	0.8167	0.1000	0.433333	0	-46.9%	-100.0%
				0.25	2.0167	0.2167	1.183333	0	-41.3%	-100.0%
			0.95	0.42	1.0333	0.0667	0.65	0	-37.1%	-100.0%
				0.25	2.2833	0.2000	1.616667	0	-29.2%	-100.0%
	0.02	0.5	0.8	0.42	0.5000	1.0667	0.216667	0.166667	-56.7%	-84.4%
				0.25	0.8000	1.7667	0.666667	0.266667	-16.7%	-84.9%
			0.95	0.42	0.6333	1.0000	0.283333	0.15	-55.3%	-85.0%
				0.25	0.9333	1.6500	0.95	0.283333	1.8%	-82.8%
		0.8	0.8	0.42	0.7167	1.0667	0.366667	0.166667	-48.8%	-84.4%
				0.25	1.4667	1.8167	1.05	0.266667	-28.4%	-85.3%
			0.95	0.42	0.9167	1.0000	0.483333	0.15	-47.3%	-85.0%
				0.25	1.7000	1.6833	1.45	0.233333	-14.7%	-86.1%
OVERALL PREFORMANCE					1.101042	0.761458	0.74375	0.105208	-32.5%	-86.2%

Table 8. Number of Killed Targets/False Target Attacks for 8 Munitions

					No-cooperation		Cooperation		# of Kills	False Target
#Munition	FTAR	P_K	P_{TR}	Weight ξ	# of Kills	# of FTA	# of Kills	# of FTA	Improvement	Attack Decrease
8	0.002	0.5	0.8	0.42	0.8667	0.2500	0.4500	0	-48.1%	-100.0%
				0.25	2.2167	0.5333	1.4500	0	-34.6%	-100.0%
			0.95	0.42	0.9500	0.2833	0.6167	0	-35.1%	-100.0%
				0.25	2.5833	0.4333	2.1333	0	-17.4%	-100.0%
		0.8	0.8	0.42	1.2333	0.2500	0.7167	0	-41.9%	-100.0%
				0.25	3.1667	0.4333	2.2500	0	-28.9%	-100.0%
			0.95	0.42	1.4333	0.2833	0.9667	0	-32.6%	-100.0%
				0.25	3.8833	0.3667	3.0333	0	-21.9%	-100.0%
	0.02	0.5	0.8	0.42	0.8500	2.4000	0.4167	0.3000	-51.0%	-87.5%
				0.25	1.6000	3.5667	1.6667	0.5167	4.2%	-85.5%
			0.95	0.42	0.8667	2.3833	0.5167	0.2167	-40.4%	-90.9%
				0.25	1.8333	3.2500	1.8667	0.6333	1.8%	-80.5%
		0.8	0.8	0.42	1.1667	2.4000	0.6833	0.3000	-41.4%	-87.5%
				0.25	2.7667	3.5667	2.2000	0.5667	-20.5%	-84.1%
			0.95	0.42	1.3000	2.3833	0.8833	0.2167	-32.1%	-90.9%
				0.25	3.0833	3.1833	2.5333	0.4667	-17.8%	-85.3%
OVERALL PREFORMANCE					1.8625	1.622917	1.398958	0.201042	-24.9%	-87.6%

The ratio of killed targets to the number of munitions represents the effectiveness of the munitions. For non-cooperative 4 munition and 8 munition scenarios, the effectiveness is 27.5% and 23.2% respectively. And for cooperative 4 and 8 munition scenarios the effectiveness of the munition is 18.5% and 17.4% respectively. The effectiveness of munitions for both cooperative and non-cooperative 8 munitions scenarios is lower than the 4 munition scenarios. Note, however, that there is less of a reduction in effectiveness due to the cooperation when greater numbers of munitions are available.

4.4 Search Weight Effects

Table 9 shows the performance of cooperative and non- cooperative behavior when they operate under low search weight, and Table 10 shows similar results for the cases where a high search weight was used. It is seen that search weight has a very important effect on the number of attacks for both cooperative and non-cooperative munition performance.

At low search weight both no cooperation and cooperation execute more attacks on targets than they do for high search weights. It is seen that high search weight has decreased the number of killed targets drastically. This is due to the fact that munitions prefer to continue to search for additional targets instead of attacking the already known ones.

Table 9. Number of Killed Targets/False Target Attacks at Low Search Weight

					No-cooperation		Cooperation		# of Kills	False Target
Weight ξ	P_K	FTAR	#Munition	P_{TR}	# of Kills	# of FTA	# of Kills	# of FTA	Improvement	Attack Decrease
0.25	0.5	0.002	4	0.8	1.2333	0.2000	0.7333	0.0000	-40.5%	-100.0%
				0.95	1.3667	0.1833	1.0833	0.0000	-20.7%	-100.0%
			8	0.8	2.2167	0.5333	1.4500	0.0000	-34.6%	-100.0%
				0.95	2.5833	0.4333	2.1333	0.0000	-17.4%	-100.0%
		0.02	4	0.8	2.0167	0.2167	1.1833	0.0000	-41.3%	-100.0%
				0.95	2.2833	0.2000	1.6167	0.0000	-29.2%	-100.0%
			8	0.8	3.1667	0.4333	2.2500	0.0000	-28.9%	-100.0%
				0.95	3.8833	0.3667	3.0333	0.0000	-21.9%	-100.0%
	0.8	0.002	4	0.8	0.8000	1.7667	0.6667	0.2667	-16.7%	-84.9%
				0.95	0.9333	1.6500	0.9500	0.2833	1.8%	-82.8%
			8	0.8	1.6000	3.5667	1.6667	0.5167	4.2%	-85.5%
				0.95	1.8333	3.2500	1.8667	0.6333	1.8%	-80.5%
		0.02	4	0.8	1.4667	1.8167	1.0500	0.2667	-28.4%	-85.3%
				0.95	1.7000	1.6833	1.4500	0.2333	-14.7%	-86.1%
			8	0.8	2.7667	3.5667	2.2000	0.5667	-20.5%	-84.1%
				0.95	3.0833	3.1833	2.5333	0.4667	-17.8%	-85.3%
OVERALL PREFORMANCE					2.0583	1.4406	1.6167	0.2021	-21.5%	-86.0%

Table 10. Number of Killed Targets/False Target Attacks at High Search Weight

					No-cooperation		Cooperation		# of Kills	False Target
Weight ξ	P_K	FTAR	#Munition	P_{TR}	# of Kills	# of FTA	# of Kills	# of FTA	Improvement	Attack Decrease
0.42	0.5	0.002	4	0.8	0.5500	0.1000	0.2833	0.0000	-48.5%	-100.0%
				0.95	0.6500	0.0667	0.4500	0.0000	-30.8%	-100.0%
			8	0.8	0.8667	0.2500	0.4500	0.0000	-48.1%	-100.0%
				0.95	0.9500	0.2833	0.6167	0.0000	-35.1%	-100.0%
		0.02	4	0.8	0.8167	0.1000	0.4333	0.0000	-46.9%	-100.0%
				0.95	1.0333	0.0667	0.6500	0.0000	-37.1%	-100.0%
			8	0.8	1.2333	0.2500	0.7167	0.0000	-41.9%	-100.0%
				0.95	1.4333	0.2833	0.9667	0.0000	-32.6%	-100.0%
	0.8	0.002	4	0.8	0.5000	1.0667	0.2167	0.1667	-56.7%	-84.4%
				0.95	0.6333	1.0000	0.2833	0.1500	-55.3%	-85.0%
			8	0.8	0.8500	2.4000	0.4167	0.3000	-51.0%	-87.5%
				0.95	0.8667	2.3833	0.5167	0.2167	-40.4%	-90.9%
		0.02	4	0.8	0.7167	1.0667	0.3667	0.1667	-48.8%	-84.4%
				0.95	0.9167	1.0000	0.4833	0.1500	-47.3%	-85.0%
			8	0.8	1.1667	2.4000	0.6833	0.3000	-41.4%	-87.5%
				0.95	1.3000	2.3833	0.8833	0.2167	-32.1%	-90.9%
OVERALL PREFORMANCE					0.9052	0.9438	0.5260	0.1042	-41.9%	-89.0%

4.5 False Target Attack Rate Effects

Table 11 shows the performance of cooperative and non-cooperative behavior at low FTAR values and Table 12 shows the comparative performance for a higher FTAR value. As it can be seen from the table non-cooperative behavior killed more targets than the cooperative behavior. On the other hand cooperative behavior executes very few false target attacks. This is a very important consideration for cooperative algorithms.

Table 11. Number of Killed Targets/False Target Attacks at Low FTAR

					No-cooperation		Cooperation		# of Kills	False Target
FTAR	P_K	#Munition	P_{TR}	Weight ξ	# of Kills	# of FTA	# of Kills	# of FTA	Improvement	Attack Decrease
0.002	0.5	4	0.8	0.42	0.5500	0.1000	0.2833	0.0000	-48.5%	-100.0%
				0.25	1.2333	0.2000	0.7333	0.0000	-40.5%	-100.0%
			0.95	0.42	0.6500	0.0667	0.4500	0.0000	-30.8%	-100.0%
				0.25	1.3667	0.1833	1.0833	0.0000	-20.7%	-100.0%
		8	0.8	0.42	0.8667	0.2500	0.4500	0.0000	-48.1%	-100.0%
				0.25	2.2167	0.5333	1.4500	0.0000	-34.6%	-100.0%
			0.95	0.42	0.9500	0.2833	0.6167	0.0000	-35.1%	-100.0%
				0.25	2.5833	0.4333	2.1333	0.0000	-17.4%	-100.0%
	0.8	4	0.8	0.42	0.8167	0.1000	0.4333	0.0000	-46.9%	-100.0%
				0.25	2.0167	0.2167	1.1833	0.0000	-41.3%	-100.0%
			0.95	0.42	1.0333	0.0667	0.6500	0.0000	-37.1%	-100.0%
				0.25	2.2833	0.2000	1.6167	0.0000	-29.2%	-100.0%
		8	0.8	0.42	1.2333	0.2500	0.7167	0.0000	-41.9%	-100.0%
				0.25	3.1667	0.4333	2.2500	0.0000	-28.9%	-100.0%
			0.95	0.42	1.4333	0.2833	0.9667	0.0000	-32.6%	-100.0%
				0.25	3.8833	0.3667	3.0333	0.0000	-21.9%	-100.0%
OVERALL PREFORMANCE					1.6427	0.2479	1.1281	0.0000	-31.3%	-100.0%

This may indicate that for moderate to high FTAR rate cooperative behavior can improve the overall performance by reducing the number of false target attacks, leaving more munitions available to find and attack real targets.

Table 12. Number of Killed Targets/False Target Attacks at High FTAR

					No-cooperation		Cooperation		# of Kills	False Target
FTAR	P_K	#Munition	P_{TR}	Weight ξ	# of Kills	# of FTA	# of Kills	# of FTA	Improvement	Attack Decrease
0.02	0.5	4	0.8	0.42	0.5000	1.0667	0.2167	0.1667	-56.7%	-84.4%
				0.25	0.8000	1.7667	0.6667	0.2667	-16.7%	-84.9%
			0.95	0.42	0.6333	1.0000	0.2833	0.1500	-55.3%	-85.0%
				0.25	0.9333	1.6500	0.9500	0.2833	1.8%	-82.8%
		8	0.8	0.42	0.8500	2.4000	0.4167	0.3000	-51.0%	-87.5%
				0.25	1.6000	3.5667	1.6667	0.5167	4.2%	-85.5%
			0.95	0.42	0.8667	2.3833	0.5167	0.2167	-40.4%	-90.9%
				0.25	1.8333	3.2500	1.8667	0.6333	1.8%	-80.5%
	0.8	4	0.8	0.42	0.7167	1.0667	0.3667	0.1667	-48.8%	-84.4%
				0.25	1.4667	1.8167	1.0500	0.2667	-28.4%	-85.3%
			0.95	0.42	0.9167	1.0000	0.4833	0.1500	-47.3%	-85.0%
				0.25	1.7000	1.6833	1.4500	0.2333	-14.7%	-86.1%
		8	0.8	0.42	1.1667	2.4000	0.6833	0.3000	-41.4%	-87.5%
				0.25	2.7667	3.5667	2.2000	0.5667	-20.5%	-84.1%
			0.95	0.42	1.3000	2.3833	0.8833	0.2167	-32.1%	-90.9%
				0.25	3.0833	3.1833	2.5333	0.4667	-17.8%	-85.3%
OVERALL PREFORMANCE					1.3208	2.1365	1.0146	0.3063	-23.2%	-85.7%

4.6 Discrimination between Target Types

Figure 4 shows the ratio of high priority attacks to total real target attacks for cooperative and non-cooperative munitions for low FTAR value scenarios.

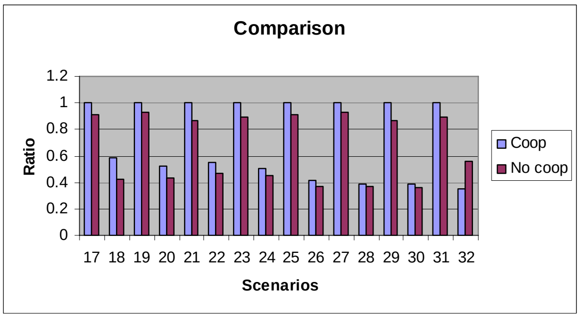

Figure 4. Comparisons of Ratio of High Priority Attacks to Total Real Target Attacks

Cooperative munitions attack high priority targets at a higher ratio than the non-cooperative munitions. This is an important improvement in favor of cooperative behavior.

4.7 Overall results

As discussed before non-cooperative munitions perform better than the cooperative munitions in terms of number of killed targets, and cooperative munitions reduced the number of false target attacks to near zero! Table 13 shows the overall results of all scenarios for number of killed targets and number of attacks executed on the false targets. Non-cooperative munitions executed more attacks on both real targets and false targets, resulting in more killed targets and false targets attacks and kills. Cooperative behavior in wide area search munitions did not improve the number of targets killed, but decreased the number of false targets attacks significantly compared to non-cooperative behavior. Cooperative behavior decreased the number of killed targets by 27.7% and also decreased the false target attacks by 87.2%. The decrease in false target attacks is a promising improvement for cooperative behavior algorithms in wide area search munitions.

Table 13. Number of Killed Targets/False Target Attacks for Overall Simulation Results

					No-cooperation		Cooperation		# of Kills	False Target
P_K	FTAR	#Munition	P_{TR}	Weight ξ	# of Kills	# of FTA	# of Kills	# of FTA	Improvement	Attack Decrease
0.5	0.002	4	0.8	0.42	0.5500	0.1000	0.2833	0	-48.5%	-100.0%
				0.25	1.2333	0.2000	0.7333	0	-40.5%	-100.0%
			0.95	0.42	0.6500	0.0667	0.4500	0	-30.8%	-100.0%
				0.25	1.3667	0.1833	1.0833	0	-20.7%	-100.0%
		8	0.8	0.42	0.8667	0.2500	0.4500	0	-48.1%	-100.0%
				0.25	2.2167	0.5333	1.4500	0	-34.6%	-100.0%
			0.95	0.42	0.9500	0.2833	0.6167	0	-35.1%	-100.0%
				0.25	2.5833	0.4333	2.1333	0	-17.4%	-100.0%
	0.02	4	0.8	0.42	0.5000	1.0667	0.2167	0.1667	-56.7%	-84.4%
				0.25	0.8000	1.7667	0.6667	0.2667	-16.7%	-84.9%
			0.95	0.42	0.6333	1.0000	0.2833	0.1500	-55.3%	-85.0%
				0.25	0.9333	1.6500	0.9500	0.2833	1.8%	-82.8%
		8	0.8	0.42	0.8500	2.4000	0.4167	0.3000	-51.0%	-87.5%
				0.25	1.6000	3.5667	1.6667	0.5167	4.2%	-85.5%
			0.95	0.42	0.8667	2.3833	0.5167	0.2167	-40.4%	-90.9%
				0.25	1.8333	3.2500	1.8667	0.6333	1.8%	-80.5%
0.8	0.002	4	0.8	0.42	0.8167	0.1000	0.4333	0	-46.9%	-100.0%
				0.25	2.0167	0.2167	1.1833	0	-41.3%	-100.0%
			0.95	0.42	1.0333	0.0667	0.6500	0	-37.1%	-100.0%
				0.25	2.2833	0.2000	1.6167	0	-29.2%	-100.0%
		8	0.8	0.42	1.2333	0.2500	0.7167	0	-41.9%	-100.0%
				0.25	3.1667	0.4333	2.2500	0	-28.9%	-100.0%
			0.95	0.42	1.4333	0.2833	0.9667	0	-32.6%	-100.0%
				0.25	3.8833	0.3667	3.0333	0	-21.9%	-100.0%
	0.02	4	0.8	0.42	0.7167	1.0667	0.3667	0.1667	-48.8%	-84.4%
				0.25	1.4667	1.8167	1.0500	0.2667	-28.4%	-85.3%
			0.95	0.42	0.9167	1.0000	0.4833	0.1500	-47.3%	-85.0%
				0.25	1.7000	1.6833	1.4500	0.2333	-14.7%	-86.1%
		8	0.8	0.42	1.1667	2.4000	0.6833	0.3000	-41.4%	-87.5%
				0.25	2.7667	3.5667	2.2000	0.5667	-20.5%	-84.1%
			0.95	0.42	1.3000	2.3833	0.8833	0.2167	-32.1%	-90.9%
				0.25	3.0833	3.1833	2.5333	0.4667	-17.8%	-85.3%
OVERALL PREFORMANCE					1.481771	1.192188	1.071354167	0.153125	-27.7%	-87.2%

5. CONCLUSIONS

Cooperative munitions a demonstrated significant decrease in the number of killed targets. In comparison, cooperative behavior performed very well in terms of false target attacks. Cooperative behavior reduced the number of false target attacks by 87.2%, and in some scenarios cooperative munitions did not execute any false target attacks, hence making more munitions available for attacking valid targets. A decrease in false target attacks is very important and represents a promising improvement for cooperative behavior. The decrease in the number of killed targets for cooperative behavior is due to the loss of additional time for classification of targets, more missed targets due to a requirement for confirming classification prior to attack and executing multiple attacks on high priority targets. Non-cooperative munitions execute nearly as many attacks on false targets as they do on real targets. This reduces the efficiency of a single munition and wastes valuable munitions.

Cooperative behavior increased the quality of attacks executed on targets. Cooperative munitions attacked high priority targets at a ratio higher than the non-cooperative munitions achieved. This shows that cooperative behavior can improve the selectivity of wide area search munitions. However, the effort for cooperative munitions to attack high priority targets may reduce the number of total attacks that can be executed. The cooperative munitions achieved better hit formula values for high FTAR values and for overall results due to the low number of false target attacks and a greater number of high priority target hits.

Although cooperative munitions performed worse than the non-cooperative munitions in terms of target kills, for low warhead lethality, high P_{TR}, greater number of munitions and high FTAR scenarios cooperative behavior achieved better results when compared to its performance for high warhead lethality, low P_{TR}, fewer number of munitions and low FTAR scenarios. FTAR and probability of target report are competing objects. For a given munition system, lower FTAR and higher P_{TR} cannot be achieved simultaneously. One must make some trade off between these competing objects. Keeping FTAR too low leads the ATR system to overlook some alarms and results in higher rate of missed targets. Likewise keeping P_{TR} too high makes the ATR system very sensitive to any kind of alarms detected by the sensor, resulting in a higher FTAR due to the misidentification non-targets.

One suggestion for trade off between these objectives is to adjust the ATR to keep P_{TR} high, and apply cooperative behavior to the munition system to achieve the desired low false target attack rates. This is a cost effective way to get the desired ATR performance without resorting to a larger, more expensive sensor/ATR system. Further, combining this approach with small low cost warheads (low P_K) results in small munitions that can be employed in greater numbers. The platform that launches these wide area search munitions will have the ability to carry more munitions to achieve the mission with success. The increase in the number of munitions will also increase the reliability of the overall munition system. Hence an effective munition system can be achieved cost efficiently. It is believed that tailoring the degree of cooperation to the real life situation may produce desirable results in terms of mission success.

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VITAE

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