18th ICCRTS

Reduction of Decision-Making Time in the Air Defense Management

Paper number:108

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Abstract

The importance of defense systems has increased during the Second World War as a result of reducing efficiency of strong offensive capability used by battled countries owing to air defense systems. Countries have augmented their research and development studies. So, these studies caused rapid development of defense systems. Along with the inclusion of network-enabled capability, there has become a mass of information. As a result of this, evaluation of information which is dynamic at battlefield has become harder and there has been a requirement for usage of computer-based systems that could make the process effective and shorten it.

In this study detailed literature scan has been done and has been used value focus thinking as an analysis method, the information that has been obtained from network enabled capability couldn't be used effectively in air defense management. It has been stated that studies on these deficiencies is continuing and countries such as U.S. Navy and China is in advance in this field.

To eliminate deficiencies that mentioned above, some suggestions have been made in this study. It has been evaluated that the process of decision-making is going to be shortened and it will become more effective and economic.

Keyword: Decision-Making, Decision Support, Air Defense, Air Defense Management, Threat Evaluation, Weapon-Target Assignment

1. Introduction

Airspace control has become more complex as a result of improving technology, increasing number of civilian/military, piloted/unmanned aircraft in the airspace, each force's tending to use of their own air defense systems, the need for further coordination in order to prevent fratricide, researches of countries and companies for cost-effective solutions. This complexity is tried to overcome with a variety of methods and procedures. However there is a new methods and computerization for faster operation of the process

Various countries are able to hit the target they detected as soon as possible with time-sensitive and dynamic targeting. But these systems are often used against ground

[1] Point of Contact

targets. Even if the same process is operates against air target, it will lose effectiveness and cannot be used when the number of targets increases. In addition, the whole air defense systems will not be able to use. When the air defense systems needed, the reaction should be fast. Optimum task sharing by comparing friendly and enemy positions has a great importance.

In this study how to use air defense systems effectively and how to do task sharing at the first reaction of irruption style of air attack began has been examined.

2. Overview of Air Defense

NATO describes air defense as “All measures designed to nullify or reduce the effectiveness of hostile air action.” in Glossary of Term and Definitions (AAP-6).(NATO, 2012)

Department of Defense defines as “Defensive measures designed to destroy attacking enemy aircraft or missiles in the atmosphere, or to nullify or reduce the effectiveness of such attack.” in Department of Defense Dictionary of Military and Associated Terms (DOD, 2010).

Air defense management has four basic steps:

- Detects the presence of airborne objects, aircraft or missiles,
- Identifies them as friendly or hostile,
- Intercepts and examines those not identified as friendly,
- Destroys those identified as hostile, using interceptor aircraft or air defense missiles.

Air defense begins with detection of any flying object from sensors. Radar operator makes a tactical situation evaluation and defines track as unknown, friend, assumed friend, neutral, suspect, hostile (MIL-STD-2525C, 2008). If the object identify itself, there isn’t any problem. Only track is labeled as friend and continued to tracing. If radar detect it as hostile, command and control center makes a decision for using defensive weapon to the aircraft. Decision maker evaluate threats and tactical situation in real time and assigns available defense system to the threat. This procedure needs effectively coordination and rapid evaluation for threat. The efficient execution of air defense operations requires the ability to quickly detect a potential air defense threat, identify it, target and track it, and attack it (AFDD-3-01, 2008).

3. Related Studies on the Subject

According to Benaskeur there are five command and control functions for air defense mission success:

a. Target detection,

b. Target tracking,

c. Target identification/classification,

d. Threat evaluation,

e. Weapons assignment:

    (1) Response Planning,

    (2) Response Execution,

    (3) Outcome Assessment

“This process necessitates a highly dynamic flow of information and decision making that involves a number of operators and sophisticated support capabilities.” (Benaskeur, Bossé, & Blodgett, 2007)

Threat evaluation and weapon assignment are two basic command and control function of air defense.

The term of “Weapon assignment” are also used as “target weapon assignment” and “weapon allocation” in literature.

Real-time decision system has functional components:

- Information management and data fusion,
- Situation assessment,
- Evaluation of alternatives,
- Decision (Seguin, Potvin, Gendreau, Crainic, & Marcotte, 1997)

Information flows continuously from network capability. Mass of information usually is not usable and needs to be evaluated. Detection of threat position and intention, and knowing of own capabilities and readiness of defense components are important for situation assessment. There should be answer to the questions like “what is the target of threat?”, “what kind of capacity has to carry weapons?” After identifying the enemy’s course of actions, solution are sought and the alternatives are evaluated in order to eliminate the danger.

There are lots of studies about threat evaluation and weapon assignment. Studies on threat analysis has been shown below:

- Grey rational analysis method (Duan, Zhang, Ma, Zhang, & Yang, 2010), (Jiaquan, Kaizhuo, Wei, Dapeng, & Yang, 2008), (Yongxin & Kaizhuo, 2008),

- Fuzzy logic (Hamed & Sobh, 2004), (Kumar & Dixit, 2012), (Li-ying, Qing, & Min-xia, 2011),

- Hybrid Learning with multi-agent coordination (Azak & Bayrak, 2008),

- Bayesian network approach (Fredrik Johansson & Falkman, 2008),

- Interpolation model (Xin, Chao, Zhengjun, & Jichang, 2010),

- Stable marriage algorithm (Naeem & Masood, 2010).

Studies on weapon assignment has been shown below:

- Particle swarm optimization (Bo, Feng-xing, & Jia-hua, 2011), (Thangaraj, Pant, & Nagar, 2009), (S. Wang & Chen, 2012), (Huadong, Zhong, Yuelin, & Yunfan, 2012), (Delin, Zhong, Haibin, Zaigui, & Chunlin, 2006),

- Ant colony optimization (J. Wang, Gao, Zhu, & Wang, 2010),

- Genetic algorithm (M. Alper Şahin & Kemal Leblebicioğlu, 2010), (Mulgund, Harper, Krishnakumar, & Zacharias, 1998), (Zne-Jung, Shun-Feng, & Chou-Yuan, 2003), (De-Lin, Chun-Lin, Biao, & Wen-Hai, 2005),(Mulgund et al., 1998),

- Very large scale neighborhood search algorithm (Niu, Gao, & Li, 2011), (Ahuja, Kumar, Jha, & Orlin, 2007),

- Fuzzy logic (M.Alper Şahin & Kemal Leblebicioğlu, 2010).

Prominent studies are “Tactical Decision Making under Stress” (Cohen, Freeman, & Thompson, 1997), “Threat Evaluation and Weapon Allocation” (Turan, 2012) and Evaluating the Performance of TEWA Systems (Fredrik Johansson, 2010).

“Tactical Decision Making under Stress”, model of decision-making based on recognitional and metacognitive elements. “A model of decision making based on this principle has been developed, and training has been designed based on the model.” TADMUS has focused on training to improve decision-making and team skill, and computer based decision support. (Cohen et al., 1997)

Liebhaber has studied about comprehensive set of cues, established the mapping between aircraft and threat rating, and determined the effect of conflicting data on threat rating. The study is about identifying and describing the factors of air defense and, assessing and prioritizing the threats (Liebhaber & Smith, 2000).

Another study is Threat Evaluation and Weapon Allocation (TEWA), computerized systems supporting human air defense decision-makers with the real time threat evaluation and uses these threat values to propose weapon allocation (Turan, 2012). Turan studied only static based weapon-target allocation. She evaluates and analyzes 19 algorithms, recommends suggested algorithm for the optimal solution.

Johansson makes another TEWA study. The purpose of threat evaluation is to determine the level of threat posed by detected air targets, to allocate available firing units to threatening targets, in order to protect the defended assets (Fredrik Johansson, 2010).

There have been lots of researches about threat evaluation. Generally, the parameters used in these researches are similar to each other. Especially, the basic parameters, which are determined by Liebhaber, are generally accepted and used most of studies. Generally threat evaluation algorithms are based on fuzzy logic, artificial neural networks, and Bayesian networks.

As the time for solution of weapons allocation problem is very long, heuristic algorithms are used for it. Different algorithms excels in the studies which compare the heuristic algorithms, due to the different models and different number of samples for solution. However genetic, maximum marginal return and particle swarm optimization algorithms excels with reliable and rapid solution.

4. Threat Evaluation and Weapon Allocation

Air defense optimization is done in two phase. The first phase is threat evaluation and second phase is weapon assignment. First of all, air picture tracks should be sorted by doing threat evaluation as Liebhaber's study. Then, user should identify it as a threat and the second phase should be started. Pairing the available weapons to the suitable target is done at this phase. After sharing, information about the mission should be sent.

Threat evaluation comes after the detection process in the air defense management. Threat evaluation is used at identification of the detected track and defining it as friendly or hostile. Allocating available firing units to threatening targets and destroying those identified as hostile is necessary. In this process, as the number of threats and weapons increase, the number pairing possibilities increase excessively. It becomes impossible for the staff to solve the problem and they must use computer systems for it.

4.1 Threat Analysis

Liebhaber has identified 6 basic (origin, IFF mode, intel, air route, altitude, radar and electronic) totally 17 (speed, closest point of approach, feet wet/dry, maneuvers, number/composition, own support, range/distance visibility, weapon envelope, wings clean/dirty) for threat evaluation (Liebhaber & Feher, 2002).

Parameters are divided into three main sections in the research of Turan:

- Proximity parameters (CPA, Time to CPA, CPA in units of time, time before hit, distance),

- Capability parameters (target type, weapon type, fuel capacity, max. radius of operation) and

- Indent parameters (target's kinematics, number of recent maneuvers) (Turan, 2012)

The same classification is made by Johansson. But there is *IFF* and *lethality* in capability parameters too. Also the indent parameters includes *following air lane*, *coordinated activity* and *feet wet* (Fredrik Johansson & Falkman, 2008). *Feet wet* parameter is quoted from Liebhaber's study (Liebhaber & Feher, 2002).

Threat Analysis of detected track is done according to the parameters shown at Figure 2 and value Analysis is done according to the parameters shown at Figure 7 with value-focused thinking. At the end of these Analysis it will be possible to sort threat priorities which we use at evaluating threat.

Value-focused thinking has ten steps (Jurk, 2002). When we apply value-focused thinking on threat evaluation:

Step 1: Problem Identification

"Determining the threat levels that gathering from sensors" is defined as problem.

Step 2: Construct the Value Hierarchy

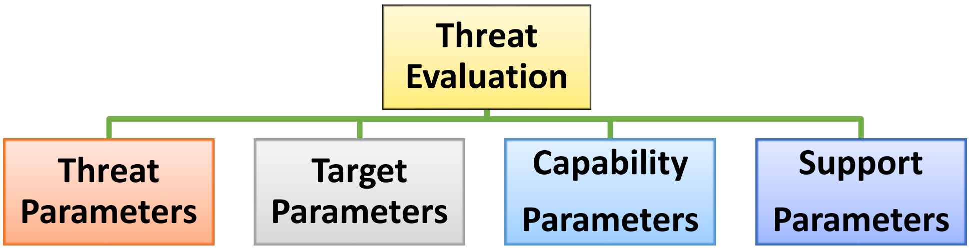

Figure 1 - Threat evaluation values

Decision-makers make some evaluation when the phase of identifying detected track. As a result evaluations, appropriate characterization will be done and if necessary tactical reaction is started. In this study, in order to evaluate the level of tracks being threat four main parameter groups defined. These groups will generate values of value-focused thinking. Values are shown at Figure 1.

Step 3 -Develop Evaluation Measures

The evaluation measures at Figure 2 are defined by evaluating value hierarchy at Figure 1.

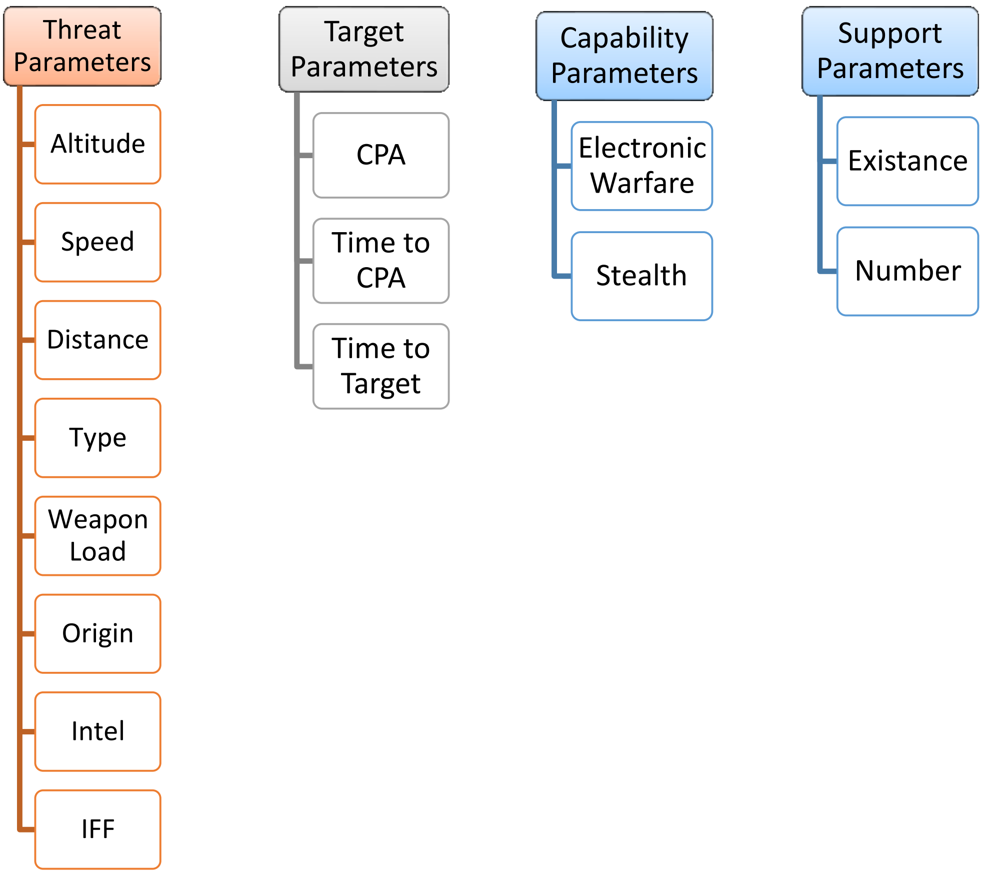

Figure 2 – Threat Analysis measures

Step 4 -Create Value Functions

Value functions for each measure must be created as a result of the conversation made with decision-maker. Paper counselor is chosen as decision-maker and appropriate values functions and categories are created after conversation.

Step 5 -Weight the Value Hierarchy

Each value's and measure's weights are pairwise comprised, ratio and sensitivity are calculated. Pairwise comparisons are made as shown at Figure 3.

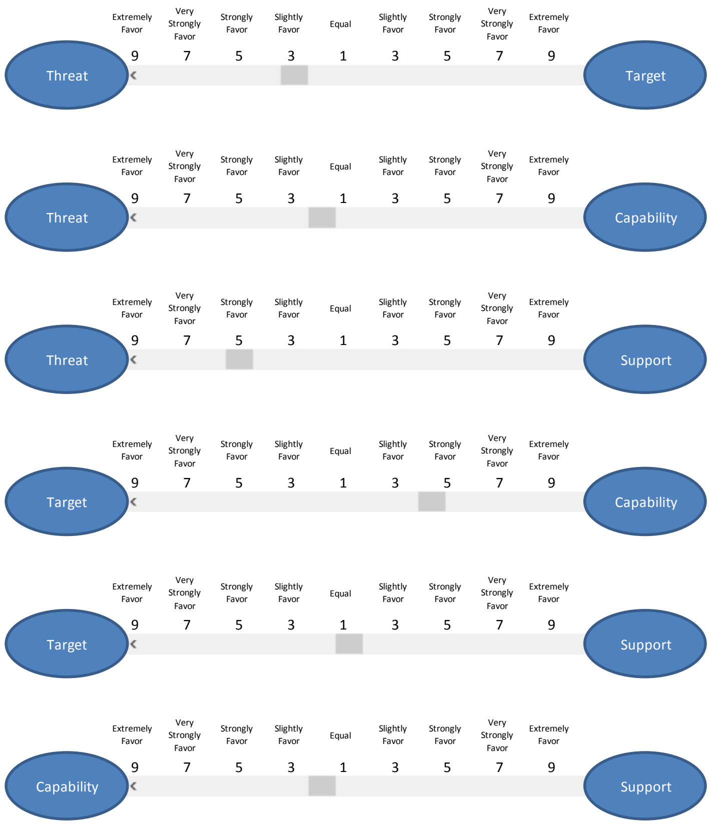

Figure 3 – Assessing the weights with pairwise comparisons

At the end of pairwise comparisons weights which are shown at Table 1 are determined and global weights are calculated.

Values	Weight	Measure Name	Weight	Global Weight
Threat Parameters	0,55	Altitude	0,13	0,072
		Speed	0,10	0,055
		Distance	0,10	0,055
		Type	0,05	0,028
		Weapon Envelope	0,06	0,033
		Origin	0,14	0,074
		Intel	0,22	0,119
		IFF	0,21	0,115

Target Parameters	0,12	CPA	0,45	0,054
		Time to CPA	0,35	0,042
		Time to Target	0,20	0,024
Capability Parameters	0,25	EW Capability	0,50	0,125
		Stealth	0,50	0,125
Support Parameters	0,08	Support Existance	0,50	0,040
		Number of Support	0,50	0,040

Table 1 – Global and Local Weights

Step 6 -Alternative Generation

There are six tracks, three strategic target, airbases, surface to air missiles and radars at the Figure 4 scenario map. Also the information about the tracks at the scenario is given at Table 2.

In this study one thousand track information are created, threat levels are calculated and sorted for measuring the system efficiency and speed except the scenario.

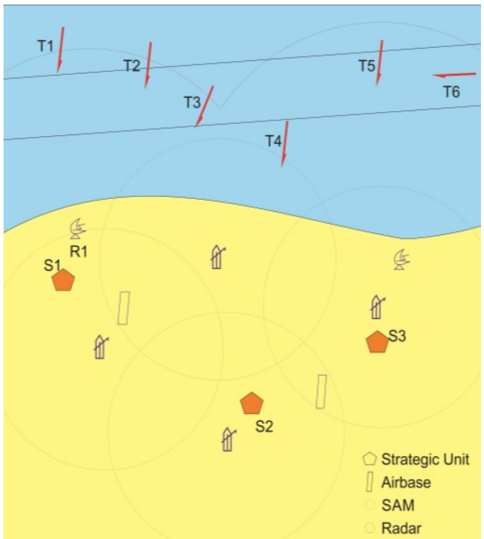

Figure 4 – Scenario Map

	T1	T2	T3	T4	T5	T6
Altitude (100XFeet)	15000	100	100	4000	30000	12000
Speed (Knot)	420	440	480	400	410	400
Distance (NM)	25	50	25	15	35	40
Type	Civilian	Unknown	Unknown	Unknown	Unknown	Civilian
Weapon Envelope	No	No	Precision 15nm	Precision 25nm	Precision 50+nm	No
Origin	D	E	C	B	A	B
Intel	No	No	No	No	No	No
IFF	Friendly	Unknown	Unknown	Unknown	Unknown	Unknown
CPA (NM)	26	20	20	14	18	32
Time to CPA (minute)	2	2	1	2	2	2
Time to Target (minute)	1	2	1	1	1	2
EW Capability	No	No	No	No	No	No
Stealth	No	No	No	No	No	No
Support Existence	No	No	No	Yes	Yes	No
Number of Support	0	0	0	2	2	0

Table 2 – Track Info

Step 7 -Alternative Scoring

The values shown at Table 2 for each alternative is calculated according to defined functions. The results are summed according to their weights and each ones' being threat value is calculated.

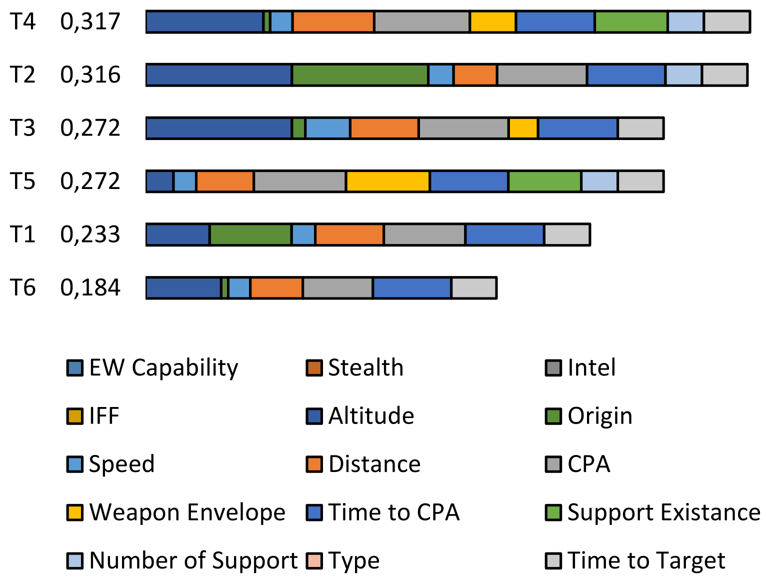

Figure 5 – Level of Threats

Step 8 -Deterministic Analysis

Alternatives are sorted and threat priorities are obtained. For this scenario threat priority will be like this: T4 > T2 > T3 > T5 > T1 > T6, as shown at Figure 5. When we evaluate the information at Table 2, we see that the sorting is appropriate as expected.

Step 9 -Sensitivity Analysis

Threat and support values, altitude, distance and origin measures are sensitive at the sensitivity analysis. If its weights are increased, priority of T2 will increase. It is seen that sensitivity of other parameters are less.

Step 10: Recommendations and Presentation

The results of the study that deterministic and sensitivity analysis have finished are presented to the decision-maker. Decision-maker can change the priority of threat by interfering in if he wants. But the results are calculated according to functions which are defined and valued by him. The scenario's results should be coherent with the results identified by decision-maker and it is seen coherent in this scenario.

4.2 Value Analysis

Threat evaluations second dimension is the importance of the target. As Liebhaber made his study on ship defense there was single or a group of target. On the other hand when country defense thought the number of targets need to defense is more and it is necessary to give priority. After Johansson made threat evaluation he used the protection value of defended target (Fredrik Johansson, 2010).

Value analysis intent target is identifying the defense order of the target which enemies attack. As targets are stable and there is less variable parameters it is enough to make value analysis only one time at the peace time. But if there is necessity reanalyzing can be done in a very short time. In value analysis, target's value is given in Figure 6. The measures defined for values can be seen at Figure 7. Their weights are stated under the defined values and measures.

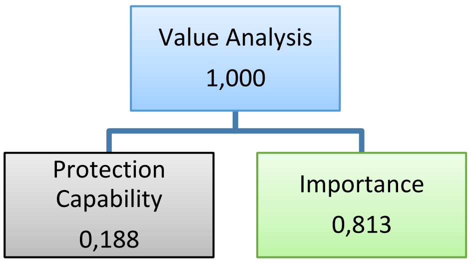

Figure 6 – Value Analysis Values and Weights

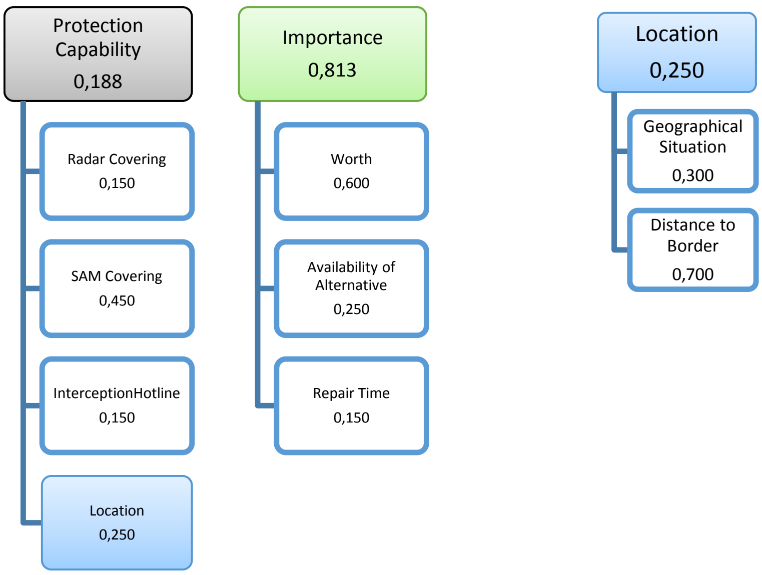

Figure 7 – Value Analysis Measures and Weights

In value analysis target's protection capability and importance are the values. Probability of being damaged will increase as a result of targets' being unprotected. So the less protected target needs more defense than more protected one and threat ratio will increase to these threats. While the next process, weapon assignment, is being done it is aimed to increase the efficiency of limited defense resources by giving priority to the less protected targets.

Importance parameter is defining how much the availability will decrease and how much the attack will effect in case of a damage. The "worth" measure in importance value has a big size which can be another study subject. Worth measure, can be obtained and used by evaluating elements of national power. Having another alternative is another value measure. If it is difficult or impossible to get defended targets' output from another source, availability of alternative will be critical. Contrary more alternatives will decrease value and importance ratio.

In value analysis, value-focused thinking is applied as in threat evaluation. Targets' priority is defined according to the information given at the scenario. At the end of evaluation on strategic targets, the results seen at Figure 8 are obtained. The priority sorting can be done like S1 > S3 > S2 according to value analysis.

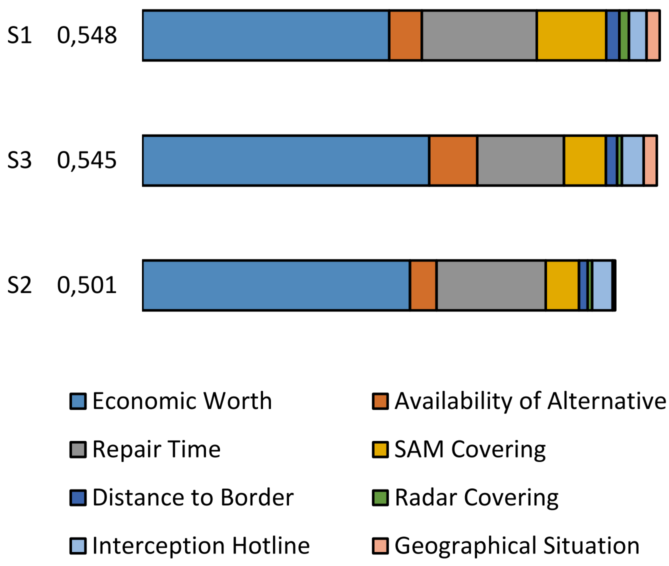

Figure 8 – Value Analysis Results

Threat level priority is updated according to the result got from value and threat analysis. The value of threats will be updated in accordance with its position and distance to strategic target.

		S1	S2	S3	S1	S2	S3	Total
Threat	TA Value	0,55	0,50	0,55				
T1	0,23	45	80	90	7,03	2,33	1,27	10,63
T2	0,32	48	72	75	9,08	4,51	4,30	17,89
T3	0,27	48	60	60	7,82	5,45	5,92	19,19
T4	0,32	55	53	45	7,82	7,54	9,50	24,86
T5	0,27	80	74	56	2,98	3,61	6,52	13,10
T6	0,18	94	80	56	0,66	1,84	4,42	6,92

Table 3 – Combining threat and value analysis' results

$$\sum_{i=1}^{m}\prod_{j=1}^{n} t_j s_i (100 - d_{ji}) \ (4.1)$$

By using the formula 4.1, priority levels are found according to distance between threats and targets. As the most effective threat's missile range is 100NM the distances are subtract from 100.

T: Set of threat,

A: Set of strategic target,

t_j: Threat T_j's threat analysis result,

s_i: Strategic target's A_i's value analysis result,

d_{ji}: Distance between T_j to A_i,

2.1.2 Weapon Allocation parameters

In the first part of Table 3 values obtained from threat and value analysis and the distances between threats and targets are given. As a result of calculations threat priority was T4 > T2 > T3 > T5 > T1 > T6, it has changed T4 > T3 > T2 > T5 > T1 > T6 because of threats' positions. T3's having higher priority than T2 as a result of its position has been calculated.

In value analysis, the aim is identifying the defense priorities of target. In the threat analysis before passing the next step, the effects of this evaluation are injected. Briefly threat analysis was re-evaluated according to target priority and level of importance, and the results will be used at weapon assignment.

4.3 Weapon Assignment

The weapon allocation problem has two versions: static and dynamic and can be classified as target-based and asset-based (Turan, 2012). Static target-based weapon allocation problem can be used in ground based air defense systems. Well known heuristic approach for Static target-based weapon allocation is the greedy maximum marginal return algorithm(Fredrik Johansson & Falkman, 2011). Dynamic target-based weapon allocation problem has rapid changes and needs reevaluation.

Weapon allocation process aims optimally assigning weapon to target. Process based on one of the three solutions(Turan, 2012):

- Minimize the threat's survival value,
- Minimize the defended asset's damages,
- Maximize the all survivability of assets.

Minimize the threats survival value is generally use in the calculation. Making comparison of study's correctness and efficiency is not verified in real exercise.

To minimize the cost of the damages targets can cause and missiles used against threats, the formula 4.2 will be used.

$$Minimum\ Cost = \sum_{i=1}^{T} \left[C_i \prod_{k=1}^{A} \varepsilon_{ik} \prod_{j=1}^{w} \left(1 - P_{ij}\right)^{X_{ij}} + \sum_{j=1}^{w} C_w X_{ij} \right] \quad (4.2)$$

T: Set of threat

W: Set of weapon

A: Set of strategic target

P_{ij}: killing probability of weapon W_i to threat T_j,

X_{ij}: If W_i engage T_j -> 1 else 0,

C_i: Economic worth of strategic target,

ε_{ik}: Estimated probability threat T_i to strategic target A_k,

C_w: Cost of each missile launch by weapons,

In this scenario T1 and T2's IFF information is identified as "friendly" and as being threat value is the least there aren't used at the weapon assignment. The number of weapons and costs of weapons and targets are seen at Table 4 and Table 5. Probability of weapons killing targets and threats killing targets are given at Table 6.

	W1	W2	W3	W4	F1	F2
Cost	12000	45000	40000	60000	35000	40000
Missile number	2	4	2	2	2	2

Table 4 – Missile numbers and costs

S1	S2	S3
7.000.000	7.500.000	8.500.000

Table 5 – Targets economic worth

	W1	W2	W3	W4	W5	W6		S1	S2	S3
T2	50%	40%	0%	3%	45%	40%		89%	42%	22%
T3	52%	78%	3%	10%	45%	40%		75%	41%	26%
T4	10%	54%	15%	60%	45%	40%		40%	95%	45%
T5	0%	10%	60%	20%	45%	40%		15%	50%	89%

Table 6 - Probability of weapons killing targets and threats killing targets.

As a result of evaluation it will be appropriate to make weapon assignment just like at Table 7.

Weapon	**W1**		**W2**				**W3**		**W4**		**W5**		**W6**	
Missile No	1	2	1	2	3	4	1	2	1	2	1	2	1	2
Threat	T2	T2	T4	T4	T3	T3	T5	T5	T4	T4	T2	T2	T5	T5

Table 7 – Weapon assignment result

5. Discussion

In threat analysis, the classification done before evaluated and separating four groups is better. Capability parameters are the parameters which show tracks' not being civilian plane. Also some values of threat parameters have some merits civilian planes don't have, just like supersonic flight, very low altitude navigation etc. These merits will cause perceiving as hostile. If there are AWACS, J-STAR, Tanker planes, if they contact with them, the number of planes around track will increase the level of being threat.

Weighting is determined by the conversation with counsellor. This data can be updated with a study intended for the users of air defense system. A model was created and it is seen that process is much faster than classical methods. It is detected that a thousand threat data can be evaluated in 148 milliseconds.

The system will transform dynamic from static form with executing the threat analysis continuously. By recording its past, instant changes at threat level ratio can be followed and it will be easy to pay attention for major changes by users.

Parameters defined in threat Analysis, the information on these parameters transferred to the system and the result is obtained by evaluating various methods. The evaluated results made by the staff and by application are compared and seen that they are coherent. Although the researches and the parameters has some difference, results are similar too. Application assist the decision maker who has bias, being heavy duty, tired. Application doesn't directly make decision and allows the user making the last decision. As a result, errors misevaluated from application source or cyber threats will be prevented and will be flexible under unpredictable situations.

Threat analysis output is used for weapon assignment. But threats position and the values of the targets they head to attack aren't considered. In this study after threat analysis, an analysis of threat's headed targets' values is done. In value analysis targets protection capacity and their importance are considered. Radar and SAM covering, interception hotline position are considered in protection capability. Also, geographical situations of the region and distance to the border are mentioned. The reason of accepting weight of protection capability as 0,188 is considering parameters intended for targets in threat analysis. Despite the parameters headed target in threat analysis are the parameters connected between threat and target, in value analysis protection parameters are target oriented. In spate of T2's having higher priority than T3 in threat analysis, T3 has higher priority than T2 when updated with value analysis. In fact, that they have same CPS value for S1. But T3's position is more valuable than T2. T3 has a capacity to head S1 and S2 and has less distance than T2.

It is aimed to minimize costs in weapon allocation. The cost of damage is calculated by considering the threats' possibility of killing targets which survive after weapons effects. Moreover missiles' costs used for defense are mentioned. The whole cost is found by the calculation of both values. If heuristic algorithms aren't used there are 4^{14} (268.435.456) possibilities at solution model. It takes 58 hours to solve this process with a computer having Intel Core i5-3317U Cpu (1.7 Ghz), 4gb RAM. With heuristic algorithms this time can be decreased under two seconds.

Actually, arbitrament couldn't be left to the algorithms executing air defense. These algorithms should be used in decision support; because aforementioned algorithms are just listing all the works of personnel in a sequence and coding that. It's possible to result all computing and works just after following a sequence and hierarchy. To do all the routine works faster, complete and standard is the main advantage of the information systems.

6. Conclusions

Most warfare has taken place within "human space," meaning the traditional four-dimensional battlespace that is discernible to the human senses. Future wars will be abandoned the human dimension (Adams, 2011). Classic decision-making process depends on past experience. If decision-makers are experienced, decisions can be made close to the truth. If not, air defense sources can't be used effectively and will increase the possibility of taking damage. If there are 4 hostile units and 10 defense units, there are 4^{10} probabilities to pair threats and weapons. Probabilities' evaluation time and selection of the best solution made by decision-makers is higher than computerized optimum solution time. As the numbers increase time difference between human decision-making and computerized solution further increase. Air defense has time sensitive nature and in case of lateness results may cause fatality. The prolongation of the period results catastrophic damage that can't be repaired in time. In that case, computerized solution increases the importance in air defense command and control.

In these verified algorithms, if the dimensions or contents of using paradigms change, all the results will also change. This is why different algorithms succeeded in different researches. Redundancy of threats, variety of weapon and munitions, difficulty of assignment, problem of time and excessive flow of information matters constrain decision makers and harden to decide in a clear judgment. Valuable information provided by network enabled capability couldn't be assessed due to density. It is seen that the model has reduced the time of decision making. It's a necessity to use this model at air defense management.

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