Optimization of Decision Support System Based on Three-Stage Threat Evaluation and Resource Management

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Abstract - **This paper demonstrates a novel decision support system for threat evaluation and weapon assignment (TEWA). The knowledge-based system is built on threat perception, optimal schedules and assignments of weapons available for the threat neutralization. Mostly, in real warfare circumstances, the quantity of threats targeting vulnerable assets/points (VA/VPs) is large in comparison with the deployed resources. Therefore, performing threat analysis and weapon assignment is critical in real-time scenarios. In this research work, an integrated unique technique is proposed for automatic TEWA technique for effective threat neutralization. Our results show that the proposed approach significantly improves on traditional manual system. In previous studies, threats are categorized based on the type assumptions and weapons are assigned accordingly. In this paper, an efficient TEWA-DSS is presented for (1) threat perception and optimum (2) multiple threat scheduling problem. This process is comprised of three stages. At first stage, threat is perceived. At the second stage, threats are evaluated. At third stage, weapons are scheduled and assigned optimally.**

Keywords – **Control, Knowledgebase, Perception, Threat Evaluation, Threat Index, Surveillance, Weapon Assignment.**

I. INTRODUCTION

Strategic cognitive decision making in real time military environment is a critical activity. The problem concerns with the threat assessment and available resource management to achieve the optimal and favorable solutions with constraints, uncertainties and other requirements. [1] In a military environment, an operator is responsible for the efficient threat identification and optimal weapon assignments (WA) process. Such situations require rapid decisions to protect vulnerable assets/points (VA/VPs). Threat Perception (TP) and evaluation activities are divided among the number of operators [2]. Mostly, there are perilous occurrences where quick decisions are essential for efficient threats neutralization as well as protection of VA/VPs. In this context, Threat Evaluation and Weapon Assignment (TEWA) are the fundamental modules of Air Defense System (ADS) [3]. In critical situations, manual threat evaluation (TE) is considered problematic because of cognitive decision making. The observer state of mind affects the TE, because he is under extreme pressure while making the decisions. Efficient weapon selection highly depends upon observers input. [4] TEWA is considered a complex system in which decisions are taken using multi-criteria approach. The important constraints of TEWA are real-time decision making. [5] In real warfare circumstances, threats must be identified, categorized and prioritized based on its known characteristics.

The weapons are deployed on the categorization of areas' vulnerability and weapon assignment refers to the reactive assignment after identification of threats. The weapons assignment problem is intricately linked with minimization of expected survival value of targets. Considering the complexity of weapon assignment problem with its constraints, fuzzy decision making can be effectively used by commanders to make quick and effective decisions [6]. Conventionally, threats are categorized based on its capability and intent. The intent is willingness and challenging to measure while capability refers to ability and can be measured using TE models [7-9].

In this paper, an efficient real-time TE and WA model is proposed to cater many-to-many relationship based on threat-weapon mapping. This proposed model contains knowledge-base for analysis and capability identification of threats. Section II of this paper, describes literature survey. The TEWA model is demarcated in section III. The results are described in section IV. Finally, the conclusion is presented at the end.

II. LITERATURE SURVEY

TEWA is a multi-layered system. The prime objective of this system is to efficiently evaluate threats and formerly assign available weapons accordingly. It is used to optimize available resources. TE is considered a key stage of TEWA. Classifying a wrong threat would cause system failure [10]. In TE, threats are identified and categorized based on its intent and capability. TE is particularly depends upon the contextual information and the established air situational picture [11]. In the previous literature, it is observed that threats are evaluated based on its capability and intent [12]. In TE, measuring the threat stabilization in maneuvering situations is a vital concept. The approach using Kohonen's self-organizing maps is an effective tool for such problems [13].

The decision support system (DSS) and strategic management are strongly dependent on each other. To be

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effective and competitive, it is necessary to cope with uncertainties and to reduce ambiguity in decision making, As compared to threat evaluation, weapon assignment has been studied more thoroughly. Weapon assignment is considered as a scheduling problem [14]. TE parameters are categorized as intent, capability and proximity. The intent refers to threat kinematic. The capability states the threat's capability to damage the VA/VPs and the proximity refers to the distance between threat and VA/VPs. [15]

Several techniques are demonstrated based on Bayesian and fuzzy logic rules. Each has its pros and cons depending upon different aerial situation. Bayesian technique has a strong foundation as compared to fuzzy logic. Bayesian technique is much more flexible and able to handle missing parameters. A hybrid technique is used to find optimal solution [16]. Nature has a best optimized system, especially how the ants transfer information. In [17] optimization techniques are presented based on ants' communication. Another approach of self-governing is adopted for optimization. Self-governing mechanism is used to identify certain situations and determine the resultant courses of action. Such systems are useful in guiding commander about their decision [18].

III. SUGGESTED APPROACH

A. Threat Evaluation Model

TP is a fundamental module of TEWA system. The effective threat identification would result in efficient utilization of available resources. The threats are identified and arranged based on numerous parameters including threat height, speed, dive angle, maneuvering capability, approach to VA/VPs, radar cross-section, and etcetera. The more number of parameters used in TP results the more precise TP. All threats along with their parameters are stored in a knowledge-base. Knowledge-base is an intelligent system. It facilitates for decision making process. This input is conveyed to data mining algorithm which outcome is a tree along with confidence level. Here, another useful strategy for TP is being added i.e. knowledge-base contains all the existing threats with their critical parameters.

Threat Index (TI) is calculated based on the threat identification process. The threats are ranked from most threatening to least one using TI. Conventionally TI is premeditated based on capability and lethality index [19]. In this research, the several other factors have been included in TI calculation including distance to nearest VA/VPs, threat capability/lethality, threat formation, height, and speed, holding missiles, maneuvering capability, missile ranges, threat profile and etcetera. WA is based on TI calculation.

In proposed TE strategy, location of threat is received from various sensors. The collected information is fused to generate the consolidated picture. This threat contextual information is further used to find distance of threats from the all approachable VA/VPs.

In TP model, there are multiple layers. It is basically used to integrate TP module with the other real-time applications. The interface module provides the interoperability between various components. It acts as a conduit between real-time applications and central processing module. This central processing module is built using the data mining algorithm. Knowledge-base is directly connected to central processing module. The prime aim of this connection is to support the classification tree. The classification of threats is based on numerous parameters. Radar cross section is a vital feature. The threat maneuvering situation is extremely difficult to attain a precise radar cross section. Based on numerous other factors, the confidence level is developed that specifies the level of trust on proposed TP model.

Confidence factor (CF) is a function of numerous parameters as heat signature, flight plans, thermal images, speed, cross section, ceiling)

Based on the availability of data acquired from sensor, it is possible that all these parameters may not be available. In such case, algorithm can intelligently use available information to compute TI.

To calculate TI, the process is shown below:

$$TI(\boldsymbol{i})=\left(\frac{\mathbf{1}}{\alpha+\beta}\right)\ (\sum_{j=1}^{n} \boldsymbol{\alpha}\, \boldsymbol{F_{ij}}(\boldsymbol{x_{ij}}) + \sum_{j=1}^{n} \boldsymbol{\beta}\, \boldsymbol{F_{ij}}(\boldsymbol{y_{ij}})\ )$$

Where

$$\boldsymbol{F(x_{ij})} = \begin{Bmatrix} \boldsymbol{d_{ij}} \\ \boldsymbol{ht_{ij}} \\ \boldsymbol{h_{ij}} \\ \boldsymbol{nv_{ij}} \end{Bmatrix}$$

$$\boldsymbol{F(y_{ij})} = \{\boldsymbol{f_{index}}\}$$

$F(x_{ij})$ → established on distance, height and heading vectors

d_{ij}→ distance of threat i from VA/VP_j

ht_{ij} → height of threat i from VA/VP_j

h_{ij} → heading vector of a threat i towards VA/VP_j

nv_{ij} →numbers of VA/VP j threatened by a specific threat i

$F(y_{ij})$ →formation index based on threat's profile and formation

α and β weights assigned based on the graphical circumstantial information.

B. Weapon Assignment Model

WA is based on TI, calculated in above section. The main objective of WA is to efficiently utilize the ammunitions. Especially in such cases, where multiple threats are heading towards the same VA/VPs. WA module receives an input from TP phase. This input is categorized based on TI. Weapon selection and its assignment is a process comprised of three stages. The first stage is to select all the candidate weapons. The candidate weapons are selected based on threat current location and heading.

Among candidate weapons, an optimum threat-weapon pair is searched based on weapon's kill probability and threat's TI. This selection of weapons is highly dependent upon capability and kill probability. Knowledge-base is used to determine weapon features, kill probability and state. Weapon state encompasses information such as: out of order, functional and ammunition left. These parameters play a vital role in weapon selection. Once an optimum pair of threat-weapon is found; the proposal is forwarded to the selected weapon. The point of engagement of selected weapon is calculated at this stage. The knowledge-base is used for calculation of POE; weapon start, range and sweep angle are used for calculation of POE. Subsequent stage is to find best available slot for the proposed threat. If the weapon is free and available during that specified POE time. It accepts the proposal of threat engagement else threat is rescheduled on the next available slot. Subsequent engagement slot is determined based on several parameters including weapon stabilization time, reload time, ammunition left, time to move from threat POE to another threat POE. The knowledge-base is used to provide weapon information.

If selected weapon is busy and there is no available slot. Then threat's proposal is sent to next optimum selected weapon. The process continues until threat is assigned. In this paper, the real warfare circumstances are assumed with no constraints on weapons regarding the number of threats. But the limitation is based only on the weapon physical system.

Weapon assignment is also based on the following constraints, (1) out of stock, (2) obsoleted and (3) less in quantity.

T_i > defined threshold value
X_{ijt} → threat i is assigned to the weapon j at time t

Maximize

$$\sum_{t}^{v}\sum_{j}^{m}\sum_{i}^{n} T_i X_{ijt}$$

Where

$W = \{W_1, W_2, W_3, \ldots, W_m\}$, m = total number of Weapons
$T = \{T_1, T_2, T_3, \ldots, T_n\}$, n = total number of threats

Weapon constraint: weapons per threat

$$\sum_{i}^{n}\sum_{t}^{v} X_{ijt} \le W_j \;\; \forall\, j = 0,1,2,\ldots.m$$

Weapon assignment to threat at one time slot

$$\sum_{i}^{n}\sum_{j}^{m} X_{ijt} \le 1 \,\forall\, t = 0,1,2,\ldots p$$

p → total number of time slots

$$W(assigned\ slot_t) = \begin{Bmatrix}0\\1\end{Bmatrix}$$

Similarly, we can perform multiple assignment of same threat on a single weapon as

$$\sum_{i}^{n}\sum_{j}^{m} X_{ijt} \;\forall\, t = 0 \ldots . W_s$$

IV. EXPERIMENTAL SETUP

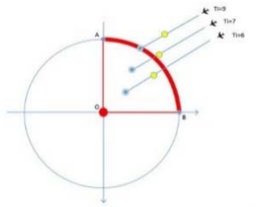

Fig. 1. Showing threat scheduling on a weapon.

To validate the effectiveness of propose approach, an experimental setup has been built based upon few independent modules. For the threat generation, an Air Defense Simulator is developed to generate threats in various formations. The warfare circumstances are formed by deploying various weapons to cover the VA/VPs. The system assigned those tracks to a most suitable weapon as defined above. Multiple threats are assigned to single weapon to better optimize the deployed resources. Traditionally there is a one-to-one assignment between threat and weapons [20]. The proposed algorithm is based on the many-to-many relationship model. The quantity of weapons is always limited and the threat numeral can vary immensely. Threat scheduling is based on TI as shown in figure 1. This index is used for scheduling and assignment. Initially a weapon system is deployed for the protection of VA/VP's. The weapons are deployed in various combinations to find the optimum deployment strategy.

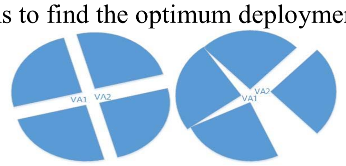

Fig. 2. Shows deployment strategies.

The effectiveness of proposed approach is demonstrated in real warfare circumstances by increasing number of threats exponentially. A separate server is used for the implementation of optimal weapon assignment model. It is then integrated to real-time applications using interfacing module. Figure 2 shows the weapon assignment using deployment schemes.

A. The 1st Scenario

In this scenario, it is assumed that there exist only two threats approaching towards 1 VA/VP. It is observed that TI for both threats increased with passage of time. TI value of threat 2 is constantly increasing [0.3791,…,0.7378], while TI value of threat 1 is increasing, decreasing and then increasing [0.3124,…,0.7632]. The speed of threat 2 is observed increasing and its distance as well as altitude from VA/VP are decreasing with time, while the speed of threat 1 has variations and its maneuverability is changing its value. The output type of threat 1 and threat 2 is ranked from 'low' to 'very high' and 'medium' to 'high' respectively in 60 seconds. Figure 3 shows that the increasing value of threats proposes commanders to neutralize them. The highest TI value assists commanders to neutralize that specific threat first [21-23]. Weapon 1 is assigned to the threat 2 at 30th second, because TI value of threat 2 is greater than threat 1. In figure 3, it has been observed that one of the threats is not neutralized and hence escaped from weapon. The weapon is reloaded after Δt and again assigned to threat. At 40th second, the weapon hits the threat 1 rather than threat 2. Another weapon is assigned to threat 2, but within 60 seconds, the threat 2 could not be neutralized as shown in Figure 3.

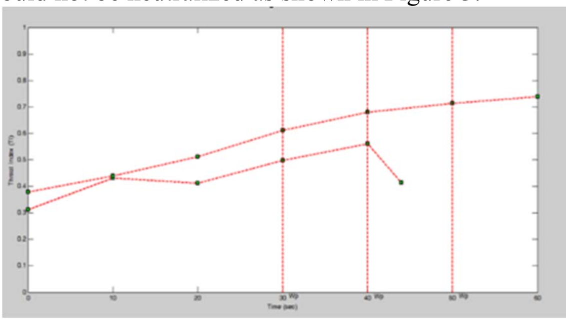

Fig. 3. Threats approaching VA/VPs

B. *The 2nd Scenario*

In this scenario, there are three threats and two VA/VPs. TI for all these threats are increased with the passage of time. The threat 1 is ranked from very low-medium with TI values [0.0939,…,0.5009], while the risk is ranked from medium-very high for threat 2 [0.4134,…,0.8321]. Similarly the threat 3 is increasing from 'medium' to 'very high' [0.5344,…,0.9221] (Figure 4). Considering the rule of threat order and give priority to threat with highest TI value [21-23], commander assigns weapon 1 to threat 3, but that threat escapes from the range of weapon. The weapon 1 is reloaded with Δt and again assigned to threat 3 and weapon 2 to threat 1. The threat 1 is neutralized because it was in the range of weapon. Whereas threat 3 is again escaped because the speed of this threat was high. The weapon 2 is immediately assigned to threat 2. This threat is neutralized by assigned weapon. After Δt, weapon is reloaded and again assigned to threat 3, but it is again succeeded in escape. The weapon 2 is reloaded after Δt and again assigned. At 55th seconds, the threat 3 is also neutralized by weapon 2. The substantial decrease in value was observed as shown in Figure 4.

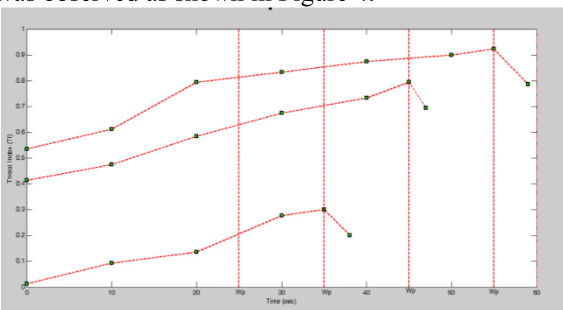

Fig. 4. Threats approaching VA/VPs

From all above scenarios, it is observed that the value of TI provides the information of criticality of situation. The higher value of TI suggests commanders to neutralize threats on priority basis. Thus, we can say that TI provides the foundation for threat neutralization by assigning weapons. Moreover, the results exhibited that the proposed strategy is an efficient approach in neutralizing threats in time critical situations.

V. CONCLUSION

TEWA is a difficult task which requires an efficient TE mechanism in order to assign weapon optimally. TE is the main processing module. Most of the research done assumes known threat types. But in real scenario it is a stimulating task. In threat identification, radars play a significant role. We used numerous parameters for threat evaluation. TE is an adaptive process of research. In this paper, an efficient real time TEWA system is designed and implemented based on knowledge base system. The knowledge-base is updated intelligently based on weapon assignments' results. In our experimental setup, we tested various weapon deployment scenarios and view the outcome of threat assignment. By varying weapon deployment, we analyzed the combination of different weapons along with total number of threats that were engaged during simulation.

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