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RESEARCH ARTICLE

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AN EVALUATION ON WEAPON TARGET ASSIGNMENT PROBLEM*

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ABSTRACT

Network-Centric Warfare (NCW) envisions taking the advantage of information technology developments by replacing traditional war management strategies. It affects both the fast and accurate decision-making process by providing organization and information exchange between military forces in geographically different locations. Combat management systems help to manage and maintain components such as sensors, weapons, platforms to create the tactical picture. As a result of the threat evaluation with a network-centric approach, effective defense strategies can be developed through the problem of weapon assignment and sensor allocation among military forces. In this paper, threat evaluation concept and parameters are firstly explained, and the static and dynamic target-based weapon assignment and sensor allocation problem are defined. We *also simulate a scenario for weapon target assignment (WTA) problem and compare different approaches. Then, the concept of NCW and the problems that may be encountered are detailed.*

Keywords: *Network Centric Warfare (NCW), Threat Evaluation (TE), Weapon Assignment and Sensor Allocation (WASA) Problem, Combat Management Systems.*

SİLAH HEDEF ATAMA PROBLEMİ ÜZERİNE BİR DEĞERLENDİRME

ÖZ

Ağ merkezli savaş, geleneksel savaş yönetim stratejilerini değiştirerek bilgi teknolojisi gelişmelerinden faydalanmayı öngörür. Coğrafi olarak farklı konumlardaki askeri birimler arasında organize olmayı ve aralarında bilgi alışverişi sağlayarak hem hızlı hem de doğru karar verme sürecine etki eder. Savaş yönetim sistemleri, taktik resmin oluşturulması için sensör, silah, platform gibi bileşenlerin yönetilmesi ve idamesine yardımcı olur. Ağ merkezli bir yaklaşım ile tehdit değerlendirmesinin gerçekleştirilmesi neticesinde askeri birimler arasında silah atama ve sensör tahsisi problemi üzerinden etkin savunma stratejileri geliştirilebilir. Bu makalede, öncelikle, tehdit değerlendirme kavram ve parametreleri açıklanarak, durağan ve dinamik hedefe dayalı silah atama ve sensör tahsisi problemi tanımlanmıştır. Sonrasında, silah-hedef atama problemi için bir senaryo verilerek, simülasyon ortamında farklı yaklaşımlar karşılaştırılmıştır. Son olarak ağ merkezli savaş kavramı ve karşılaşılabilecek problemler detaylandırılmıştır.

Anahtar Kelimeler: *Ağ Merkezli Savaş, Tehdit Değerlendirme, Silah Atama ve Sensör Tahsisi Problemi, Savaş Yönetim Sistemleri.*

1. THREAT EVALUATION

Combat management consists of consecutive stages including threat detection, tracking, discrimination of real threats and decoys, identification, planning, weapon target assignment (WTA), engagement, kill/damage assessment (Athans, 1987) as in Fig. 1. Threat detection is based upon the data from several sensors. Tracking is the process of estimating the future target parameters like speed and position. Tracking process makes use of the target observations history. Identification involves the classification of the detected target. WTA process assigns the appropriate weapons to the identified threat, WTA is deemed as the resource allocation. The engagement phase is the execution of the planning and assignment phases in real time. Outcomes of the engagement are assessed in the assessment phase. Recent advancements in computer, network and communication make the Network Centric Warfare (NCW) possible. In NCW, the diverse warfighting platforms share their knowledge about the scene with each other through the communication links.

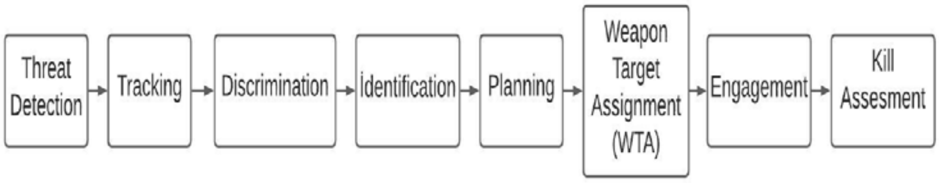

Figure 1. Combat management stages.

Command Control Communications Computer Intelligence Surveillance Reconnaissance (C4ISR) systems help the formation of the tactical picture in which the warfare scene including the warfighting components, their sensory information and weapons are managed. Combat Management Systems control and coordinate all these components, manage the operation, and build a decision support system.

Threat Evaluation (TE) is the use of multi-disciplinary actions to classify the threat levels. Threat levels allow the determination of minimum security reactions by military units, taking into account the prevailing conditions.

According to threat level, reaction is either independently or jointly applied in specific areas. TE and reaction are based on the type of the threat, scope of the mission or the size of the operational area.

In the case of multiple attacks on a combat ship, the operators or decision makers have to evaluate the situation and threat levels in real time to protect the force. More importantly, due to the limited time to give a decision against to the attack, all possible factors have to be considered. TE process requires data from radar and associated sensors. With the collected attributes and on-board computation, the threat value is determined. The attributes are classified in the research of (2014) M.L. Truter and J.H. van Vuuren as follows:

- **Proximity:** The parameters are evaluated based on the distance between a threat and the defended assets. If the threat is far away the defended assets, it cannot be classified as a possible threat.
- **Capability:** The parameters are evaluated based on the threat's capability so that the damage can be determined in the event of an attack.
- **Intent:** The parameters are evaluated based on threat's attitude. For example, a threat can follow its attack maneuvers.

Thus, for a combat scenario, there are various parameters that affect the decision-making process. They can be listed as follows:

- The properties and capabilities of sensors such as range, type, time;
- The properties and capabilities of weapons such as range, type, time;
- The capabilities and types of targets, their fuel capacity;
- Operational area.

All these parameters make the Weapon Assignment Sensor Allocation (WASA) problem more complex. The military units jointly select the best-suited subsets of the weapons and sensors that minimize the total expected value of the surviving targets. However, it brings multiple challenges, which we itemize as follows:

- Distributed resource allocation requires perfect coordination and synchronization among units. In a real problem where every millisecond is very important, there is no compensation for the consequences of an error in the calculation.
- The subgroup of sensors and weapons cannot be chosen arbitrary. The decision-making mechanism to be applied for each target not only depends on the characteristics of the target, but also differs in every time according to the possibilities and capabilities of the friendly units.
- A long-term scheduling is needed to prevent the rapid depletion of resources. Otherwise, an error in planning will have irreversible consequences.

In addition to a wide range of weapons and sensors that support warfare, threat features and damage properties are also varied. Effective defense eliminates all the threats with minimum damage received. Effective defense is that our own forces receive the least damage while eliminating all possible threats. For this purpose, the right weapons and sensors must be engaged at the right time with the right targets. This process is called Threat Evaluation Weapon Assignment and Sensor Allocation (TEWASA). Modern combat management systems should solve the TEWASA problem fast and autonomously.

This paper provides general guidance for using the existing algorithmic solutions in executing the Weapon Assignment and Sensor Allocation (WASA) problem. There are two types of weapon target assignment problem: static WTA and dynamic WTA. In static WTA, all weapons engage the targets at a single stage. All parameters are known by the decision makers. Thus, the aim is to find optimal assignment solution for a defined task. On the other hand, dynamic WTA is a multistage problem, thus decision makers assess each engagement for the next decisions till all threats are destroyed or all weapons are used. Dynamic WTA is more complex than static WTA (Xin et al., 2016). The problem described above relates to a scheduling and resource allocation problem, where the number of accomplished tasks needs to be maximized and resources should be available for possible use in the near future. The thread level or executing a specific mission is out of the scope. Our main goal is to provide a comparison to maintain an efficient use of limited resources while maximizing the number of accomplished tasks. We explain the distributed sensor allocation and weapon assignment relation with a simulation environment.

The rest of the paper is structured as follows. WASA problem is described in Section II. Network Centric Warfare is detailed in Section III. In Section IV, we simulate a scenario and compare different approaches for weapon target assignment problem. In Section V, we review the existing literature on the WASA problem and solutions. Finally, we conclude the paper in Section VI.

2. WEAPON ASSIGNMENT SENSOR ALLOCATION

Efficient resource management requires coordination of sensors and weapons in the combat systems. Different from the traditional resource allocation problems, WASA creates a resource pool via sharing its own resources. These are leveraged collectively or independently to address WASA problem. The defenders can provide a fixed number of sensors and weapons to tract the threat. Therefore, evaluating the threat and dynamically allocating sensor and assigning weapon are fundamental challenges to enable survivability of the force. WASA is a decision-making problem that actively manages sensors and weapons to maximize the resource utilization. The underlying challenge in WASA is to manage weapons and sensors for long-term benefits in the face of unpredictability.

As shown in Fig. 2, consider a combat scenario where military units equipped with sensors and weapons coordinate together. This is a distributed management of the resource allocation that requires perfect co-ordination and synchronization among sensors and weapons. The target sensors and weapons cannot be arbitrarily chosen. The sensors and weapons allocated for each possible threat (surface, underwater and aerial target) will differ. This turns the problem from a simple scheduling problem into a more complex one that minimizes the total expected value of the surviving targets.

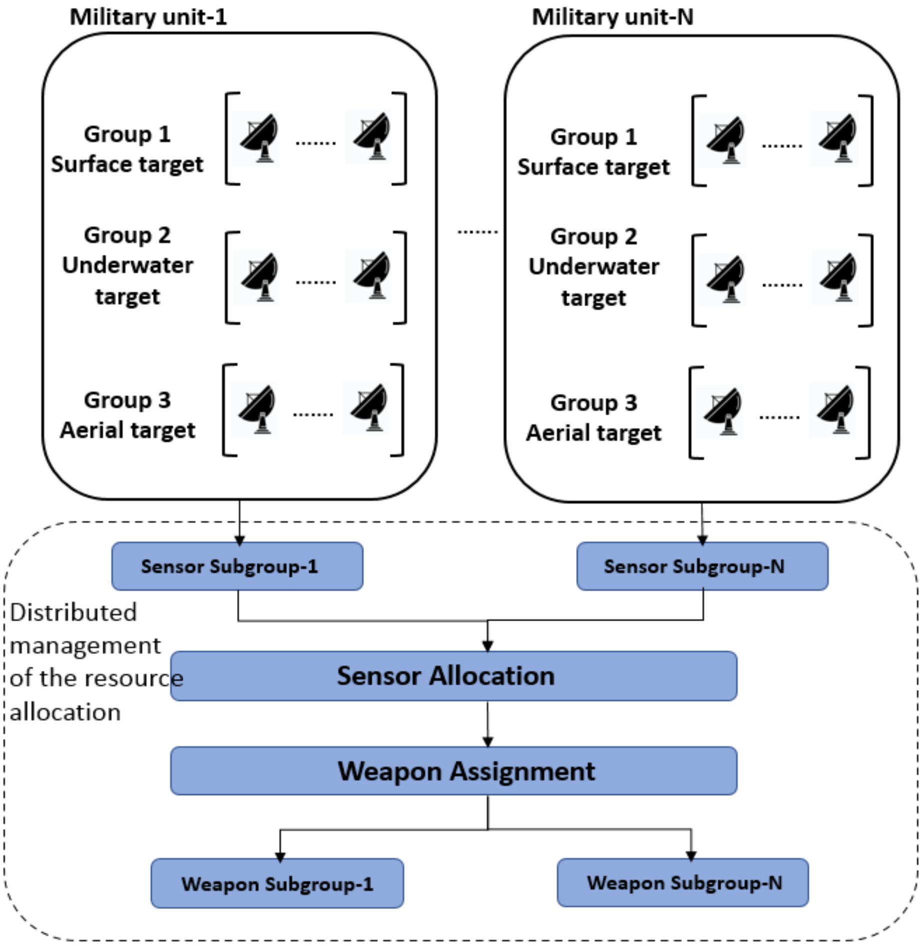

Figure 2. The considered combat scenario.

The research of (2010) F. Johansson and G. Falkman emphasize that the evaluations for sensor-weapon allocation problems are problematic since there are no standard scenarios to test the solutions. Therefore, they presented a testbed SWARD (System for Weapon Allocation Research and Development) for the static weapon allocation algorithms. The research of (2019) B. Xin, Y. Wang, and J. Chen propose a marginal-return-based constructive heuristic algorithm to solve sensor weapon target assignment problems. They use a mathematical model with the collaboration of sensors and weapons.

While evaluating the WASA problem, besides defining the problem, performance evaluation also comes to the fore. Two of these parameters, survivability and engagement effectiveness are defined below.

Survivability is the ability to remain mission capable and to continue their operations of the defended assets in a hostile environment. Survivability is a vital feature for military forces which aims to retain the functionalities in the face of threats.

In the research of (2010) F. Johansson, survivability is defined as follows:

$$s = \frac{\sum_{j=1}^{D} w_j u_j}{\sum_{j=1}^{D} w_j} \qquad \textbf{(1)}$$

where D is the number of defended assets, w_j is the importance of the j^{th} defended asset and u_j is a binary variable. u_j is equal to 1 if j^{th} defended asset survives, otherwise it will be 0. This represents the value of the importance of surviving assets against threats.

Another important parameter is engagement effectiveness. It depends on the platform reaction time, command and control, fire control systems, weapon performance characteristics, threat capabilities and importance.

In the research of (2014) M.L. Truter and J.H. van Vuuren, engagement effectiveness metric is defined as follows:

$$E = \frac{\sum_{j=1}^{T} v_j e_j}{\sum_{j=1}^{T} v_j} \qquad \textbf{(2)}$$

where T is the number of threats, v_j is the importance value of the j^{th} destroyed threat and e_j is a binary variable. e_j is equal to 1 if j^{th} threat destroys, otherwise it will be 0.

WASA problem is addressed to allocate the sensors and assign the weapons to the enemy targets. The problem is also referred as Weapon Target Assignment (WTA) problem and can be classified as static and dynamic target-based. The difference between static WTA and dynamic WTA is whether the time is considered as a dimension (Zhang, Zhou, Yang, Pan & Kong, 2019). In the static WTA problem, there are defensive weapons deployed at certain points and threats directed at this defense. Each weapon has a different possibility of neutralizing a particular threat. Threats are also prioritized based on their distance, arrival time and impact. The aim is to destroy threats with appropriate weapons according to their priorities so that the defense receives the least damage. There can be different numbers of weapons and threats. Moreover, a threat can be engaged with more than one weapons. The reason for the problem being called static is that all weapon target assignment decisions are made in advance and that they remain unchanged during the engagement. Static WTA problem is proven to be NP-complete (Lloyd & Witsenhause, 1986). On the other hand, in the dynamic WTA problem, decisions are spread over a period of time and carried out gradually. The result of the previous stages is reflected in the subsequent stages. This gives dynamic engagement flexibility to dynamic threats. Another distinction for the WTA problem is whether it is target-based or asset-based. The goal in the target-based method is to destroy as many dangerous targets as possible. The asset-based method aims to protect the most valuable assets from threats. Although the target-based problem can be considered as an example of the asset-based problem, it is examined separately. This is due to the need for additional information on which asset the targets are directed to in the asset-based problem (Hosein, 1990). In the next subsections, we formulate these two different approaches.

2.1. Static Target-based Problem

Each weapon has a different kill probability to destroy the targets. The objective is to assign weapons to the targets and minimize the total expected value of the surviving targets. Please note that in the assignment problem; each weapon can be only assigned one target at a time and more than one weapon can be assigned to the same target because of the high value. The problem is illustrated in Fig. 3. In the figure, green circles represent the weapons with the kill probability (P). Orange and blue circles represent the value of assigned and unassigned target, respectively. Similarly, the orange lines give the assignments. For example, weapon 2 and w are assigned to v_T.

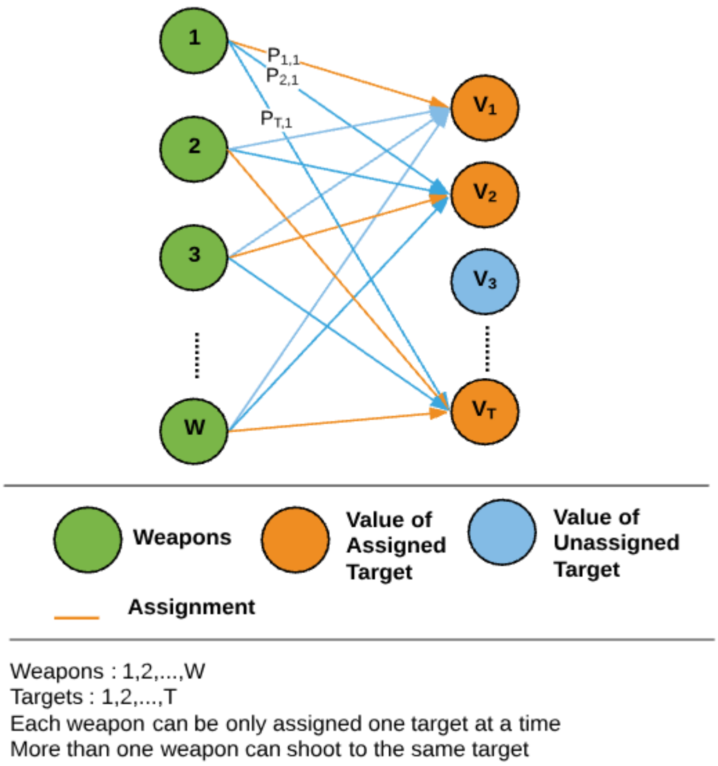

Figure 3. Static weapon-target assignment problem.

The problem optimally assigns a set of weapons to a number of targets such that it is aimed that total expected survival value of the targets is minimal after the engagements. The problem can be defined for single class of weapons in static target-based problem as follows (Hosein, 1990):

$$\min \sum_{i=1}^{T} V_i (1 - P_{ij})^{x_{ij}} \quad \textbf{(3)}$$

subject to

$$\sum_{i=1}^{T} x_{ij} = 1, \qquad j = 1, 2, ..., W \quad \textbf{(4)}$$

where x_{ij} is a decision variable and equals to 1 if a weapon j is assigned to the target j. Otherwise, $x_{ij} = 0$. T is the number of targets, V_i is the value of the target i and W is the number of weapons assigned to target i and P_i represents the kill probability of the weapon on target i.

2.2. Dynamic Target-based Problem

Dynamic decision-making process is divided into several time segments (Hosein, 1990). In the initial stage, a subset of weapons is chosen and assigned to the targets. Then, based on this observation, second stage is constructed with the remaining weapons. Therefore, the objective is to assign weapons to the targets, and minimize the total expected value of the surviving targets and maximize the combat benefits at the final stage (Hu et al., 2020). Please note that in the assignment problem; more than one weapon can be assigned to the same target because of the high value. The problem is illustrated in Fig. 4. At each stage, remaining weapons are assigned to the surviving targets. The process is continued until all weapons are used or all targets are destroyed. In the figure, green and grey circles represent the remaining weapons with the kill probability (P) and used weapons, respectively. Orange and blue circles represent the value of destroyed and surviving target, respectively. The orange lines give the assignments.

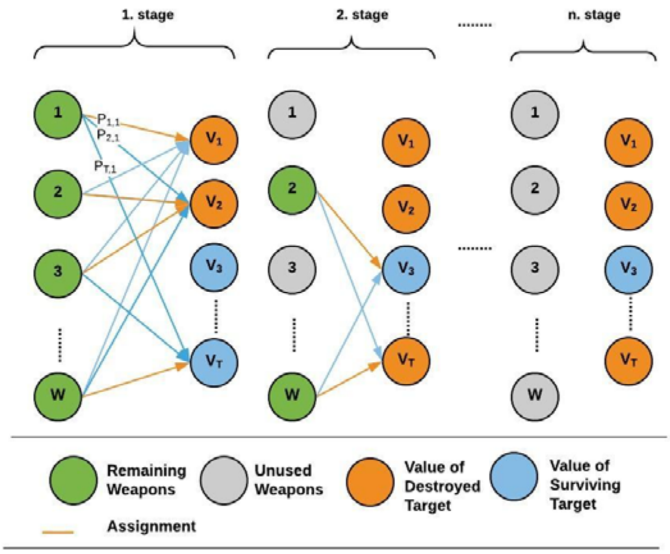

Figure 4. Dynamic weapon-target assignment problem.

3. WHAT IS NETWORK CENTRIC WARFARE (NCW)?

The advancements in information technology (such as sensor networks, mobile computing, data transmission etc.) have enabled to development of battlefield weapons and increased both speed and accuracy in decision making in the fields of Intelligence, Surveillance and Reconnaissance (ISR). Advances in technology have not only transformed weapons, warships, or aircraft, but also accelerated communication and information sharing among forces over the network. In this way, military assets in different locations are connected to decision makers and to each other over computer, radio and data networks link. NCW concept has been identified as one of the key warfare concepts in the future (Roux & van Vuuren, 2007). All the information collected from the sensors is shared with the weapons in the network environment (Xin, Wang & Chen, 2019).

NCW is defined in the research of (2000) D. S. Alberts, J. J. Garstka & F.P. Stein as “an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization."

With the NCW concept, the ability of sharing and accessing the information increase the combat power by networking sensors, decision makers, and shooters. NCW focuses on a robust flow of information between platforms and military personnel using high-speed data links. While information sharing increases the quality of information, situational awareness and mission effectiveness also increase (Anand, Raja & Rajan, 2011).

More specifically, information technology has allowed the development of new policies and procedures that ensure the timely collection, management and analysis of accurate information. However, in this process, we also encounter problems arising from the network-centric approach. The first of these is the requirement for robust and seamless network connectivity. Different types of networks (for example: satellite networks, heterogeneous sensor networks, radio nets) cause problems in terms of communication difficulties and information sharing. There will be many entities in the network environment, from sensors to platforms, from servers to users. Considering that many participants are autonomous, the management and coordination of assets is another issue to consider. In addition, bandwidth limits are even more constrained for satellite and tactical radio communications. It may not be possible to increase capacity due to increasing demand (Renner, 2003). In the network-centric approach, privacy and security will also be essential parameters.

The time it takes for the Commanding Officer to evaluate to make a decision and then convey it in combat is critical and vital. Speed is one of the most important parameters in terms of sustainability and efficiency of the operation. When military forces are geographically different locations from each other, their ability to act together, organize and exchange information are related to the speed factor in the network environment. Therefore, NCW is a network-centric approach for a new way of thinking. Thus, we simulate a network-centric scenario for WTA problem and compare different approaches.

4. COMPARISON OF WTA STRATEGIES THROUGH SIMULATION

In this subsection, we conduct a simulation environment with the following parameters from (Xie et al., 2018). Three targets and five fire units are considered in the simulations. Damage probability threshold of each target is set to 0.8. Damage probabilities for the solutions below that threshold value are deemed as unsuccessful solutions and they are ignored. Damage probabilities of each firing unit to each target in the scenarios are used as in Table 1.

Table 1. Damage probabilities of each firing unit to each target in the scenarios.

	Target 1	**Target 2**	**Target 3**
Fire Unit 1	0.824	0.851	0.752
Fire Unit 2	0.782	0.692	0.822
Fire Unit 3	0.683	0.863	0.834
Fire Unit 4	0.810	0.831	0.721
Fire Unit 5	0.843	0.790	0.795

Threat degree of each target in the scenarios are used as in Table 2.

Table 2. Threat degree of each target in the scenarios.

	Target 1	**Target 2**	**Target 3**
Target Threat Degree	0.17	0.51	0.32

Remaining times in seconds for each target to enter the fire unit's firing zones are used as in Table 3. Using these parameters, we compare five WTA strategies of which the first is from (Xia et al., 2016) and the second is from (Xie et al., 2018).

Table 3. Remaining time in seconds for each target to enter the fire unit's firing range in the scenarios.

	Target 1	Target 2	Target 3
Fire Unit 1	10	15	19
Fire Unit 2	16	12	9
Fire Unit 3	11	8	17
Fire Unit 4	9	12	15
Fire Unit 5	13	11	12

Scenario 1: Assignment of fire units to targets with the aim of maximizing the damage probability, while minimizing the ammunition cost (Xia et.al., 2016).

Scenario 2: Assignment of fire units to targets with the aim of maximizing the ratio of (Xie et al., 2018).

$$\frac{Target\ Threat\ Degree}{Remaining\ Time\ to\ Enter\ the\ Fire\ Unit's\ Range} \quad \textbf{(5)}$$

Scenario 3: Assignment of fire units to targets with the aim of maximizing the damage probability.

Scenario 4: Assignment of fire units to targets with the aim of minimizing the target's remaining time to enter the fire unit's range. Scenario 4 tries to give priority to the closer targets in fire unit assignment.

Scenario 5: Assignment of fire units to targets with the aim of maximizing the ratio of.

$$\frac{Target\ Threat\ Degree * Damage\ Probability}{Remaining\ Time\ to\ Enter\ the\ Fire\ Unit's\ Range} \quad \textbf{(6)}$$

WTA solutions for each scenario are as in Tables 4 through 8 for scenarios 1 through 5 respectively. In Table 4, Fire Unit 5 is assigned to Target 1, Fire Unit 1 is assigned to Target 2, and Fire Unit 3 is assigned to Target 3. Assignment solutions in the Tables 5 through 8 should be interpreted similarly.

Table 4. Firing unit to target assignment solutions for the scenario 1.

Scenario 1	Target 1	Target 2	Target 3
Fire Unit 1	0	1	0
Fire Unit 2	0	0	0
Fire Unit 3	0	0	1
Fire Unit 4	0	0	0
Fire Unit 5	1	0	0

Table 5. Firing unit to target assignment solutions for the scenario 2.

Scenario 2	Target 1	Target 2	Target 3
Fire Unit 1	0	0	0
Fire Unit 2	0	0	1
Fire Unit 3	0	1	0
Fire Unit 4	1	0	0
Fire Unit 5	0	0	0

Table 6. Firing unit to target assignment solutions for the scenario 3.

Scenario 3	Target 1	Target 2	Target 3
Fire Unit 1	1	0	0
Fire Unit 2	0	0	1
Fire Unit 3	0	1	0
Fire Unit 4	1	0	0
Fire Unit 5	0	0	1

Table 7. Firing unit to target assignment solutions for the scenario 4.

Scenario 4	Target 1	Target 2	Target 3
Fire Unit 1	0	0	0
Fire Unit 2	0	0	1
Fire Unit 3	0	1	0
Fire Unit 4	1	0	0
Fire Unit 5	0	0	0

Table 8. Firing unit to target assignment solutions for the scenario 5.

Scenario 5	Target 1	Target 2	Target 3
Fire Unit 1	1	0	0
Fire Unit 2	0	0	1
Fire Unit 3	0	1	0
Fire Unit 4	1	0	0
Fire Unit 5	0	0	1

The damage probabilities and target remaining times to enter the firing units firing zones for the WTA solutions of scenarios 1 through 5 are as in Table 9. As the scenario 3 only tries to maximize the firing unit's damage probability to the target, it achieves the maximum damage probability. However, scenario 3, does not give priority to the nearer targets which should be attacked earlier than the far away targets. Scenario 4 aims to attack nearer targets first. Hence, scenario 4 achieves the minimum remaining time for the targets to enter the firing zone of the firing units. When the damage probability of the scenario 4 is considered, it is least among the other scenarios. In addition to the targets remaining time to enter the firing unit's firing zone, taking the target's threat degree into account as in scenario 2, does not make any significant difference with respect to the scenario 4. Scenario 1 also tries to maximize the damage probability while maintaining the minimum ammunition cost, it seems that the scenario 1 achieves this aim by engaging the far away targets first.

Table 9. Damage probabilities and targets remaining times to enter the firing units firing zones.

	Damage Probability to All Targets	**Damage Probability to Individual Targets**			**Average Remaining Time for All Targets to Enter Fire Unit's Firing Zone**	**Average Remaining Time for Individual Targets to Enter Fire Unit's Firing Zone**		
		Target 1	**Target 2**	**Target 3**		**Target 1**	**Target 2**	**Target 3**
Scenario 1	0.598	0.843	0.851	0.834	15.0	13.0	15.0	17.0
Scenario 2	0. 575	0.81	0.863	0.822	8.667	9.0	8.0	9.0
Scenario 3	0.804	0.967	0.863	0.964	9.333	9.5	8.0	10.5
Scenario 4	0.575	0.81	0.863	0.822	8.667	9.0	8.0	9.0
Scenario 5	0.804	0.967	0.863	0.964	9.333	9.5	8.0	10.5

Hence the maximum time to enter the firing units firing zone for the targets is encountered with the scenario 1. Besides that, scenario 1 achieves slightly more damage probability than the scenarios 2 and 4, and less damage probability than the scenarios 3 and 5. Scenario 5, tries to consider the target threat degree, target remaining time to enter the firing units firing zone, and the firing unit's damage probability to the target all at once. Hence, scenario 5 seems like a balance between the firing unit's damage probability and the target's remaining time to enter the firing unit's firing zone.

5. RELATED WORK

TE and WASA are two important components in Command and Control (C2) system (Ghanbari et al., 2021). Performing these processes and finding optimal results are possible with good decision making and planning. Dynamic and time-critical decision making, multiple criteria decision making, uncertain situations come among the problems that need to be addressed. The problems become more complicated when the human factor, stress and time constraint are added to the semi-autonomous or non-autonomous mode of TEWA (Naseem et al., 2017). Therefore, in this study, it is argued that the inclusion of a decision support system in the problem will reduce the risks arising from human errors. Decision support system takes the inputs of information of threats and weapons, operating tactics, Geographical Information System (GIS) mapping for vulnerable areas and produces the scheduling of weapons and weapon supply and inventory management strategy.

In this subsection, we discuss the proposed solutions in the combat scenarios as seen in Fig. 5.

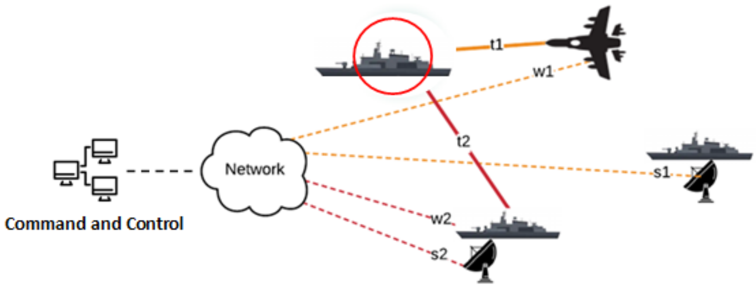

Figure 5. Network-centric combat scenario.

Many studies use Genetic Algorithm (GA), Tabu Search (TS), Simulated Annealing (SA) and Ant Colony Optimization (ACO) techniques to weapon target assignment problem and compare the results with each other. The optimization problem is to maximize the total value of surviving defense assets. Among these, GA is based on the survival of the fittest through natural evolution (Hillier & Lieberman, 2010). GA algorithm creates an initial population and uses genetic operators to alter composition of offspring, thus potential solutions are represented until it reaches better solutions. The research of (2018) H. Sun, X. Xie and T. Sun model anti-aircraft WTA problem and GA algorithm is used including damage probability, flying time from target to weapon and the target threat degree. The research of (2016) Y. Yan, Y. Zha, L. Qin and K. Xu also use GA algorithm to analyze the damage to target and losses on defense assets.

In the research of Lu et al. (2006), the fire-allocation of naval fleet air defense is studied, and an improved GA model is proposed for optimal weapon-target assignment problem. It is assumed that there are 7 batches targets and 11 weapons. The importance weight of targets and kill probability of weapon to the targets are created. Accordingly, average kill expectation and achieved global optimal assignment are calculated for improved GA and simple GA.

The research of (2019) Wang et al. studies a specific type of WTA problem and proposes a ground target attacking WTA since the ground targets are diverse and suitable for many types of weapons,. The authors design a GA based variable value control method for solving large-scale problems. Weapon consumption value and time consumption are calculated. The parameters are the mean of the weapon value required to meet the specified damage requirement and the mean of the run times of 20 simulations, respectively.

In the research of (2020) K. Zhang, D. Zhou, Z. Yang, W. Kong and L. Zeng, threat evaluation model is defined according to altitude, velocity, short course, remaining intercept time. Then, sensor detection probability and weapon killing probability are formulated. The authors formulate dynamic sensor heterogeneous weapon assignment problem including threat evaluation model, sensor detection and weapon killing probabilities, decision timing and propose an evolutionary algorithm for ground-to-air defense scenarios.

ACO models the observations. Each one of the ants handles a candidate solution from source to destination. They coordinate their activities through indirect communication mediated by the modification of the environment in which they move. At each step, a decision policy is used, and the decisions are given based on the local information. The probability of using a trail increases as more ants choose it. The research of (2008) G. Shang aims to minimize the loss of defense assets by modelling static WTA problem. The authors first consider GA with local search to solve the optimization problem. The local search starts with a feasible solution found and iteratively searches an improvement for the current assignment. When a better solution is found, it replaces the existing solution, and the process continues until a criterion is satisfied. Then, SA is used for the optimization problem, which tries to avoid local optima by accepting probabilistically moves to solutions. Better solutions are always accepted, while worse solutions are accepted with a probability. SA uses the analogy of a physical annealing process, and it is conducted until no improved solution found for a few iterations. Then, the authors implement ACO algorithm. In the modified ACO algorithm, a heuristic is executed between colonies for only the best solution through a greedy reformation.

In the research of (2017) Li et al., a modified Pareto ACO algorithm is proposed to maximize the total effectiveness of attack and minimize the cost of missiles for static WTA problem. Different strategies are embedded into the traditional Pareto ACO to improve the optimization performance, including dynamic heuristic information calculation approach, improved movement probability rule, dynamic evaporation rate strategy, global updating rule of pheromone, and boundary symmetric mutation strategy. It is observed that Pareto ACO is more suitable for solving large-scale problems.

The research of (2018) Chang et al. addresses the dynamic weapon target assignment problem. An improved artificial bee colony algorithm is proposed for solving the battlefield firepower optimization in multiple stages and multiple rounds. 4 kinds of rule-based heuristic factors are considered to improve the quality of the initial solution. These are weapon-choice-priority, target-choice-priority, target-choice-priority with a random sequence, and target-choice-priority with a random sequence and Cannikin Law. The authors use “shoot-look-shoot” strategy. In the shoot strategy, weapon allocation decision to the targets is calculated and the attack is executed. In the look strategy, decision makers observe the battle field to identify the targets and available weapons.

The research of (2019) K. Zhang, D. Zhou, Z. Yang, Q. Pan & W. Kong propose a multi-objective evolutionary algorithm for WTA model and aim to minimize the expected survival probability of targets and weapon consumption by including unit type, damage effect, lethal radius etc. The authors focus on two main challenges: (i) handling the multi-constraints and (ii) finding the complete Pareto-optimal set. The constraints are based on the actual operational requirements of security avoidance, survival threshold, and preference assignment.

In the research of Li et al. (2018), multi-objective evolutionary algorithm is proposed based on decomposition for asset-based static WTA problem. The asset-based problem aims to maximize the expected total value of assets which are defended by the defensive weapons. If the higher number of weapons is used, there is greater probability of destroying the target. However, if less weapons are used, then the targets have a higher probability of surviving in the engagement. Therefore, the consumption of weapons and the destruction of targets are conflicting objectives. In this study, the authors convert the asset-based problem into a multi-objective optimization problem.

6. CONCLUSION

Information technology enables the development of new policies and procedures that allow the timely collection, management, and analysis of accurate information. With the network-centric warfare concept, the ability of sharing and accessing the information increase the combat power by networking sensors, decision makers, and shooters. In this paper, we explain the threat evaluation concept with a network-centric approach and define weapon assignment and sensor allocation problem. More specifically, we give static and dynamic target-based problem, and also simulate a scenario for WTA problem and compare different approaches. Then, we explain the concept of NCW and the problems that may be encountered are detailed.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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