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Designing a Framework for Target-site Assignment in Naval Combat Management

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ABSTRACT

In this study, using operational research techniques, a model has been presented to assess battlefield threat, to prioritise aggressive targets, to evaluate the capability of own sites and the risks of the conflict with the targets, to define conflict scenarios and finally to select the best scenario using an assignment model. The above proceedings were added as an intermediate phase of target-site assignment, called 'deciding the best conflict scenario', to the 'threat assessment' and 'weapon-target assignment' in the naval combat management system. For each of the own site, the data collected from the environment together with the panels of experts are shown in a two-dimensional matrix, in which the four areas of the matrix represent the conflict scenarios. Considering that the study was done in a simulated environment, the expert's verification and the convergence of the results in Monte Carlo method were used to validate the research. The proposed model can offer optimised decision to the operational commander through predicting the battlefield and managing the site's capacity and the interaction in between during the combat.

Keywords: Combat management system; Conflict scenario; Threat assessment, Target's threat; Assignment model

1. INTRODUCTION

In a military environment an operator is typically required to evaluate the real-time situation and to protect defended assets against enemy threats by assigning available weapons to engage with the enemy. This situation requires rapid operational planning and computerised decision support systems[1]. Not only a battlefield could be modeled in different environments, but also diverse conditions could be considered here. Some factors causing these varied conditions of the battlefield are as follows: the number of the own sites and the variety of the weapons, the number and diversity of aggressive targets, the capability of own sites in destroying the targets, target prioritisation to commence the conflict and etc. The problem with the weapon-target assignment (WTA) is an important theoretical one in military operational research, and it is one of the most pivotal issues in combat management[2,3].

The main issue regarding this study, is how we can provide a quick overview of the battle field so that after threat assessment and before weapon assignment, (due to the 'threat of each target' and 'the capabilities of the own sites') an overall perception of the battlefield could be interpreted. Also it is important to familiarise with the conflict scenarios of the sites. It means each site could enter the conflict with one scenario four states after determination of own sites situation and targets situation (Fig. 2). Subsequently, the targets are assigned to the sites, using the assignment model. Due to the delicacy of the issue raised above, an overall solution to this problem in the combat management-related research has not yet been provided. After threat assessment, weapon assignment is done immediately[4]. Therefore, in this study in order to solve the problem, an intermediate phase has been developed and the details are as shown in Fig. 1. In fact, the problem regarding the battlefield, after aggressive target identification is how to be able to set the conflict mission of the sites according to threat assessment parameters already received, and the data collected from the battlefield. Accordingly, in the current study the task of target destruction, due to their classification, is presented in a two-dimensional matrix and the conflict scenarios are assigned to the sites as well. Another point here is that the interaction between different sites for a successful conflict should be in a way to manage the capabilities thoroughly or in other words, the target-site assignment has to be in such way in which the operations reliability rest at an acceptable level. For this purpose, it is necessary to determine the capabilities and the conflict risk for each site with any target, so that the target-site assignment could be determined with the least degree of risk. Finally, the output of this research which is the target-site assignment, is one of the stages of combat management and also it provides an appropriate input for 'weapon-target assignment' problem since each site might have diverse and different weapons.

Naval combat management is the most comprehensive of combat managements, since the diversity of sites and targets situations is at the maximum possible level. These situations could be the littoral (Mainland), surface (water) or undersurface (underwater) and even the air.

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In combat management after the threat assessment phase where the threat is evaluated on the battlefield, the weapon assignment phase is executed where such weapons are assigned to aggressive targets. What has not been mentioned in various researches[5,6] in which the experts emphasised the need for its existence, is an intermediate phase until after the 'threat assessment' and prior to the 'weapon assignment'. The commander of the operations can evaluate the entire battlefield, can determine the 'conflict scenarios' of different sites with regard to their ability and can finally select the best conflict scenario due to the interaction and synergy among all sites. And according to the selected scenario, the 'weapon assignment' is done at the site.

In this study, to achieve the above objective, the intermediate phase is added as 'conflict scenarios' to the conflict management. In general, what has been considered in this study is the set of actions providing the intermediate phase in which its overall position has been shown in Fig. 1.

Purpose of the current study is designing an integrated model to determine the conflict scenarios of each site selecting the best scenario i.e. the target-site assignment.

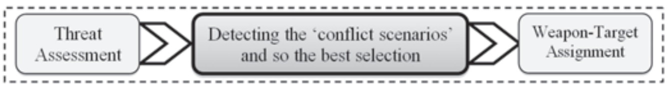

Figure 1. Conceptual area of combat management and intermediate phase in the current research.

2. LITERATURE REVIEW

Since the weapons in a single site are diverse, the unified threat management along with the proper accountability and efficient usage of the existing equipment have led to the formation of a new generation of weapon systems with novel capabilities called the combat management systems[7]. The high-tech weapon systems use computers to achieve surgical precision and the computer technology has had a major role in defence applications[8].

Changwen & You[9], presented a method for the evaluation of threat assessment, using multi-attribute decision making techniques (MADM) to prioritise targets. In their study, they have used analytic hierarchy process (AHP) to evaluate the threat assessment by using membership functions and fuzzy technique, and they have believed order of preference by similarity to an ideal solution (TOPSIS) is practically an easy real-time method. In another study, Liebhaber & Feher[10] evaluated the Surface war in which two general objectives were pursued; the first was to achieve the information that surface warfare experts used to determine the level of the vehicles' threat, while the other was to submit a basic algorithm for threat assessment. Yin[11], *et.al* have presented an algorithm for threat assessment using AHP techniques and principal component analysis. They compared assumptive targets using five criteria of AHP paired comparisons and eventually they were prioritised. In another study[12], fuzzy inference and the logic along with fuzzy membership functions were used for threat assessment. Finally using three assumptive air target simulation, the system's validity was evaluated.

In providing weapon-target assignment (WTA) models and the relevant methods solving them, numerous studies have been done[13-18]. Ahner & Parson[19] have submitted a model for WTA, by using dynamic programming and stochastic process approach. It was aimed at increasing the rate of target destruction with a multi-stage assignment model. The steps are as follows: (i) Target appearance, (ii) target entrance with random distribution, and (iii) simulation and dynamic programming.

3. CONCEPTUAL MODEL

In Combat Management research, several researches have been done in threat assessment phase[9-12] or WTA phase[20-22]. The researches have also considered that the intermediate phase was not mentioned in the both phases[1,4,23]. However, this four-step intermediate phase which has been presented in this study, is a new phase and had not been mentioned in any research. The so-called four steps are identified in Fig. 2 at the dotted box.

In the first step of conceptual model, although some researches have used Fuzzy/crisp MCDM methods for threat assessment[9,11] and also some other studies were carried out on threat assessment[24,25], their approaches were completely different from the method presented in this study. The advantage of the proposed method at this step of the research, is that the weights of threat assessment parameters were calculated according to a fuzzy relationship between these parameters and FDEMATEL and FANP. It has to be mentioned that the target's threat is calculated according to the parameters' weights using VIKOR method, since the increasing and decreasing trend of the parameters is to be considered.

In the second step, the hit probability has been highlighted as one of the most important issues which has dedicated various technical research to itself. Regarding the other risk parameters presented in this study as risk priority number (RPN), not enough evidence had been found in the literature of combat management research. The satisfying advantage of RPN is that it leads to a more complete calculation of the risk.

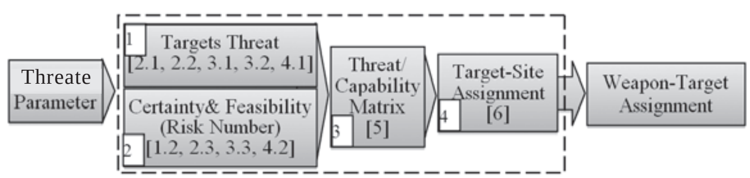

Figure 2. The conceptual model of the steps of combat management with intermediate phase 'conflict scenarios' as the contribution of the current research.

The hybrid output of the first and the second step in this research, which were presented as a portfolio matrix and consequently could define the conflict scenarios for each site as the third step, are not mentioned in previous researches regarding combat management. Although one of the researches[26] regarding the idea of using portfolio matrix in combat management, was closest to the current research, it has mainly focused on WTA phase and single site analysis, and it does not mention the intermediate phase and conflict scenarios which are being presented in the current research.

Finally, in the fourth step, according to the relevant research on weapon assignment with the purpose of achieving proper conflict scenario, the target-site assignment model has been proposed. Numerous studies have been done[16,17,19] concerning the WTA model, while in the current study, target-site assignment has been discussed. The output of this model can be added as a parameter to WTA problem.

The numbers cited in the boxes in Fig. 2 are related to the research procedures which have been fully explained in Fig. 3. The implementation of steps 1-3 is based on two-dimensional matrix.

4. METHODOLOGY AND OPERATIONAL MODEL

The implementation steps as shown schematically in Fig. 3 include:

1. Parameter identification of x-axis and y-axis:

1.1 Ten parameters of the threat assessment were determined by reviewing the literature and for the verification of these parameters the experts' opinions were collected. The parameters' description is summarised in Table 1.

1.2 In order to identify the parameters of the conflict risk number and to determine the measuring features, the study's literature was reviewed using FMEA approach shown in the first row of Table 3.

2. Weighting the parameters

2.1 The necessary information was obtained from the experts to determine the weight of the threat assessment parameters and the data was analysed using a combination of FDANP method. The output of this step is shown in the last column of Table 1. According to the expert's opinion in which the nature of the parameters are not independent of each other, AHP or FAHP method cannot be used in weighting them. ANP or FANP method has also its own complexity, but in the combined FDANP method this problem has been fixed. Therefore, FDEMATEL was used to determine the effectiveness of the each parameter, and then FANP was used to determine the final weight of the parameters. Although there are different approaches to the integration of FDANP[27], the calculations of the current study is done based on the reference here[28]. Defuzzification process in FDEMATEL is carried out using CFCS method[29]. In the weighting process, the opinions of seven scientists and operational experts were taken into account in combat management and the inconsistency rate was calculated less than 0.1; therefore, we have assumed the comments made by the experts is compatible with what we have expected.

2.2 Weight determination of risk parameters in each site by using the simplistic weighted method: The parameters' weights are listed in the first row of Table 3.

3. Data reception from the sensors and the battlefield

3.1 - 3.3: In this study the battlefield's data reception has been

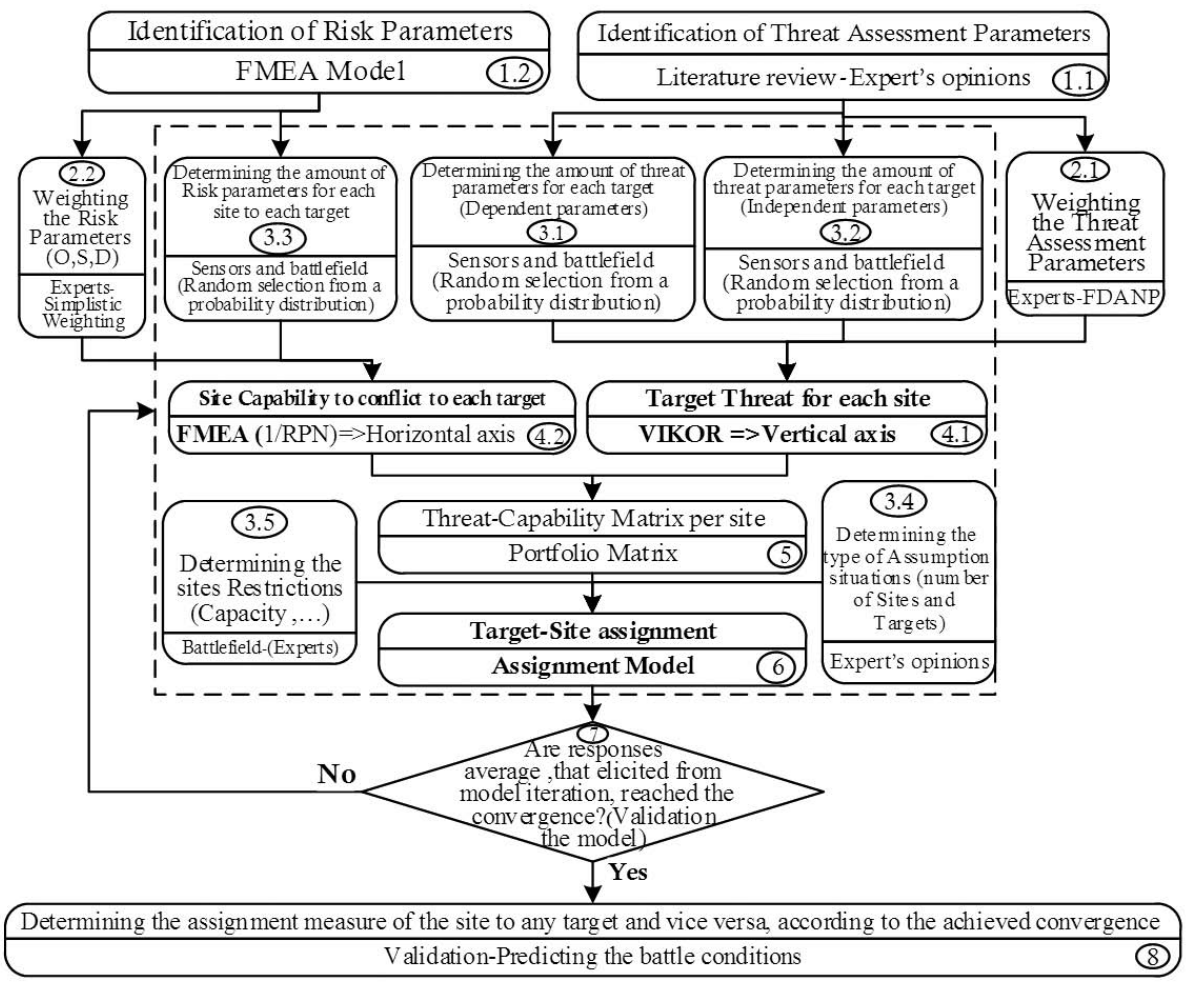

Figure 3. The steps of the research implementation.

Table 1. Threat assessment parameters and their weights

		Parameter	Description	Nature	Weight
Dependent to site	1	CPA	Closest Point of Approach: Estimated distance that track will pass by own site if the track and own site remain on their current courses.	-	0.012
	2	TCPA	The required time for getting the target to CPA	-	0.013
	3	Weapon envelope	The track's position with respect to its estimated weapons envelope	+	0.037
	4	Closing	Represents the target 'moving away' or 'approaching' to own site	+	0.016
Independent from site	5	Speed	Approximate speed or an indication of change	+	0.016
	6	Distance from A long	The target's distance from the high seas/international airlines and commercial path	+	0.009
	7	Jamming	The number of times an attacker has disrupted in own radars	+	0.254
	8	Manoeuver	The number of manoeuvers the target has done	+	0.013
	9	Emission sensing monitor (ESM)	Electronic emissions from the track	+	0.175
	10	Platform	The Type (Helicopter, Fighter, Missiles, Submarine and Battleship), platform and the class of aggressive target	+	0.455

simulated using Monte Carlo approach along with the distribution probability of the random data.

3.4. Determination of the assumptive situation under the experts' opinion (the number of the targets is more , equal or less than the number of the site's capacity: Table 7)

3.5. Setting the sites constraint facing a real environment, which in this study the only constraint is the capacity of the conflict for each site (Table 7).

4. The integration and analysis of the received data from the experts and the environment

4.1 Calculation of the threat for each target in each site using VIKOR method (e.g. Table 4). Since the utility function of threat assessment is a quadratic non-linear, TOPSIS or VIKOR methods could be used. However VIKOR and TOPSIS are much similar, a positive ideal point is considered in VIKOR method. It is worth mentioning that the optimum point must have the shortest possible distance from this point. The advantage of VIKOR over TOPSIS, is that in TOPSIS in order to achieve the optimum point, we might be led to a place where it is far from both the negative ideal and subsequently the positive ideal which is a big flaw here[30].

4.2 Calculation of the capability amount for each site conflicting with any targets using FMEA method along with inverse calculation of RPN (1/RPN) (e.g. Table 3).

5. Formation of the threat-capability two-dimensional matrix per each site (One matrix is formed per site) and determination of the conflict scenarios for each site:

The portfolio matrix was the main idea for the creation of this matrix[31]; nevertheless, the axis of these two-dimensional matrix are defined in a four- zone area with each zone containing a single conflict scenario.

Vertical axis: Target Threat; it represents the level of target's threat and it is calculated by using a combination of fuzzy/crisp decision-making techniques, because some data was the experts' opinions in uncertain and fuzzy conditions and the other data was obtained from the sensors on the battlefield. The weight of the threat assessment parameters was obtained through a combination of both fuzzy analytical network process (FANP) and Fuzzy Decision Making Trail and Evaluation Laboratory (FDEMATEL). Later in the study, each target's threat was specified using VIKOR methods.

Horizontal axis: The capability of each conflict is defined by each target in which the inverse of RPN is presented and is calculated by FMEA method (failure mode and effects analysis).The product of the three parameters, which determines the risk of site confliction for each target is being calculated; the probability of failure occurrence (O), the effect and the severity of failure (S) and the probability of failure detection (D).

After receiving the initial information from the experts along with the battlefield data used by simulation and the use of random numbers in this study, the overall data was analysed and evaluated and then presented in a two-dimensional matrix in Fig. 4, as each site was determined by the target's status and conflict scenario.

As it is shown in Fig. 2, the matrix has four zones as follows:

Zone 1: whenever after calculating, the targets in this zone place themselves in only one site, it signifies that firstly these targets have an extremely high level of threat and secondly, as a result of low level of risk, the site capability has high tendency in having conflicts with the targets. Therefore, these targets have shooting priority from the site.

Zone 2: It is recommended to assign these targets to the rest of the site, which have higher capability and lower risk conflict towards these targets.

Zone 3: If the targets in this zone are not covered by the

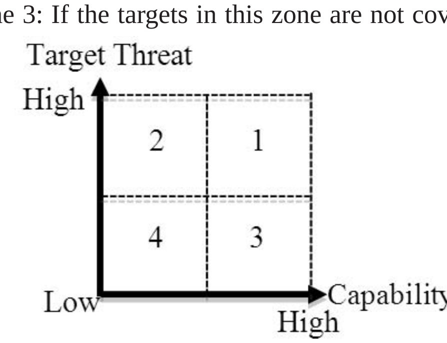

Figure 4. Target-Site status in a two-dimensional matrix with four conflict scenarios.

other sites for any possible reason, this site could enter the conflict with the mentioned targets.

Zone 4: It's better to ignore the above targets, unless these targets are located in one of the three zones in another site, in this case the target's conflict would be in accordance with one of those three zones mentioned before.

Eventually, by submitting an assignment model, all matrixes (in which for 'n' site, there is 'n' matrix) are integrated in order to determine the proposed decision through results integration and the site's constraints consideration.

6. Designing and solving linear assignment model by the software (Eqns. (1)-(3) and e.g. Tables 4 and 5): This model is provided with the aim of integrating the existing matrixes per site; therefore, due to the conflict scenarios, all targets are to be assigned to one or more site in such a way the most effective scenario or the optimised scenario is being implemented on the battlefield (according to the defined parameters and each site's constraints).
7. Repetition of the steps of the submitted model from random data generation step to solving the assignment model, until reaching convergence (Fig. 5).
8. Target-site assignment with percentage determination of the capacity of each site assigned to each target and conversely, the percentage of each type of the target assigned to each site according to the achieved convergence (Fig. 6).

5. MODEL FORMULATION AND RESULTS

Threat Assessment parameters have been identified in the form of 10 parameters[6]. The parameters' description and the weights are presented in Table 1. The term 'Nature' is used to demonstrate the reducing or increasing trend of the parameter. The less value of the parameter, the greater threat of the target. 'regarding the parameters' weight used in threat assessment, platform and jamming and ESM parameters have the highest weights, respectively. These parameters are divided into; 'dependent to site' and 'independent from site'.

The random data generation ranges have been presented by the experts and Monte Carlo approach in which catalogs and military references were used. So, the parameters obtained from a real environment of the battlefield are created in the simulation study.

For example, in the helicopter conflict with Littoral site, the Helicopter CPA is between 0-1 with 40 per cent probability. Moreover, at 30 per cent probability, the Helicopter CPA is expected to be between 1-5. While at 20 per cent probability, it is between 5-15, and finally at 10 per cent probability, it is between 15-25, for this site.

The weights presented in Table 1 along with the random data determine the importance of the target's threat (using VIKOR method). The amounts of the target's threat are set in a vertical axis. The data in Table 3 also determine RPN amount for each target according to FMEA calculation in which its reverse number is located in horizontal axis of the two-dimensional matrix.

Since a matrix has been provided for each site; therefore, for optimal Target-site assignment and in order to deal with the highest threat with the lowest risk and based on the site capacity, which is defined in simulation mode, the assignment model was designed as follows:

$$\max z = M * \sum_{i=1}^{n} \max_{j=1,..,m} W_{ij} * X_{ij} + \sum_{i=1}^{n}\sum_{j=1}^{m} F_{ji} * X_{ij} \qquad (1)$$

s.to:

$$\sum_{i=1}^{n} X_{ij} \le C_j \qquad j = 1,\ldots,m \qquad (2)$$

$$\sum_{j=1}^{m} X_{ij} \le 1 \qquad i = 1,\ldots,n \qquad (3)$$

Table 2. An example of VIKOR table to calculate the target's threat in Littoral site

Target	Parameter W	CPA 0.012	TCPA 0.013	W.E 0.037	Closing 0.016	Speed 0.016	A Long 0.009	Jamming 0.254	Maneuver 0.013	ESM 0.175	Platform 0.455	W_{i1} =Y Axis
1	Helicopter	21.3	3.180	-7.045	-1	146.4	2.829	0	3	0.87	1.26	0.1202
2	Fighter	3.246	11.99	-1.343	2	1129	8.095	0	1	0.63	1.58	0.1295
3	Missiles	23.6	0.432	9.987	1	1845	0	0	3	0.75	2.76	0.4963
4	Submarine	19.1	9.509	-3.567	1	9.597	0	0	4	0.44	0.81	0.069
5	Battleship	22.7	4.364	-4.579	0	28.53	0.462	1	3	0.77	0.94	0.185

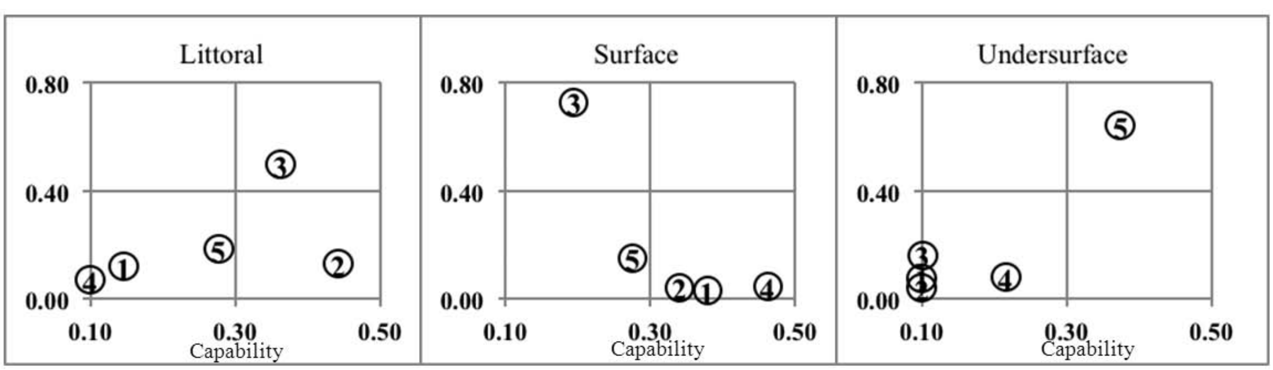

Figure 5. Two-dimensional matrixes 'Threat-Capability' for three assumptive sites.

The symbols used in this function are defined as follows:

i: counter of targets (1,…,n)

j: counter of own sites (1,…,m)

W_{ij}: threat (weight) of ith target for jth site

F_{ji}: capability (certainty and feasibility) of jth site for conflict to ith target (Inverse of RPN_{ji})

C_j: capacity of jth site for conflict (maximum of targets that could assign with jth site)

X_{ij}: if ith target is assigned to jth site = 1; otherwise = 0

The Eqn. (1), objective function, was designed in order to destroy the targets with higher level of threat (large M) and also with more compatible sites (less risk). The Eqn. (2), first constraint, is related to the number of assigned targets to each site which cannot exceed the maximum rated capacity of that site. Also, the Eqn. (3), second constraint, has been created in order to assign each target to one site.

One of the advantages of this assignment model is the linearity, which leads to a more precise and deterministic answer in a very short time. This is exactly the crucial factor that needed in the operating environment and combat situation.

The data obtained from running the model for one iteration, based on random data in an assumptive situation with 3 sites (littoral, surface and undersurface), and 5 targets is as shown in Tables 2 to 4. Based on the presented data in Table 4, the two-dimensional matrixes have depicted in Fig. 5.

The symbols used in RPN are defined as follows:

RPN_{ji}: risk priority number of jth site for conflict with ith target (product of $W_O.O_{ji} * W_S.S_{ji} * W_D.D_{ji}$)

O_{ji}: occurrence of potential failure in conflict from jth site to ith target

S_{ji}: severity of the potential failure in conflict from jth site to ith Target on combat conditions

D_{ji}: Indicating the degree of detectability of failure in conflict from jth site to ith Target

For the other two sites, the tables were developed such as Tables 2 and 3, which ultimately the output of these Tables for the 3 sites is given in Table 4. These values have constituted the two-dimensional matrixes as shown in Fig. 5.

Based on the above data, the assignment model for this assumptive problem will be as follows:

$$\begin{aligned} Max\,Z = {} & 1.91x_{11} + 2.14x_{12} + 1.86x_{13} + 2.34x_{21} + 2.24x_{22} \\ & + 2.00x_{23} + 11.05x_{31} + 10.88x_{32} + 10.79x_{33} + 1.27x_{41} \\ & + 1.63x_{42} + 1.38x_{43} + 9.69x_{51} + 9.69x_{52} + 9.79x_{53} \end{aligned}$$

$$S.to:$$

$$\sum_{j=1}^{3} X_{ij} \le 1 \qquad i = 1,\ldots,5$$

$$\sum_{i=1}^{5} X_{ij} \le C_j \qquad j = 1,\ldots,3$$

when the sites do not have any conflict capacity constraint (C_j = 5); after solving the assignment model, the obtained answers are as Table 5.

The results in Table 5 indicate that in these conditions Littoral site should enter the conflict with the fighter and missile. Helicopters and submarines should be assigned to the surface site, and undersurface site should also be involved with the battleship. Therefore, because there is no capacity constraint, all the targets have assigned to sites with the greatest capability to destroy them.

However, if the sites have the conflict constraint capacity and they could only conflict with just one target (C_j = 1); after solving the assignment model, the answers are as in Table 6.

According to Table 6, it could be said that since in this case there are capacity constraints to maximise the objective function, the helicopter and submarine are negligible than the other targets with less threat, and they are not assigned to any of the sites. So, the missile should be assigned to Littoral site, the surface site is inevitably the best choice if there is a conflict with the fighter and finally, undersurface site should also enter the conflict with battleship.

Table 3. Capability and risk conflict of the Littoral site with the targets

Target \ Parameter	O_{1i} 0.31	S_{1i} 0.38	D_{1i} 0.32	RPN_{1i}	$1/RPN_{1i}$ = X Axis
Helicopter	7.51	5.53	8.16	6.8699	0.1456
Fighter	2.70	2.30	1.86	2.2617	0.4421
Missiles	2.67	5.20	1.35	2.7614	0.3621
Submarine	10.00	10.00	10.00	10	0.1
Battleship	2.71	2.63	6.95	3.6133	0.2768

Table 4. Obtained data for all the sites to depict the two-dimensional matrixes in the previous tables

Targets \ Sites		Littoral		Surface		Undersurface	
		x	y	x	y	x	y
1	Helicopter	0.15	0.12	0.38	0.03	0.10	0.08
2	Fighter	0.44	0.13	0.34	0.04	0.10	0.04
3	Missiles	0.36	0.50	0.19	0.73	0.10	0.16
4	Submarine	0.10	0.07	0.46	0.05	0.22	0.08
5	Battleship	0.28	0.19	0.28	0.15	0.37	0.64

Table 5. The results of the assignment model in an assumptive situation with no conflict capacity constraint

Z=26.955	Littoral	Surface	Undersurface
Helicopter	X_{11}=0	X_{12}=1	X_{13}=0
Fighter	X_{21}=1	X_{22}=0	X_{23}=0
Missile	X_{31}=1	X_{32}=0	X_{33}=0
Submarine	X_{41}=0	X_{42}=1	X_{43}=0
Battleship	X_{51}=0	X_{52}=0	X_{53}=1

Table 6. The results of the assignment model in an assumptive situation with conflict capacity constraint

Z=23.079	Littoral	Surface	Undersurface
Helicopter	X_{11}=0	X_{12}=0	X_{13}=0
Fighter	X_{21}=0	X_{22}=1	X_{23}=0
Missile	X_{31}=1	X_{32}=0	X_{33}=0
Submarine	X_{41}=0	X_{42}=0	X_{43}=0
Battleship	X_{51}=0	X_{52}=0	X_{53}=1

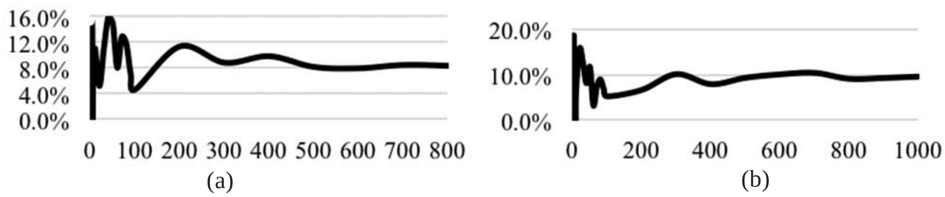

Figure 6. The convergence of two examples after several iterations of the model running. (a) Assigned submarine to the surface and (b) The amount of the littoral site capacity that assigned to the helicopters.

5.1 Validation of the Numerical Results

Due to the nature of the simulation model and in order to validate the model, the experts have defined three assumptive positions as shown in Table 7.

Here are some of the expert's arguments for the model validation in each of the three assumptive situations: In the first assumptive situation, the sites with conflict capacity constraints, such as helicopter and submarine have not been assigned. On the other hand, the missiles with the highest threat among the targets are often assigned at least to one of the sites. The evidence regarding this claim is described in Fig. 7(a). In the second assumptive situation, in which the number of the targets is equal to the sites' conflict capacity, all targets have assigned to the sites regarding to the sites' capability and there have been no targets without assignment. In the third assumptive situation, in which the sites' conflict capacity is greater than the number of the targets, all targets were assigned to the sites and those sites with more capabilities will be engaged with the maximal capacity; and the other sites with fewer capabilities will be entered into the conflict with minimal capacity. It is to be mentioned that in all the three assumptive situations observed in the output of the model, where the conflict risk had been very high or the conflict had been impossible, the assignment has not been made; such as the assignment of helicopters and fighters to undersurface site or submarines to littoral site. In addition to the expert's opinion, convergence graph of target-site assignment is one of the subjects that can be cited as validation to the reliability of the model.

After running the model in each of these three assumptive situations, the final results graph, has reached to a convergence after about 1000 iterations. Two examples of these graphs which are related to the first assumptive situation are as shown in Fig. 6, they indicate the fact that the submarines have assigned to the surface site (Fig. 6(a)) and the amount of assignment of the littoral site capacity to the conflict of helicopters (Fig. 6(b)):

The final results of the Model running after 1000 iterations, which have approximately reached to convergence, are shown in Fig. 7 by two approaches.

From Fig. 7(a), which is related to the first assumptive situation, the amount of the assignment of each type of the targets to each site has been presented based on the target type. For instance, 8.4 per cent of the submarines have to be attacked by the surface sites, as shown in Fig. 6(a). In Fig. 6(a), the submarines assigned to the surface site have converged at about 8 per cent.

From Figure 7(b), the amount of the conflict capacity of each site to each target has been shown based on the site type. For example, 9.7 per cent of the littoral site capacity assigned to helicopters has been presented in Fig. 6(b). Subsequently, in Fig. 6(b) the littoral site capacity which has been assigned to

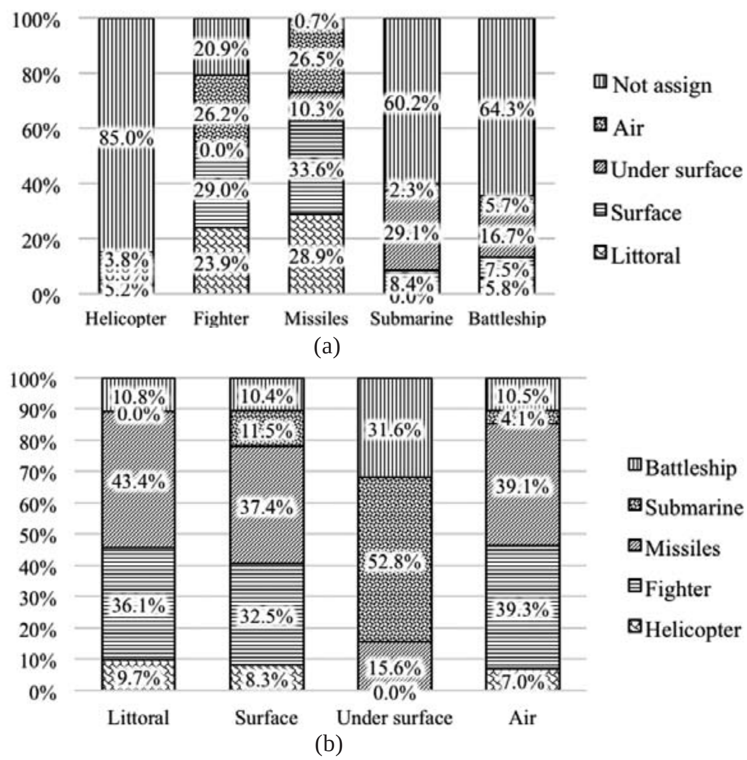

Figure 7. (a) The amount of the targets assigned to each site and (b) The amount of sites capacity assigned to each type of targets.

Table 7. The Conditions of three assumptive situations for research model validation

Assumptive situations			Number of sites and conflict capacity (C_j)				Number of targets (i)				
			Littoral	Surface	Under surface	Air	Helicopter	Fighter	Missiles	Submarine	Battleship
1	$\sum i > \sum C_j$	Num.	1	2	1	1	3	4	3	1	9
		(C_j)	2	3 2	2	2					
2	$\sum i = \sum C_j$	Num.	2	2	1	2	3	4	3	1	9
		(C_j)	3 4	3 4	2	2 2					
3	$\sum i < \sum C_j$	Num.	2	2	1	2	1	2	2	1	4
		(C_j)	3 4	3 4	2	2 2					

helicopters, has converged around 10 per cent.

To perform sensitivity analysis between the positions, the fourth position was defined by the experts. In this assumptive situation, every site has the possibility of conflict with any of the ten targets. An example of this sensitivity analysis is shown in Fig. 8, which is about comparing the assignment of helicopters in four assumptive situations. What is clear in this figure, is the fact that by going from the 2nd position to 4th, due to the fixed capacity constraints at position 4, there would be a descending and ascending routine. On the other hand, they try to reach the optimal conditions with no constraint. For example in position 4, because there are no capacity constraints, the best scenario would be assigning about 62 per cent of the helicopters to the air site. In position 2, due to the capacity constraints, this percentage is 21 per cent and other helicopters must inevitably be attacked by other sites. In position 3, which has less constraint than position 2, approximately 48 per cent of the helicopters are assigned to the air site, which almost indicates the ideal scenario as it is in position 4. In position 1, due to the extreme constraint of capacity in which many helicopters are not assigned, the results are not very comparable with the other three positions. In a general sense, it could be said that due to the defined conditions at the assumptive situations, the more the capacity constraints of the site reduces, more helicopters would be assigned to the air site and consequently fewer helicopters would be assigned to littoral and surface sites. The undersurface site has entirely no ability to have conflict with helicopters in any situations. Matching the routine results in Fig. 8 with the actual conditions was confirmed by the experts.

Another example of a sensitivity analysis on how to manage littoral site capacity of four assumptive situations is shown in Fig. 9. It can be assumed, the less the capacity constraints of the Littoral site, the more capacity should be dedicated to Battleships and missiles and vice versa, less capacity is dedicated to fighters and helicopters. Certainly this routine is more evident in comparing the positions 2, 3 and 4. Matching the routine results in Fig. 9 with the actual conditions was confirmed by the experts.

6. DISCUSSION AND CONCLUSIONS

In combat management, researches have been mainly aimed at 'threat assessment' and 'weapon-target assignment', while in this research an intermediate phase has been introduced.

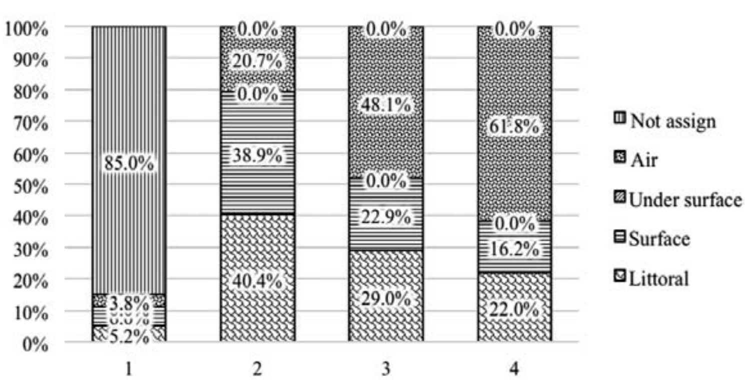

Figure 8. Comparison of the assignment of helicopters in four assumptive situations.

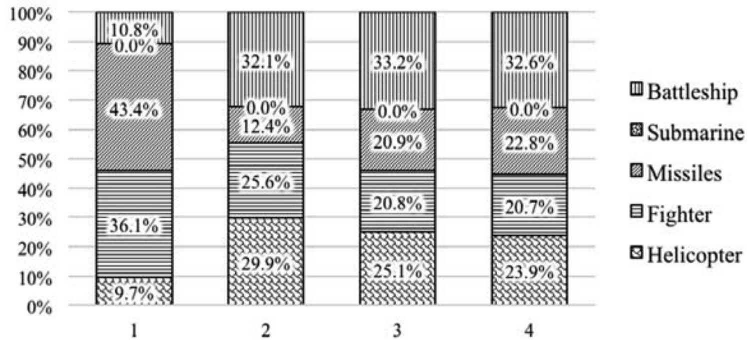

Figure 9. Comparison of Littoral site capacity management in four assumptive situations.

This phase consists of four steps in which the issues here had not been mentioned in previous researches. Threat assessment is being mentioned[9,11,24,25], but 'conflict scenarios' and 'target-site assignment' are not. The necessity of this intermediate phase is the simplification of the final issue and the definition of site conflict scenarios. Due to the complexity of the real combat situation, the model's efficiency would increase, once the issue is simplified and a more accurate answer is achieved. Consequently, in comparison with other assignment model[15,17,19], a linear assignment model is being presented based on a simplification of the issue. Even if there is a big number of targets and sites, it only takes about 3 s to solve the model by obtaining the information from the experts before the combat with the information from the sensors.

The idea of portfolio in combat management had been used[26], they have assumed that there is only one site on the battlefield and they did not discuss the conflict scenarios. Any target's threat is assumed to be the same with different weapons, while in the current study the threat is different in each site in addition to various sites and defined conflict scenarios. The assignment model presented[26], is a non-linear weapon-target assignment while in the current study, the linear target-site assignment is presented in which the solution time and the accuracy of the answers are more acceptable than in the non-linear model. The conflict constraints have not been considered for the weapons, and they have expected that all the weapons would enter the conflict with all the targets. But in the current study, it has evaluated different restricted and unrestricted situations. In their study, the weapons' capability in engaging the targets is expressed only as 0 or 1, while in the current study it is defined in a clear range. In that study, they only considered the hit probability as the weapon capability parameters, but in the current study three risk parameters are considered.

In this intermediate phase, the factors involved are as follows: determining the threat assessment weights by considering the fuzzy communication among these parameters; increasing or decreasing nature of such parameters; determining the risks and capabilities of the site with the targets in the conflicts; forming the threat-capability matrix per each site; determining the conflict scenarios for each site and designing the linear assignment model to determine the optimal conflict scenario. Another important point to be mentioned in this model, is that if in the operational environment before the battle, we could determine the probability of various values of the parameters; therefore, it is even possible to operate the running model for several iterations. The achieved converging data could even predict the future conditions of the battle along with the operational space and the site's scenarios.

The overall decision model, which was presented in the current study, in the form of two-dimensional matrix, can also be used in other fields; such as selecting the defence/non-defence projects. In this context, the projects are put in the target's place and the analysis will be done accordingly.

One limitation we have faced in this study, because of the possibility of the schematic diagram analysis in two-dimensional space, was the fact that no other dimensions were added to the model for the analysis and the creating scenarios. Further research on some battlefield issues such as the cost, the time and protection of a specific area are necessary which consequently affect the number of scenarios. For instance, if another axis called 'conflict cost' is added to 'threat' and 'capabilities', each site could have 8 scenarios instead of 4, and the best scenario occurs when there is the conflicts with the sites in which they have greatest threat, high capability and low costs. Another important point to be considered in future research, is considering all the existing limitations in a real environment for the assignment model, for the results obtained from the solved models have a more vivid resemblance with reality. Also according to the expert's opinions, other cases in objective function could be added; such as maximising the protection of specific geographic location and supporting a specific site. Furthermore, in the assignment model we could add the timing and the conflict transposition with the intervals between the two conflicts from one site, which certainly leads to a more complex model and the availability of more data. Another consideration in future research, should be the multi assignment of different sites to one target.

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