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RESEARCH ON BALLISTIC MISSILE THREAT ASSESSMENT BASED ON MAXIMUM DEVIATION

Bo Chen[1,2,3], Bo Yan[2,3], Yunming Wang[2,3] and Chengsheng Pan[1,2]

[1]University Key Laboratory of Communication and Signal Processing
[2]Key Laboratory of Communication Networks and Information Processing
[3]College of Information Engineering
Dalian University
No. 10, Xuefu Street, Jinzhou Xinqu, Dalian 116622, P. R. China
{ chenbo; pcs }@dlu.edu.cn

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Abstract. *The existing missile threats are surface to air missile, air to air missile, rarely on ballistic missiles. At the same time, the existing multi-objective sorting has the disadvantage of unilateralism and one-sidedness. In determining the goal weight, the existing expert decisions have greatly subjective capriciousness, and objective weighting methods are limited to practical problems, poor universality. According to the shortages, this paper according to the maximum deviation method, to construct a goal threat assessment model the ballistic missile objective information and decision makers of subjective information are effectively combined with, through the Lagrange function method to solve the target weights, and overcome the shortcomings of the single expert decision-making method and the single objective weighting method. Theoretical analysis and simulation show that has the overall advantage to overcome the one-sidedness of the traditional algorithm and the lack of unity. This method improves the accuracy of the multi-objective ranking also.*

Keywords: Ballistic missile, Threat index, Multiple attribute decision making, Optimal model, Objective sorting

1. Introduction.

All countries in the world have developed and equipped all kinds of medium-long range ballistic missile, the speed faster and faster, distant range farther and farther, motor performance better and better, penetration combat ability stronger and stronger. The situation of some ballistic missile attacks in a certain time is not impossible. Therefore, there is an urgent need for a multi-objective sorting strategy research to provide a basis for establishing target intercept order and target fire distribution, which can improve the efficiency of command and decision. At the present time, target threat sort researches are mostly the sort strategy research of the ground-to-air missiles and the air-to-air missiles [1,2], such as stand-alone multi-target aerial defense, multi-machine collaborative multi-target combat and ground-air collaborative fire distribution, which rarely involves the threats sort of ballistic missile; at the same time, the existing multi-objective sorting has the disadvantage of unilateralism and one-sidedness.

There are many methods to estimate multi-target threat in the air defense operations, mainly including: the arrival time determination method, the relative distance determination method, the relative orientation determination method, the linear weighted determination method, the variable weight theory method, the attribute analysis method, the neural network method and the fuzzy mathematics method and so on [3-5]. Because the multi-attribute decision method takes many factors in the incoming target threat into consideration and it can fully reflect the impact of multiple factors on the final assessment, it has become a hotspot in target threat research [6-8]. However, the existing target threat estimation method treated the value of the target property as a real number and did not consider the impact of the subjective experience of decision-makers on the threat assessment, and this is clearly not in line with the actual situation. The control early warning satellites and the various radar sensor systems are used to detect and search for incoming targets mostly in air defense operations. The threats target property information obtained from different sensors presents incompleteness, uncertainty and unreliability, due to their own performance differences or the external environment effect. At the same time, the preference information of operational decision makers to threat target has played an important role in the goal threat assessment process and the preference information is with fuzziness and incompleteness. Therefore, signally considering the expert subjective factors or objective attributes cannot fully reflect the decision-making information, and it is required to combine the target attribute information provided by different sensors and preference information of decision-makers.

Based on this, we have proposed the ballistic missile threat assessment method based on the maximizing deviation method, which effectively combines objective attribute information of ballistic missile and preferences information of decision-makers, overcomes the unilateralism and one-sidedness of the algorithm, and improves the accuracy of the multi-objective threat sorting.

2. Define the Threat Index.

In the target threat assessment of the air-defense operations, the two sides are mutually confidential. The defense side can only judge the target information by the detection, tracking devices and usually grasping the enemy information. According to principles of weapon system information and characteristics provided by sensor, the main factors affecting the ballistic missile threat include damage ability factors, the flight characteristics information factors and target battle value factors.

2.1. Kill capability threat index.

Existing medium-long range ballistic missiles mainly have nuclear warheads or large-scale of biochemical warheads. The destructive of ordinary warhead is incomparable to ballistic. For more results on this topic, we refer to [9,10]. Therefore, damage ability factor is indispensable to ballistic missile threat assessment. The definition of the damage ability index was defined shown in Table 1.

Table 1. Kill capability threat index

Warheads	Normal	Nuclear	Biochemical
Threat index Td	0.7	0.9	1

2.2. The flight characteristics information of ballistic missile.

The process of anti-missile combat is similar to air-to-air combat. The success rate of the intercept is determined by the flight characteristics information of ballistic missile directly. For more results on this topic, we refer to [11,12]. This paper considers the situation factors including ballistic missile range, speed, and maximum flying high.

(1) Ballistic missile range

Ballistic missile range is generally far, so the scope of the fight will be very wide. It will give our interceptor to make great difficulty. The maximum rang of ballistic missiles is 16000km, which can cover all the major strategic objectives of the Earth. So rang threat index was defined by Formula (1):

$$Ts_k = \begin{cases} 0 & s < \beta \\ 1 - e^{-c(s-\beta)} & s \geq \beta \end{cases} \tag{1}$$

where s is missile range, $c = 4 \times 10^{-7}$, $\beta = 0$.

(2) Ballistic missile speed

According to the design theory of ground to air missile, it is known that the greater of goal speed will induce a higher requirement of guidance and bring far more difficulty to intercept. Therefore, speed threat index was defined by Formula (2):

$$Tv_k = \begin{cases} 0.2 & v_k < 0.7v_r \\ v_k/v_r - 0.5 & 0.7v_r \le v_k \le 1.5v_r \\ 1 & v_k \ge 1.5v_r \end{cases} \tag{2}$$

where v_k is ballistic missile speed; v_r is intercept missile speed.

(3) Ballistic missile flight altitude

The medium-long range ballistic missile intercept is carried out usually in the middle of the flight process. The higher flying height of missile is, the higher cost of launch and the more advanced guidance technology are. Flight altitude threat index is defined by Formula (3):

$$Th_k = \begin{cases} 1 & \Delta h_k < -80\text{km} \\ 0.7 & -80\text{km} \le \Delta h_k < -40\text{km} \\ 0.5 & -40\text{km} \le \Delta h_k < 40\text{km} \\ 0.1 & \Delta h_k \ge 40\text{km} \end{cases} \tag{3}$$

where Δh_k is height difference between defense missile and ballistic missile.

2.3. **Campaign target value.** The aim of ballistic missile strike is the important territory, so it must endow each vital area with a priority to show its importance degree. For more results on this topic, we refer to [13]. Campaign target value is defined shown in Table 2.

Table 2. Campaign target value index

Importance degree	general	More important	Particularly important
Threat index W_k	0.25	0.55	0.86

3. Multiple Objective Decision Making Model.

This paper adopts linear superposition method to construct the total threat index model.

$$T_k = \omega_1 t_{k1} + \omega_2 t_{k2} + \omega_3 t_{k3} + \omega_4 t_{k4} + \omega_5 t_{k5} \tag{4}$$

where T_k is the integrated value of the missile threat; t_{k1}, t_{k2}, t_{k3}, t_{k4}, t_{k5} are kill capability, rang, speed, flight altitude and campaign target value threat index of the kth missile respectively; ω_1, ω_2, ω_3, ω_4, ω_5 are the weights.

Calculate all integrated values of ballistic missile T_k, and the bigger T_k, the greater the threat degree. So we can determine the sorting of ballistic missile.

3.1. **Threat index normalization.** For multi-objective decision making problems, the objective space can be denoted by decision-making matrix F.

$$F = \begin{array}{c} \\ \\ \\ \\ \end{array} \begin{array}{c} \begin{array}{ccc} t_1 & t_2 & t_n \end{array} \\ \begin{pmatrix} a_{11} & a_{12}\cdots & a_{1n} \\ a_{21} & a_{22}\cdots & a_{2n} \\ & \cdots & \\ a_{m1} & a_{m2}\cdots & a_{mn} \end{pmatrix} \end{array} \begin{array}{c} x_1 \\ x_2 \\ \vdots \\ x_m \end{array} \tag{5}$$

Decision space is constituted by limited decision variable in F, where x_i $(i = 1, 2, \ldots, m)$ is scheme, t_j $(j = 1, 2, \ldots, n)$ is evaluation index, and $a_{ij} = t_j(x_i)$ is the jth objective value of scheme x_i.

All the evaluation indexes of objectives are mutual different in many target constraint conditions; the value of the target threat will be fuzzy standardization. Because this paper is the sorting of objective threat, the bigger, the better, we adopt the benefit of the fuzzy standardization:

$$\mu_{ij} = [(a_{ij} - a_{i\min})/(a_{i\max} - a_{i\min})] \tag{6}$$

where $a_{i\max} = \max\limits_{1\le i\le m}\{a_{ij}\}$, $a_{i\min} = \min\limits_{1\le i\le m}\{a_{ij}\}$.

By calculating the objective standardization, the decision F can be transformed into the objective fuzzy standardization matrix μ.

$$\mu = \begin{array}{c} \begin{array}{ccc} t_1 & t_2 & t_n \end{array} \\ \begin{pmatrix} \mu_{11} & \mu_{12}\cdots & \mu_{1n} \\ \mu_{21} & \mu_{22}\cdots & \mu_{2n} \\ & \cdots & \\ \mu_{m1} & \mu_{m2}\cdots & \mu_{mn} \end{pmatrix} \end{array} \begin{array}{c} x \\ x_2 \\ \vdots \\ x_m \end{array} \tag{7}$$

3.2. **Principles and methods to establish objective weights.** The main idea of the maximum deviation is that the choice based on weighted vector makes total deviation largest, which is the deviation between all evaluation indexes and all decision schemes.

Considering from the subjective factors, decision makers M_k $(k = 1, 2, \ldots, q)$ have given the weights of attributes $w'_k = (w'_{k1}, w'_{k2,}, \ldots, w'_{kn})$. The total deviation is small as far as possible between the required attribute weights w and decision maker weights w'_{kj}. So the following optimization model can be constructed as follows:

$$\begin{cases} \min f'(w) = \sum\limits_{k=1}^{q}\sum\limits_{j=1}^{n} \alpha_k (w_j - w'_{kj})^2 \\ w' = \sum\limits_{k=1}^{q} \alpha_k w'_k \end{cases} \tag{8}$$

where $\sum\limits_{k=1}^{q} \alpha_k = 1$, $\sum\limits_{j=1}^{n} w_j^2 = 1$.

Considering from the objective factors, it ought to maximize the whole deviations between all attributes and all decision schemes according to the concepts mentioned above. The objective function can be constructed as follows:

$$\min[-f''(w)] = -\sum_{j=1}^{n} f''_j(w) = -\sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{m} |\mu_{ij} - \mu_{kj}| w_j \tag{9}$$

Finally, comprehensive above the subjective and objective factors, solving goal weight is equivalent to solving the following optimization problem:

$$\begin{aligned} \min f(w) &= \eta f'(w) - (1-\eta) f''(w) \\ &= \eta \sum_{k=1}^{q}\sum_{j=1}^{n} \alpha_k (w_j - w'_{kj})^2 - (1-\eta)\sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{m} |\mu_{ij} - \mu_{kj}| w_j \end{aligned} \tag{10}$$

where $\sum\limits_{j=1}^{n} w_j^2 = 1$, $w_j \ge 0$, $j = 1, 2, \ldots, m$; $0 < \eta < 1$, is given according to actual, which is subjective and objective of balance coefficient.

Then, the Lagrange function can be developed as:

$$L(w,\lambda)=\eta\sum_{k=1}^{q}\sum_{j=1}^{n}(w_j-w'_{kj})^2-(1-\eta)\sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{m}|\mu_{ij}-\mu_{kj}|w_j+\lambda\left(\sum_{j=1}^{n}w_j^2-1\right), \tag{11}$$

where λ is a Lagrange multiplier.

In the decision-making models, the sum of weights is often equal to 1. Therefore, from $w_j^*=\frac{w_j}{\sum_{j=1}^{n}w_j}$ and above equation, we can obtain

$$w_j^*=\frac{2\eta w'_j+(1-\eta)\sum_{i=1}^{m}\sum_{k=1}^{m}|\mu_{ij}-\mu_{kj}|}{\sum_{j=1}^{n}\left[2\eta w'_j+(1-\eta)\sum_{i=1}^{m}\sum_{k=1}^{m}|\mu_{ij}-\mu_{kj}|\right]} \tag{12}$$

Thus, all the weights of factors are determined.

4. Target Threat Assessment Method and Simulation Analysis.

4.1. Multiple attribute decision making based on maximum deviation method.

Multiple attribute decision making method is as follows:
(1) By radar satellite and other means detect the target attribute information;
(2) Establish objective decision matrix and transform it into a fuzzy decision matrix by fuzzy processing;
(3) By Formula (12) we can obtain target threat w'_j;
(4) We can calculate all integrated attribute values of each target based on Formula (4);
(5) According to the total attribute value we can determine the sorting of target.

4.2. Air defense simulation analysis. Suppose the enemy fired six ballistic missile airstrike on our area. According to early warning satellites, radar sensors and infrared detection means we can detect the parameters of the missile, as shown in Table 3. Then

Table 3. Parameters of ballistic missile

Missile	Warheads	Range (km)	Speed (km/s)	Altitude (km)	Campaign target value
1	normal	2500	4.5	150	more important
2	nuclear	1500	2.5	150	particularly important
3	normal	1100	5.8	250	general
4	nuclear	13000	6	350	more important
5	biochemical	12000	6.5	350	more important
6	biochemical	10500	4.5	250	more important

Table 4. Threat index

Missile	Td	Ts	Tv	Th	W
1	0.6321	0.4545	0.40	0.1625	0.55
2	0.4512	0.3333	0.20	0.3250	0.85
3	0.3560	0.3902	0.66	0.6500	0.25
4	0.9945	0.8125	0.80	0.2467	0.55
5	0.9918	0.8000	0.80	0.2167	0.55
6	0.9850	0.7778	0.68	0.4000	0.55

the target threat index Td, Tv, Th, Ts and W can be obtained respectively by the preceding formula, such as shown in Table 4.

The qualitative and quantitative attributes of results are given in Table 4. By Formula (5) construct multi-objective decision matrix, then we can calculate ballistic missiles fuzzy normalization matrix by Formula (6):

$$\mu = \begin{bmatrix} 0.6356 & 0.5594 & 0.5000 & 1.0000 & 0.6471 \\ 0.4537 & 0.4102 & 0.2500 & 0.1000 & 0.2941 \\ 0.3580 & 0.4802 & 0.8250 & 0.1000 & 1.0000 \\ 1.0000 & 1.0000 & 0.8750 & 1.0000 & 0.2941 \\ 0.9973 & 0.9846 & 1.0000 & 0.5000 & 0.6471 \\ 0.9904 & 0.9573 & 0.5000 & 0.5000 & 0.6471 \end{bmatrix}$$

The weights of incoming targets are given by three experts respectively as follows: $\omega_1' = (0.2, 0.1, 0.1, 0.2, 0.4)$, $\omega_2' = (0.1, 0.1, 0.1, 0.3, 0.4)$ and $\omega_3' = (0.1, 0.1, 0.3, 0.2, 0.3)$. The importance of every expert is $\alpha = (1/3, 1/3, 1/3)$. By expert decision-making method [14] target weight can be calculated $w' = (0.1667, 0.1333, 0.2000, 0.1667, 0.3333)$. According to Formula (4) decision makers preferences of threat target can be obtained, $T = (0.6946 \;\; 0.2744 \;\; 0.6233 \;\; 0.7203 \;\; 0.7520 \;\; 0.6650)$. The sorting result is $T5 > T4 > T1 > T6 > T3 > T2$.

Then, according to satellite reconnaissance and sensor systems detect the target objective information. The target weights can be obtained by the objective weighting method [15], $w' = (0.1113, 0.2672, 0.3088, 0.1022, 0.2105)$. By Formula (4), we can calculate the integrated value of the target threat based on the target objective information, which is $T = (0.6130 \;\; 0.3094 \;\; 0.6436 \;\; 0.8128 \;\; 0.8702 \;\; 0.7077)$. Sorting result is $T5 > T4 > T6 > T3 > T1 > T2$.

Finally, set $\eta = 0.7$, use the method considering objective attribute information of ballistic missile and subjective preferences of decision makers proposed in this paper, and calculate the incoming target attribute weight through Formula (11), which is $w^* = (0.1875, 0.1734, 0.1902, 0.2636, 0.1853)$. According to Formula (4), calculate the integrated value of the target threat, which is, $T = (0.7050 \;\; 0.3154 \;\; 0.5732 \;\; 0.8204 \;\; 0.7830 \;\; 0.6711)$. The sorting result is $T4 > T5 > T6 > T1 > T3 > T2$.

We can get different results of the corresponding goal threat degrees sequence through the above three kinds of sorting method, as shown in Figure 1.

Figure 1 shows that the maximum deviation method considering objective attribute information of ballistic missile and subjective preferences of decision makers have differences with target threat values based on expert decision and objective weighting. Due to the subjective of expert decision and the limitations of objective weighting theory, we cannot get a real sort when the incoming targets parameters are not a single, which will lead a deviation of military operation. However, the method of maximum deviation can do better in solving the problem.

5. **Conclusions.** This paper analyzed the factors impacting decision-making of long-range ballistic missiles. On the issue of determining multi-target weight, considering objective information and the subjective preferences of decision makers comprehensively according to the idea of maximizing deviation method, this paper has established the threat assessment model which can obtain the optimal weight of the target properties, and made weight information of the incoming targets property reflect the actual situation more accurately. This method balanced the advantage of the decision-makers preferences and objective weighting to large extent, overcame the problem that the existing decision-making method is too subjective and it considers problems too one-sided resulting in larger

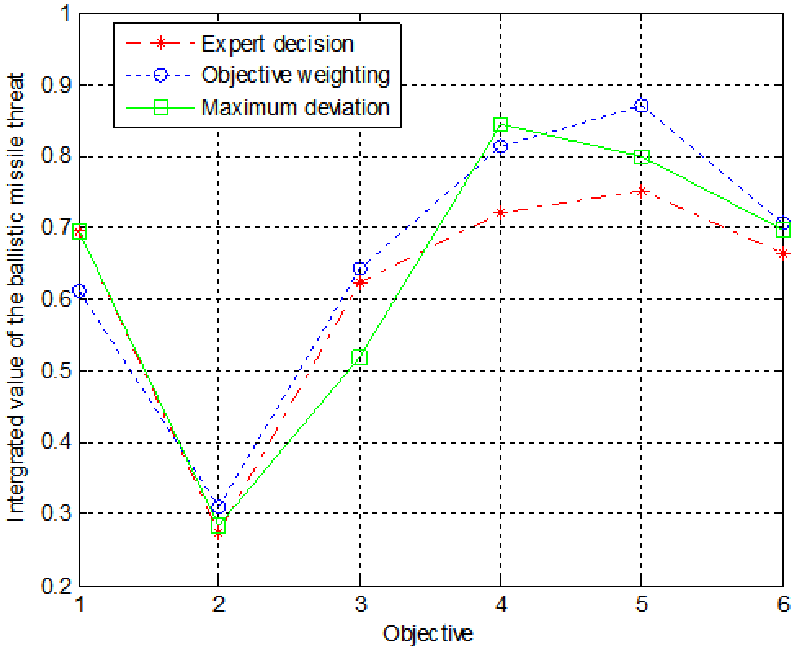

FIGURE 1. Three kinds of sorting chart

deviations. Finally, an example simulation analysis is designed to verify the feasibility of the method. This method is simple to calculate, easy to implement and real-time, and it is of great value for solving multi-target threat sort in battlefield. However, how to carry out effective firepower distribution to incoming targets based on the derived sort results will become the focus of future research.

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REFERENCES

[1] Z. Chen and Z. Zhou, Priority decision of air-to-surface multi-target attack based on improved entropy, *Systems Engineering and Electronics*, vol.33, no.2, pp.229-333, 2011.
[2] N. Zhang, X. Xu and Q. Pan, Battle damage calculation and simulation for aircraft under attack of air-air missile, *Journal of Nanjing University of Aeronautics & Astronautics*, vol.40, no.2, pp.205-208, 2008.
[3] P. Zhi and Z. Li, Simplification of decision making matrix in fuzzy multiple attribute decision making, *Proc. of International Conference on Industrial Engineering and Engineering Management*, pp.36-40, 2011.
[4] U. Shofwatul and R. Imam, A fuzzy Topsis multiple-attribute decision making for scholarship selection, *Telkomnika*, vol.9, no.2, pp.37-46, 2011.
[5] P. Liu and Y. Su, Multiple attribute decision making method based on the trapezoid fuzzy linguistic hybrid harmonic averaging operator, *Informatica*, vol.36, no.1, pp.83-90, 2012.
[6] K. Guo, Possibility degree method for determining weights of criteria in multiple attribute decision making with intervals, *Journal of Convergence Information Technology*, vol.7, no.10, pp.206-215, 2012.
[7] J. Chen and X. Gao, A comprehensive threat assessment method for group aircrafts cooperative air defensive combat under command of AWACS, *Journal of Northwestern Polytechnical University*, vol.27, no.5, pp.624-629, 2009.
[8] M. Zhao and W. Qiu, Relative entropy evaluation method for multiple attribute decision making, *Control and Decision*, vol.25, no.7, pp.1098-1104, 2010.

[9] D. Hang and A. Guo, An object-group threat assessment method based on attribute significance of multi-field expert systems, *Acta Armamentarii*, vol.31, no.10, pp.1357-1362, 2009.

[10] X. Song, F. Wang and H. Guo, New threat assessment method in beyond-the-horizon range air combat, *Systems Engineering and Electronics*, vol.31, no.9, pp.2163-2166, 2009.

[11] H. Zhang and W. Zheng, Evaluation method study on attack capability of intercontinental ballistic missile, *Journal of Ballistics*, vol.20, no.2, pp.64-71, 2008.

[12] X. Liu and Z. Liu, Missile threat assessment to fleet in the cooperative antimissile area, *Proc. of International Conference on Electronic and Mechanical Engineering and Information Technology*, pp.3765-3768, 2011.

[13] Y. Pei, Q. Dong and T. Guo, Petri Net based safety evaluation approach for aircraft under the threats of traditional weapons, *Proc. of 2011 International Conference on Measuring Technology and Mechatronics Automation*, pp.856-861, 2011.

[14] H. Yan, A probabilistic model for linguistic multi-expert decision making involving semantic overlapping, *Expert Systems with Applications*, vol.38, no.7, pp.8901-8912, 2011.

[15] B. Chen and N. Wang, Research on modeling of GEO communication satellite threat index, *ICIC Express Letters*, vol.5, no.9, pp.3395-3401, 2010.