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Threat Evaluation of Air Targets Based on the Generalized λ-Shapley Choquet Integral of GIFSS

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Abstract: Fast and accurate threat evaluation (TE) of incoming air targets has a great influence on air defense. In this paper, two new generalized intuitionistic fuzzy soft set (GIFSS) methods are proposed for threat evaluation of air targets. Firstly, the threat evaluation index system is reasonably constructed by analyzing the relative kinematics between the targets and assets, apart from that between the targets and interceptors, which is more reasonable and practical. Secondly, after the threat indexes (TI) are properly obtained, two new aggregation operators for GIFSS are put forward based on the generalized λ-Shapley Choquet integral. The proposed operators not only depict the correlations among the evaluation index but also consider the importance of them globally. Finally, the effectiveness and superiority of the proposed methods are verified through a numerical simulation including four air targets in different index systems.

Keywords: air target threat evaluation; generalized intuitionistic fuzzy soft set; fuzzy measure; generalized Shapley index; Choquet integral

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1. Introduction

TE is the process of evaluating the threat value of targets to defense forces and their interests, and also the process of ranking these targets according to the threat degree [1,2]. Rapid and accurate TE of incoming air targets is the core part of air defense systems and can significantly improve the efficiency of weapon assignment to deal with a multi-target attack [3].

With the advancement of the aerospace industry, highly sophisticated aircraft such as unmanned aerial vehicles, hypersonic vehicles and tactical ballistic missiles deem the air combat environment more complex and changeable, posing severe challenges to target threat evaluation. Therefore, it is of great significance to carry out research on air target threat evaluation methods.

Threat evaluation is essentially a multicriteria decision making (MCDM) problem. The traditional scheme is determined by experts or commanders according to the battlefield situation and their own experience, which is relatively simple and flexible, but the process is of great subjectivity and is vulnerable to a lack of expert knowledge. Furthermore, as the modern battlefield situation becomes more complex, a massive number of factors need to be considered in the evaluation process, which makes the empirical determination of the threat values impractical and hard to be reproduced. Therefore, there is a lot of demand for mathematical methods which could be implemented into computer systems for automatic threat evaluation. Up to now, there have been a lot of research results, for example, the TOPSIS method [4–6], intuitionistic fuzzy sets (IFSs) [7–9], Bayesian networks [10–12] and rough sets [6], amongst others. These methods have their own characteristics and theoretical bases and can apply to different operating environments. However, threat evaluation cannot be carried out as a whole merely by mathematical methods, and the intention of decision-makers is usually ignored. This is why more and more approaches seek to conduct threat evaluation on the basis of mathematical methods and expert experience.

The concept of soft sets (SSs) was proposed by Molodtsov to overcome the limitations of the personal preferences and professional knowledge of decision-makers, in addition to the incompleteness and uncertainty of the evaluation index information [13]. On the basis of IFSs and SSs, Maji et al. [14–16] put forward the theory of intuitionistic fuzzy soft sets (IFSSs), and Agarwal et al. [17,18] proposed the concept of GIFSS. Compared with IFSS, a framework is provided by GIFSS to evaluate the information credibility to compensate for the distortion of the index information. By adding the generalized parameters into the IFSS matrix, the possible errors caused by inaccurate information can be reduced, and this has a good effect when dealing with inaccurate and uncertain index information. Therefore, GIFSS is suitable for threat evaluation of air targets with greater measurement uncertainty, and some research results have been obtained. Wu Hua introduced a multi-expert parameter set to address the knowledge limitation of only one expert in the original GIFSS and constructed a group GIFSS for threat evaluation of aerial targets [19]. Feng et al. introduced the relative entropy theory to GIFSS to determine the reasonable weight for TI [20].

All these methods under intuitionistic fuzzy theory need to aggregate the intuitionistic fuzzy values (IFVs) by the so-called aggregation operators to obtain the evaluation results and rank the alternatives, which demonstrate the preferences of decision-makers. Agarwal [18] and Harish Garg [21] introduced the geometric and averaging aggregation operators for GIFSS, which are denoted by GWG and GWA operators. Although, when combined with different entropy theories, the existing aggregation operators can depict different preferences for the indexes, they only consider the situations in which all the indexes are independent. That is, only the additive relation of the importance of each index is considered. However, in practical air defense operations, the indexes of the threat evaluation are usually correlative, for example, we may intend to attach more importance to the targets who are closer to the defending assets and at a higher velocity. In order to solve such problems, the Choquet integral [22], as a very useful tool for measuring the expected utility of an uncertain event, has been successfully applied in decision problems. Tan and Chen [23] proposed an intuitionistic fuzzy Choquet integral for multi-criteria decision making. Xu [24] used the Choquet integral to propose some aggregation operators for IFS and interval-valued intuitionistic fuzzy sets (IVIFSs). These operators can not only depict the importance of the independent index but also demonstrate the correlations among the index system.

Since the fuzzy measure is defined on the power set, the problem of determining the fuzzy measure of each index and index set is exponentially complex. To solve this problem, some special fuzzy measures have been proposed, such as the λ-fuzzy measure [25] and the k-additive measure [26]. Tan [27] provided a method of interval-valued intuitionistic fuzzy multi-criteria group decision making based on the λ-fuzzy measure. On the basis of the λ-fuzzy measure, Meng [28] introduced the generalized λ-Shapley index to the IVIFS Choquet integral to reflect the overall interaction among the index system. Qu extended the generalized λ-Shapley index to the IFS Choquet integrals and developed an algorithm for ranking alternatives with the TOPSIS method [29].

Air defense scenarios usually involve three bodies, that is, the incoming targets, the interceptors and the defending assets; therefore, threat evaluation index systems should not only consider the relative kinematics between the targets and assets but also include the relative kinematics between the targets and interceptors. However, to the best of our knowledge, only the former kinematics is considered in all of the existing literature. Furthermore, none of the aforementioned IFS-based methods applied in threat evaluation of aerial targets consider the interaction or correlation among the criteria set, and, to the best of our knowledge, there is no aggregation operator for GIFSS considering how to obtain the fuzzy measure on each index set, nor reflecting the overall average contribution of each index and index set to the index system. This paper fills these gaps by constructing a threat evaluation index system with both relative kinematics between the three bodies and by proposing two new aggregation operators for GIFSS with the generalized λ-Shapley Choquet integral.

The contributions of this study are summarized as the following two aspects:

1. The threat evaluation index system is reasonably constructed by analyzing the relative kinematics between the targets and assets, apart from that between the targets and defending interceptors, which is more reasonable and practical;
2. Based on Choquet integral theory, the generalized Shapley index and λ-fuzzy measure, two new aggregation operators for GIFSS, are proposed, which can depict the correlations among the evaluation index and reflect the overall average contribution of each index and index set to the whole index system.

The remainder of this paper is organized as follows. Section 2 introduces the basic concepts and definitions relevant to IFS and GIFSS. In Section 3, the threat evaluation index system is constructed and the threat indexes are properly obtained. Thereafter, the generalized λ-Shapley Choquet integral operators for GIFSS are proposed in Section 4, and in Section 5, the evaluation example including four targets and result analyses are shown. Finally, conclusions are drawn in Section 6.

2. Preliminaries

This section briefly introduces some basic definitions and concepts relevant to FS, IFS, IFSS and GIFSS for the set of elements X on the universal set E.

Definition 1 ([30]). *A fuzzy set A defined on $X = \{x_1, x_2, \ldots, x_n\}$ is an ordered pair of the element $x_i \in X, i = 1, 2, \ldots, n$ and degree of membership $t_A : X \to [0, 1]$, defined as*

$$A = \{(x_i, t_A(x_i)) \mid x_i \in X\} \tag{1}$$

Definition 2 ([31]). *An intuitionistic fuzzy set on X is defined as*

$$A = \{\langle x_i, t_A(x_i), f_A(x_i), \rangle \mid x_i \in X\} \tag{2}$$

where the numbers $t_A(x_i)$ and $f_A(x_i)$ represent the degree of membership and the degree of non-membership of the element x to the set A, respectively, satisfying $t_A(x_i) \in [0, 1], \quad f_A(x_i) \in [0, 1], \quad t_A(x_i) + f_A(x_i) \leq 1$. In particular, if $t_A(x)_i + f_A(x_i) = 1$, then the intuitionistic fuzzy set reduces to a fuzzy set.

Definition 3 ([32]). *We call the ordered pair $\alpha(x_i) = (t_\alpha(x_i), f_\alpha(x_i))$ an intuitionistic fuzzy value (IFV). The score function s_α is defined as*

$$s(\alpha) = t_\alpha - f_\alpha \tag{3}$$

and the accuracy degree of α is

$$h(\alpha) = t_\alpha + f_\alpha \tag{4}$$

Suppose $\alpha_i = (t_{\alpha_i}, f_{\alpha_i})(i = 1, 2)$ are two IFVs; the order relation between two IFVs is defined as follows:

- *If $s(\alpha_1) < s(\alpha_2), \alpha_1$ is smaller than α_2, which is denoted by $\alpha_1 < \alpha_2$.*
- *If $s(\alpha_1) = s(\alpha_2)$:*
    1. *If $h(\alpha_1) = h(\alpha_2), \alpha_1$ and α_2 represent the same information, which is denoted by $\alpha_1 = \alpha_2$.*
    2. *If $h(\alpha_1) < h(\alpha_2), \alpha_1$ is smaller than α_2, which is denoted by $\alpha_1 < \alpha_2$.*

Definition 4 ([33]). *Some basic operations and operators for IFVs. Suppose $\alpha_i = (t_{\alpha_i}, f_{\alpha_i})(i = 1, 2)$ are two IFVs, $k > 0$; then, we have*

1. $\alpha_1 \oplus \alpha_2 = (t_{\alpha_1} + t_{\alpha_2} - t_{\alpha_1} t_{\alpha_2}, f_{\alpha_1} f_{\alpha_2})$

2. $\alpha_1 \otimes \alpha_2 = (t_{\alpha_1} t_{\alpha_2}, f_{\alpha_1} + f_{\alpha_2} - f_{\alpha_1} f_{\alpha_2})$
3. $k\alpha = \left(1 - (1 - t_\alpha)^k, f_\alpha^k\right)$
4. $\alpha^k = \left(t_\alpha^k, 1 - (1 - f_\alpha)^k\right)$

As it is proved in [33], the results of the operations and operators are also IFVs.

Definition 5 ([31]). *The pair (F, X) is called a soft set over E, where $F : X \to P^E; P^E$ is all subsets of E.*

Definition 6 ([31]). *A pair (F, X) is called IFSS over E if and only if $F : X \to IF^E$, where IF^E represents the set of all intuitionistic fuzzy subsets of E, and for any $a_i \in X, i = 1, 2, \ldots, n$ and $e_j \in E, j = 1, 2, \ldots, m$, the IFSS is defined as*

$$F(a_i) = \left\{\left(e_j, t_i(e_j), f_i(e_j)\right) \mid e_j \in E\right\} \tag{5}$$

where $t_i(e_j)$ and $f_i(e_j)$ are exact numbers which denote the membership degree and non-membership degree of the element e_j to the set E, respectively.

Definition 7 ([18,34]). *Let $E = \{e_1, e_2, \ldots, e_m\}$ denote the universal set of parameters and $X = \{x_1, x_2, \ldots, x_n\}$ be a set of elements; assume α is an intuitionistic fuzzy subset of X. A pair (E, X) is called a soft universe, F_α is defined as a mapping $F_\alpha : X \to IF^E \times IF$ and the generalization parameter is defined as a mapping $\alpha : X \to IF$, where a GIFSS F_α over the soft universe (E, X) is defined as follows*

$$F_\alpha(x_i) = (F(x_i), \alpha(x_i)), \quad i = 1, 2, \ldots, n \tag{6}$$

where $F(x_i) \in IF^E$ and $\alpha(x_i) \in IF, \alpha(x_i)$ indicate an expert's evaluation on the parameters of E in $F(x_i)$, and IF denotes an IFS.

3. Construction of the Threat Evaluation Index System

As an important part of the air target threat evaluation process, the index system depicts the complete characterization of the incoming aerial targets. The construction of the threat index system can be divided into three sequence procedures: determination of the threat indexes, perception of the threat indexes and standardization of the indexes. The procedures are specified as follows.

3.1. Determination of the Threat Indexes

The actual air defense operation is dynamic, interactive and sophisticated, and air targets have various types and diverse characteristics. Therefore, when determining an evaluation index, it is necessary to choose representative factors that can depict the threat level of the targets from different perspectives, and these factors need to be considered as a whole.

According to the domestic and foreign literature, most of the indexes considered in establishing the threat evaluation model of air defense are based on two bodies, that is, the defending assets and the targets, though these indexes are classified from different perspectives, for example, the target capability and target intent [5,11,12,35] or the overall target characteristics, the target position characteristics and the target motion characteristics [20,36]. However, in fact, the interceptors usually play an important role in the air defense scenario, and the relative kinematics between the targets and defending interceptors should certainly be included in the evaluation index system.

The objective of this paper is to evaluate the threat of aerial targets, the target characteristics and the relative kinematics between the targets and interceptors, where the relative kinematics between the targets and defending assets are taken as the selection criteria, and then to determine eight evaluation indexes: target type, target height, distance from asset, route shortcut from asset, distance from the interceptor, relative velocity between the target and the interceptor, target velocity and acceleration, which can all be obtained with the measurement from the infrared (IR) seekers equipped in the interceptors. The target route shortcut is the vertical distance from the asset to the projected extension line of the velocity of the target in the horizontal plane. The evaluation index system of air target threats is shown in Figure 1, where the indexes in red boxes represent cost indexes, which indicate that the bigger the index, the greater the threat of the target; meanwhile, the indexes in the green boxes belong to benefit indexes, which indicate that the smaller the index, the greater the threat of the target.

However, in addition to the above eight indexes, other factors also have an important influence on the threat evaluation of air targets in actual air combat, for example, jamming ability and lethality (marked in dotted boxes), amongst others, which are difficult to be measured and expressed quantitatively; therefore, it is of great necessity to introduce GIFSS to provide a generalized parameter set for the various aforementioned factors highlighted by the experts. In this way, the evaluation result is more reasonable.

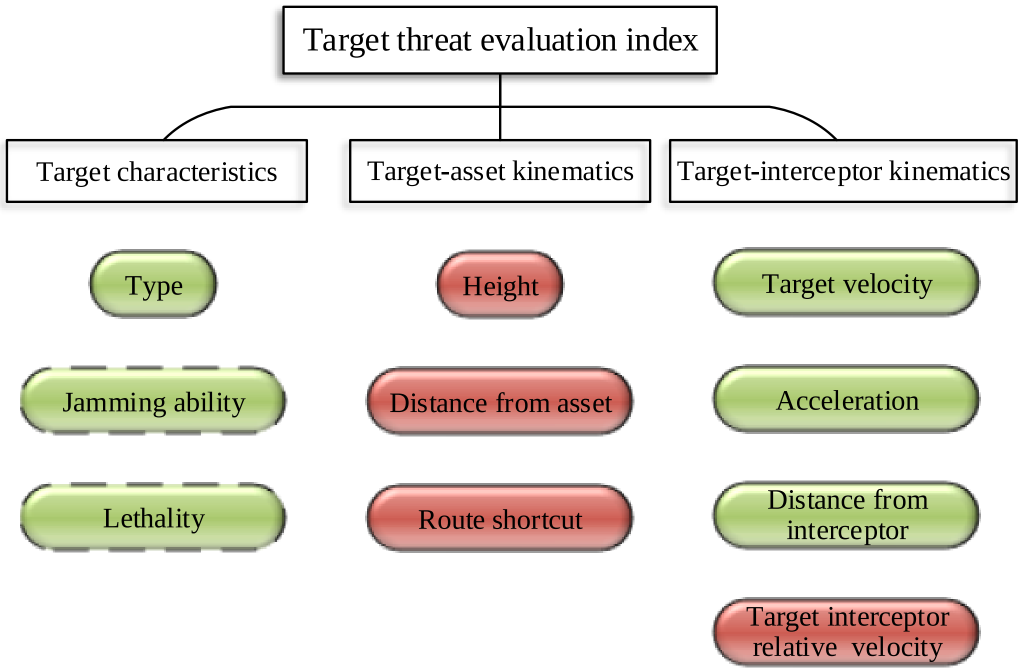

Figure 1. The evaluation index system of air target threats.

3.2. Perception of the Threat Indexes

It is assumed that each interceptor is equipped with an inexpensive IR sensor, which can only provide noisy bearing-only measurements. However, the indexes related to the kinematics between the interceptors and the targets such as the distance from the interceptor and the target velocity can still be obtained through cooperative estimation [37–40]. In addition, we assume the type of target can be determined by the infrared signature. Figure 2 presents the planar geometry of an interceptor, one target and the defending asset. The defending asset is located at the origin of the axis. The distance between the target and the interceptor is denoted as R_{TI}, q_{TI} is the angle between the interceptor's LOS to the target and the X axis and θ_T is the angle between the target velocity and the X axis. In addition, the coordinates of the interceptor are obtained by the inertial navigation system and denoted as (x_I, y_I).

The height of the target can be calculated as

$$H_T = R_{TI} * sin(q_{TI}) + y_I \tag{7}$$

The range between the target and the asset can be calculated as

$$R_{TA} = [(R_{TI} * cos(q_{TI}) + x_I)^2 + (R_{TI} * sin(q_{TI}) + y_I)^2]^{1/2} \tag{8}$$

Finally, the target route shortcut can be calculated as

$$RS = R_{TA} \sin\left(\arcsin \frac{H_T}{R_{TA}} - \theta_T\right) \tag{9}$$

At this point, all the selected indexes for target threat evaluation are obtained.

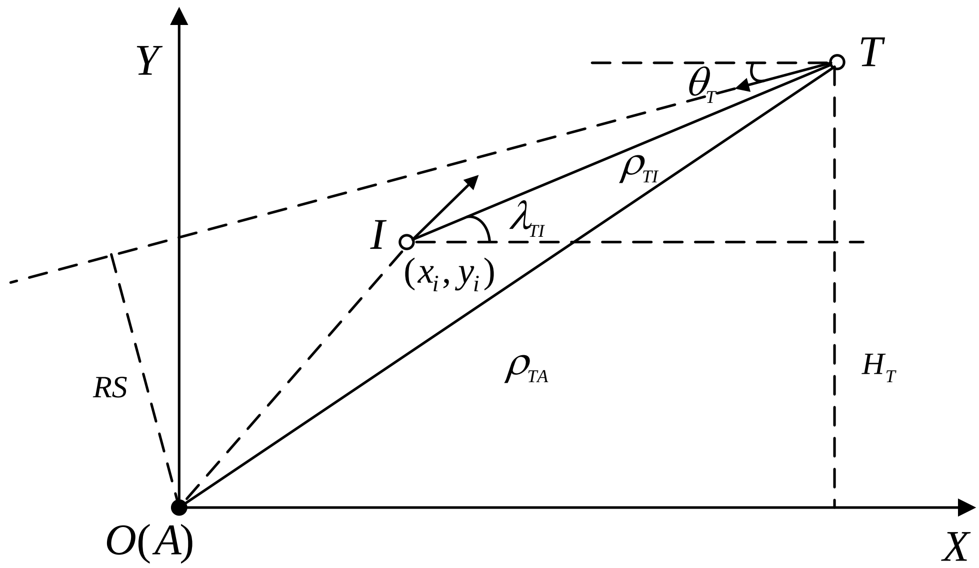

Figure 2. The planar geometry of the interceptor, target and defending asset.

3.3. Quantification of the Threat Indexes

As it was mentioned before, the air target threat assessment index of air defense operation includes various types of data. Each index value in the index system has an impact on the comprehensive evaluation value of the system; therefore, it is necessary to standardize different types of data to intuitionistic fuzzy numbers to evaluate the threat of the targets.

3.3.1. Quantification Method of Indexes in Fuzzy Evaluation Language

In this paper, the fuzzy language of the target type is divided into five levels. It is necessary to transform the fuzzy language into an intuitionistic fuzzy set. Table 1 shows the relationship between the fuzzy language and intuitionistic fuzzy set pair.

Table 1. Corresponding relationship between the target type and IFVs.

Target Type	Rank	Membership Degree	Non-Membership Degree
Missile	1	0.9	0.05
Battleplane	2	0.7	0.15
Bomber	3	0.5	0.3
Amed helicopter	4	0.3	0.6
Early warning aircraft	5	0.1	0.85

3.3.2. Quantification Method of Indexes in Real Numbers

For the benefit indexes, such as the target velocity and acceleration, assume there are m targets and n indexes; the membership degree and non-membership degree can be determined as follows:

$$t_{ij} = p \frac{\min_{1 \le k \le m} \left(x_{kj} \right)}{x_{ij}} \qquad (10)$$
$$f_{ij} = q \frac{\min_{1 \le k \le m} \left(x_{kj} \right)}{x_{ij}}$$

where p, q are adjusting parameters which are determined according to the air defense situation satisfying $0 \leqslant p \leqslant 1, 0 \leqslant q \leqslant 1, 0 \leqslant p + q \leqslant 1$.

For the cost indexes, such as the target route shortcut and height, the membership degree and non-membership degree can be determined as

$$t_{ij} = \alpha \frac{\min_{1 \le k \le m} \left(x_{kj} \right)}{x_{ij}} \qquad (11)$$
$$f_{ij} = \beta \frac{\min_{1 \le k \le m} \left(x_{kj} \right)}{x_{ij}}$$

where α, β are also adjusting parameters and defined the same as p, q.

4. The Generalized λ-Shapley Choquet Integral Operators

Proposed G-GIFSS Aggregation Operators Based on Generalized λ-Shapley Choquet Integral

In actual MCDM application situations, the determination of the weights for the indexes is a problem. Many studies determine the weights by entropy-based methods [9,20], which can only reflect the additivity property of the importance of the indexes. In order to address the problem, Sugeno introduced the following concept of a fuzzy measure with a monotonicity rather than an additivity property [25].

Definition 8 ([25])**.** *Given a fixed set $X = \{x_1, x_2, \ldots, x_n\}$, a fuzzy measure on X is the set function $\mu : P(X) \to [0,1]$, satisfying*

(1) $\mu(\varphi) = 0, \mu(X) = 1$;

(2) If $A, B \in P(X)$ and $A \subseteq B$, then $\mu(A) \le \mu(B)$.

As the fuzzy measure is defined on the power set $P(X)$, $2^n - 2$ values need to be determined (except 0 and 1), which makes it difficult to determine each value corresponding to each combination of the indexes and extremely restricts its application. To avoid the problem, Sugeno developed the so-called λ-fuzzy measure in [25] as the following form:

$$g_\lambda(C \cup D) = g_\lambda(C) + g_\lambda(D) + \lambda g_\lambda(C) g_\lambda(D) \qquad (12)$$

for $\forall C, D \subseteq X$ and $C \cap D = \varnothing$, where $\lambda \in (-1, \infty)$.

According to Equation (12), if $\lambda > 0$, then $g_\lambda(C \cup D) > g_\lambda(C) + g_\lambda(D)$, g_λ is a super-additive measure, which means coalitions C and D exhibit a positive synergetic interaction. If $\lambda < 0$, then $g_\lambda(C \cup D) < g_\lambda(C) + g_\lambda(D)$, g_λ is a sub-additive measure, which means coalitions C and D exhibit a negative synergetic interaction.

In particular, if $\lambda = 0$, then Equation (12) reduces to an additivity property weight, and all the indexes are considered to be independent:

$$g_\lambda(C \cup D) = g_\lambda(C) + g_\lambda(D) \qquad (13)$$

For finite set A, g_λ can be obtained by reiteration of Equation (12):

$$g_\lambda(A) = \begin{cases} \frac{1}{\lambda}(\prod_{i \in A}[1 + \lambda g_\lambda(i)] - 1) & \text{if } \lambda \neq 0, \\ \sum_{i \in A} g_\lambda(i) & \text{if } \lambda = 0, \end{cases} \tag{14}$$

According to $\mu(X) = 1$, we have

$$\prod_{i \in X}[1 + \lambda g_\lambda(i)] = 1 + \lambda \tag{15}$$

It is clear that if each $g_\lambda(i)$ is fixed, the value of λ is obtained, and then the fuzzy measure corresponding to every subset of the indexes can be calculated with Equation (14).

As one of the most important payoff indexes, the Shapley function has been extensively studied in game theory, which is the only solution satisfying the four axioms: efficiency, symmetry, dummy player and additivity [41]. In this paper, we introduce the generalized Shapley index put forward by Marichal [42], which can measure the overall average influence of each coalition rather than each player, in order to obtain a more rational fuzzy measure for each index subset. The generalized Shapley index can be expressed as

$$\varphi_S^{Sh}(\mu, N) = \sum_{T \subseteq MS} \frac{(n-s-t)!t!}{(n-s+1)!}(\mu(S \cup T) - \mu(T)) \quad \forall S \subseteq N \tag{16}$$

where μ is a fuzzy measure on N.

Then, the generalized Shapley index for the λ-fuzzy measure g_λ on N can be expressed as follows:

$$\varphi_S^{Sh}(g_i, N) = \sum_{T \subseteq N \setminus S} \frac{(n-s-t)!t!}{(n-s+1)!}(g_\lambda(S \cup T) - g_\lambda(T)), \quad \forall S \subseteq N \tag{17}$$

By Equation (4), if $S = \{i\}$, then

$$\varphi_i^{Sh}(g_\lambda, N) = \sum_{T \subseteq N \setminus i} \frac{(n-1-t)!t!}{n!} g_\lambda(i) \prod_{j \in S}[1 + \lambda g_\lambda(j)], \quad \forall i \in N \tag{18}$$

It can be seen that Equation (17) is an expected average value of the overal interaction between the coalition S and every coalition in $N \setminus S$. As a special case, Equation (18) provides the expected value of the overall interaction between the element i and every coalition in $N \setminus i$. Furthermore, as it is proved in [28], the calculated φ^{Sh} given as Equation (17) is still a fuzzy measure.

According to Definition 8, we define the arithmetical generalized λ-Shapley Choquet operator for GIFSS as follows:

Definition 9. *Let g_λ be a fuzzy measure on E and let $F_\alpha(a_i) = (F(a_i), \alpha(a_i)), i = 1, 2, \ldots, m$ be a collection of GIFSS over (E, N), where $F(a_i) = F(a_i(e_1), a_i(e_2), \ldots, a_i(e_n)) = \{a_{i1}, a_{i2}, \ldots, a_{in}\} \in IF^E$ and $\alpha(a_i)$ is an expert's evaluation on N for the ith element $F(a_i)$. If $a_{ij} = \left(t_{a_{ij}}, f_{a_{ij}}\right), j = 1, 2, \ldots, n$ and $\alpha(a_i) = (t_{\alpha_i}, f_{\alpha_i})$. The GIFSS arithmetical generalized λ-Shapley Choquet (G-AGSC$_{g_\lambda}$) operator is defined as follows:*

$$
\begin{aligned}
&\alpha(a_i)\otimes\int a_i d\varphi^{\mathrm{Sh}}(g_\lambda,N)=\text{G-AGSC}_{g_\lambda}(a_{i1},a_{i2},\ldots,a_{in})\\
&=\alpha(a_i)\otimes\left(\oplus_{j=1}^{n}a_{i\kappa(j)}\left(\varphi^{\mathrm{Sh}}_{A_{(j)}}(g_\lambda,N)-\varphi^{\mathrm{Sh}}_{A_{(j+1)}}(g_\lambda,N)\right)\right)\\
&=\left(t_{\alpha_i}\cdot\left(1-\prod_{j=1}^{n}\left(1-t_{a_{i\kappa}(j)}\right)^{\varphi^{\mathrm{Sh}}_{A(j)}(g_\lambda,N)-\varphi^{\mathrm{Sh}}_{A(j+1))}(g_\lambda,N)}\right),\right.\\
&\left.f_{\alpha_i}+\prod_{j=1}^{n}\left(f_{a_{i\kappa(j)}}\right)^{\varphi^{\mathrm{Sh}}_{A(j)}(g_\lambda,N)-\varphi^{\mathrm{Sh}}_{A(j+1)}(g_\lambda,N)}-f_{\alpha_i}\cdot\prod_{j=1}^{n}\left(f_{a_{i\kappa(j)}}\right)^{\varphi^{\mathrm{Sh}}_{A(j)}(g_\lambda,N)-\varphi^{\mathrm{Sh}}_{A_{(j+1)}}(g_\lambda,N)}\right)
\end{aligned}
\tag{19}
$$

and the GIFSS geometric generalized λ-Shapley Choquet (G-GGSC$_{g_\lambda}$) operator is written as

$$
\begin{aligned}
&\alpha(a_i)\otimes\int a_i d\varphi^{\mathrm{Sh}}(g_\lambda,N)=\text{G-GGSC}_{g_\lambda}(a_{i1},a_{i2},\ldots,a_{in})\\
&=\alpha(a_i)\otimes\left(\oplus_{j=1}^{n}(a_{i\kappa(j)})^{\varphi^{\mathrm{Sh}}_{A_{(j)}}(g_\lambda,N)-\varphi^{\mathrm{Sh}}_{A_{(j+1)}}(g_\lambda,N)}\right)\\
&=\left(t_{\alpha_i}\cdot\prod_{j=1}^{n}\left(t_{a_{i\kappa}(j)}\right)^{\varphi^{\mathrm{Sh}}_{A(j)}(g_\lambda,N)-\varphi^{\mathrm{Sh}}_{A(j+1)}(g_\lambda,N)},\right.\\
&\left.f_{\alpha_i}+\left(1-\prod_{j=1}^{n}\left(1-f_{a_{i\kappa(j)}}\right)^{\varphi^{\mathrm{Sh}}_{A(j+1)}(g_\lambda,N)-\varphi^{\mathrm{Sh}}_{A(j+1)}(g_\lambda,N)}\right)-f_{\alpha_i}\cdot\left(1-\prod_{j=1}^{n}\left(1-f_{a_{i\kappa(j)}}\right)^{\varphi^{\mathrm{Sh}}_{A(j+1)}(g_\lambda,N)-\varphi^{\mathrm{Sh}}_{A(j+1)}(g_\lambda,N)}\right)\right)
\end{aligned}
\tag{20}
$$

where φ^{Sh} is the generalized Shapley index given as Equation (5), and $(\kappa(1),\kappa(2),\ldots,\kappa(n))$ is a permutation of $(j=1,2,\ldots,n)$ such that $a_{i\kappa(1)}\le a_{i\kappa(2)}\le\cdots\le a_{i\kappa(n)}$ and $A_{(j)}=\{j,\ldots,n\}$ with $A_{(n+1)}=\emptyset$.

Theorem 1. *The aggregated values of the proposed G-AGSC$_{g_\lambda}$ and G-GGSC$_{g_\lambda}$ operators are also IFVs.*

Proof. The theorem is proved by using the basic operational rules of FS and mathematical induction.

For $n=1$,

$$
\begin{aligned}
&\text{G-AGSC}_{g_\lambda}(a_{i1})\\
&=\left(t_{\alpha_i}\cdot\left(1-\left(1-t_{a_{i\kappa}(1)}\right)^{\varphi^{\mathrm{Sh}}_{A(1)}(g_\lambda,N)-\varphi^{\mathrm{Sh}}_{A(2))}(g_\lambda,N)}\right),\right.\\
&\left.f_{\alpha_i}+\left(f_{a_{i\kappa(1)}}\right)^{\varphi^{\mathrm{Sh}}_{A(1)}(g_\lambda,N)-\varphi^{\mathrm{Sh}}_{A(2)}(g_\lambda,N)}-f_{\alpha_i}\cdot\left(f_{a_{i\kappa(1)}}\right)^{\varphi^{\mathrm{Sh}}_{A(1)}(g_\lambda,N)-\varphi^{\mathrm{Sh}}_{A_{(2)}}(g_\lambda,N)}\right)\\
&=\alpha(a_i)\otimes(k_1a_{i1})
\end{aligned}
\tag{21}
$$

where $k_1=(\varphi^{\mathrm{Sh}}_{A(1)}(g_\lambda,N)-\varphi^{\mathrm{Sh}}_{A_{(2)}}(g_\lambda,N)$, and the result is an IFV according to Definition 4.

For $n=2$,

$$
\begin{aligned}
&\text{G-AGSC}_{g_\lambda}(a_{i1},a_{i2})\\
&=\Bigg(t_{\alpha_i}\cdot\left(1-\left(1-t_{a_{i\kappa(1)}}\right)^{\varphi^{\text{Sh}}_{A(1)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A(2))}(g_\lambda,N)}\left(1-t_{a_{i\kappa(2)}}\right)^{\varphi^{\text{Sh}}_{A(2)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A(3))}(g_\lambda,N)}\right),\\
&f_{\alpha_i}+\left(f_{a_{i\kappa(1)}}\right)^{\varphi^{\text{Sh}}_{A(1)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A(2)}(g_\lambda,N)}\left(f_{a_{i\kappa(2)}}\right)^{\varphi^{\text{Sh}}_{A(2)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A(3)}(g_\lambda,N)}\\
&-f_{\alpha_i}\cdot\left(f_{a_{i\kappa(1)}}\right)^{\varphi^{\text{Sh}}_{A(1)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A_{(2)}}(g_\lambda,N)}\left(f_{a_{i\kappa(2)}}\right)^{\varphi^{\text{Sh}}_{A(2)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A_{(3)}}(g_\lambda,N)}\Bigg)\\
&=\alpha(a_i)\otimes((k_1a_{i1})\oplus(k_2a_{i2}))
\end{aligned}
\tag{22}
$$

and the result is also definitely an IFV.

Assume when $n=p$, the theorem holds, that is,

$$
\begin{aligned}
&\text{G-AGSC}_{g_\lambda}(a_{i1},a_{i2},\ldots,a_{ip})\\
&=\Bigg(t_{\alpha_i}\cdot\left(1-\prod_{j=1}^{p}\left(1-t_{a_{i\kappa(j)}}\right)^{\varphi^{\text{Sh}}_{A(j)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A(j+1))}(g_\lambda,N)}\right),\\
&f_{\alpha_i}+\prod_{j=1}^{p}\left(f_{a_{i\kappa(j)}}\right)^{\varphi^{\text{Sh}}_{A(j)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A(j+1)}(g_\lambda,N)}-f_{\alpha_i}\cdot\prod_{j=1}^{p}\left(f_{a_{i\kappa(j)}}\right)^{\varphi^{\text{Sh}}_{A(j)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A_{(j+1)}}(g_\lambda,N)}\Bigg)
\end{aligned}
\tag{23}
$$

is an IFV.

Then, for $n=p+1$, we have

$$
\begin{aligned}
&\text{G-AGSC}_{g_\lambda}(a_{i1},a_{i2},\ldots,a_{ip+1})\\
&=\Bigg(t_{\alpha_i}\cdot\left(1-\prod_{j=1}^{p}\left(1-t_{a_{i\kappa(j)}}\right)^{\varphi^{\text{Sh}}_{A(j)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A(j+1))}(g_\lambda,N)}\cdot\left(\left(1-t_{a_{i\kappa(p+1)}}\right)^{\varphi^{\text{Sh}}_{A(p+1)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A(p+2))}(g_\lambda,N)}\right)\right),\\
&f_{\alpha_i}+\prod_{j=1}^{p}\left(f_{a_{i\kappa(j)}}\right)^{\varphi^{\text{Sh}}_{A(j)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A(j+1)}(g_\lambda,N)}\cdot\left(\left(f_{a_{i\kappa(p+1)}}\right)^{\varphi^{\text{Sh}}_{A(p+1)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A(p+2)}(g_\lambda,N)}\right)\\
&-f_{\alpha_i}\cdot\prod_{j=1}^{p}\left(f_{a_{i\kappa(j)}}\right)^{\varphi^{\text{Sh}}_{A(j)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A_{(j+1)}}(g_\lambda,N)}\cdot\left(\left(f_{a_{i\kappa(p+1)}}\right)^{\varphi^{\text{Sh}}_{A(p+1)}(g_\lambda,N)-\varphi^{\text{Sh}}_{A(p+2)}(g_\lambda,N)}\right)\Bigg)\\
&=\alpha(a_i)\otimes\left((\text{G-AGSC}_{g_\lambda}(a_{i1},a_{i2},\ldots,a_{ip}))\oplus(k_{p+1}a_{ip+1})\right)
\end{aligned}
\tag{24}
$$

It is clear that the conclusions remain valid; therefore, the theorem is proved. □

Remark 1. *It is easy to see that Equations (18) and (19) are, respectively, the extensions of some arithmetical aggregation operators and geometric aggregation operators based on additive measures.*

5. Threat Evaluation Example and Analysis

Assume the air defense system launches a carrier cabin carrying six small interceptors to intercept a target group consisting of four targets in an air defense interception operation. In the terminal interception phase, the carrier cabin releases small interceptors to intercept each target. Suppose that the initial target assignment scheme is $(1,1,2,3,3,4)$, that is, two interceptors are allocated to target 1 and target 3. The initial positions and following trajectories of the interceptors and targets are shown in Figure 3, where the defending asset is set at the origin throughout the simulation.

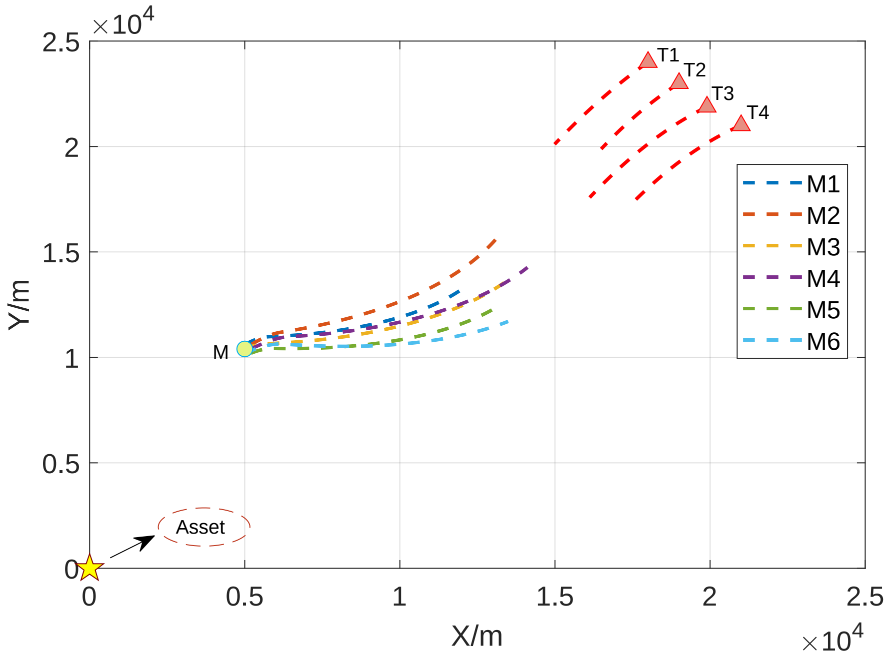

Figure 3. Initial positions and trajectories of the interceptor and the target.

5.1. Evaluation Process

The two methods based on GIFSS generalized λ-Shapley Choquet operators, G-AGSC$_{g\lambda}$ and G-GGSC$_{g\lambda}$, are applied to the threat evaluation of four air targets, and the specific steps of the evaluation process are as follows:

Method 1: The method with the G-AGSC$_{g\lambda}$ operator.

Step 1 At the initial time (the process of any other time is consistent with this), the target threat index values are summarized, as shown in Table 2.

Table 2. The index values with respect to the targets.

Index	Type	Height (m)	T–A Distance (m)	Velocity (m/s)	Acceleration (m/s^2)	Route Shortcut (m)	T–M Distance (m)	T–M Velocity (m/s)
T1	Missile	23,999.92	29,999.89	107.96	1.00	98,098.79	18,669.47	293.50
	Missile	23,999.92	29,999.89	107.96	1.00	98,098.79	18,530.70	355.39
T2	Bomber	22,999.94	29,832.78	85.43	1.00	97,738.04	18,834.77	307.52
T3	Missile	21,879.93	29,575.96	116.15	2.00	99,214.27	18,651.19	361.96
	Missile	21,879.93	29,575.96	116.15	2.00	99,214.27	18,775.00	317.80
T4	Bomber	209,99.94	29,698.38	107.30	2.00	100,015.36	19,303.57	311.97

Step 2 Denote the set of targets as $A = \{T1, T2, T3, T4\}$ and the set of indexes as $C = \{C_1, C_2, \cdots, C_8\}$. Based on the index quantification method in Section 3.3, the IFS matrix of the targets is calculated as shown in Table 3, where the multi-source information of targets 1 and 3 is simply weighted according to the distance between each interceptor and the target.

Table 3. IFS matrix of the air target TI.

Index	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
T1	(0.90, 0.05)	(0.70, 0.21)	(0.79, 0.11)	(0.74, 0.09)	(0.40, 0.05)	(0.80, 0.10)	(0.77, 0.10)	(0.73, 0.18)
T2	(0.50, 0.30)	(0.73, 0.18)	(0.79, 0.11)	(0.59, 0.07)	(0.40, 0.05)	(0.80, 0.10)	(0.78, 0.10)	(0.76, 0.14)
T3	(0.90, 0.05)	(0.77, 0.14)	(0.80, 0.10)	(0.80, 0.10)	(0.80, 0.10)	(0.79, 0.11)	(0.76, 0.10)	(0.69, 0.22)
T4	(0.50, 0.30)	(0.80, 0.10)	(0.80, 0.10)	(0.74, 0.09)	(0.80, 0.10)	(0.78, 0.12)	(0.80, 0.10)	(0.75, 0.15)

Step 3 Suppose a single expert gives his/her preference in the form of the generalization parameters, which are summarized in Table 4.

Table 4. The generalization parameters given by the expert for each target.

	T1	T2	T3	T4
Expert	(0.857, 0.021)	(0.834, 0.081)	(0.876, 0.016)	(0.733, 0.023)

Step 4 According to Definition 3, rearrange the threat index values of the targets in ascending order. The rearranged index values of each target are shown in Table 5.

Table 5. The rearranged IFS matrix of the air target TI.

Index	$C_{\kappa(1)}$	$C_{\kappa(2)}$	$C_{\kappa(3)}$	$C_{\kappa(4)}$	$C_{\kappa(5)}$	$C_{\kappa(6)}$	$C_{\kappa(7)}$	$C_{\kappa(8)}$
T1	(0.40, 0.55)	(0.70, 0.21)	(0.73, 0.18)	(0.74, 0.16)	(0.77, 0.13)	(0.79, 0.11)	(0.80, 0.10)	(0.90, 0.05)
T2	(0.40, 0.55)	(0.50, 0.20)	(0.59, 0.34)	(0.73, 0.18)	(0.76, 0.14)	(0.78, 0.12)	(0.79, 0.11)	(0.80, 0.10)
T3	(0.69, 0.22)	(0.77, 0.14)	(0.78, 0.13)	(0.79, 0.11)	(0.80, 0.10)	(0.80, 0.10)	(0.80, 0.10)	(0.90, 0.05)
T4	(0.50, 0.20)	(0.74, 0.17)	(0.75, 0.15)	(0.78, 0.12)	(0.80, 0.10)	(0.80, 0.10)	(0.80, 0.10)	(0.80, 0.10)

Step 5 It is assumed that compared with other indexes, the decision-maker attaches more importance to route shortcut, missile–target distance and missile–target relative velocity, and the fuzzy measure value of each indicator is

$$g_\lambda(C_1) = 0.12, g_\lambda(C_2) = 0.1, g_\lambda(C_3) = 0.23, g_\lambda(C4) = 0.15 \tag{25}$$

$$g_\lambda(C_5) = 0.05, g_\lambda(C_6) = 0.33, g_\lambda(C_7) = 0.35, g_\lambda(C_8) = 0.27 \tag{26}$$

Step 6 According to Equation (14), the parameter $\lambda = -0.7212$ of the fuzzy measure of the index is obtained, and then the basic correlation measure between the indexes is obtained. Considering the emphasis on the correlation between the indexes, the correlation measure that includes both distance and velocity is increased, and the adjustment factor is taken as 1.25.

Step 7 By using Formulas (17) and (18), the λ-Shapley fuzzy measure of each index and combination of indexes is obtained.

Step 8 Combine the IFS matrix with the generalization parameter matrix, and then we can obtain the GIFSS matrix. The aggregation results for the targets can be obtained after applying the G-AGSC$_{g_\lambda}$ operator, and they are

$$R_{T1} = (t_{T1}, f_{T1}) = \text{G-AGSC}_{g_\lambda}(a_{11}, a_{12}, \ldots, a_{18}) = (0.6558, 0.1223) \tag{27}$$

$$R_{T2} = (t_{T2}, f_{T2}) = \text{G-AGSC}_{g_\lambda}(a_{21}, a_{22}, \ldots, a_{28}) = (0.5986, 0.1860) \tag{28}$$

$$R_{T3} = (t_{T3}, f_{T3}) = \text{G-AGSC}_{g_\lambda}(a_{31}, a_{32}, \ldots, a_{38}) = (0.6974, 0.1210) \tag{29}$$

$$R_{T4} = (t_{T4}, f_{T4}) = \text{G-AGSC}_{g_\lambda}(a_{41}, a_{42}, \ldots, a_{48}) = (0.5599, 0.1405) \tag{30}$$

Step 9 By using the score function and exact function, we can obtain the score values s_T and the exact values h_T of the targets, as shown in Figure 4.

According to the ranking rules, the ranking result of the targets is

$$T1 > T3 > T2 > T4 \tag{31}$$

Method 2: The method with the G-GGSC$_{g_\lambda}$ operator.

The evaluation process is similar to Method 1 but with the replacement of the aggregation operator with G-GGSC $_{g_\lambda}$ when aggregating the threat evaluation GIFSS matrix, and the aggregation results are as follows:

$$R_{T1} = (t_{T1}, f_{T1}) = \text{G-AGSC}_{g_\lambda}(a_{11}, a_{12}, \ldots, a_{18}) = (0.7204, 0.1510) \quad (32)$$

$$R_{T2} = (t_{T2}, f_{T2}) = \text{G-AGSC}_{g_\lambda}(a_{21}, a_{22}, \ldots, a_{28}) = (0.6898, 0.1984) \quad (33)$$

$$R_{T3} = (t_{T3}, f_{T3}) = \text{G-AGSC}_{g_\lambda}(a_{31}, a_{32}, \ldots, a_{38}) = (0.6765, 0.1374) \quad (34)$$

$$R_{T4} = (t_{T4}, f_{T4}) = \text{G-AGSC}_{g_\lambda}(a_{41}, a_{42}, \ldots, a_{48}) = (0.5952, 0.1214) \quad (35)$$

The score values and the exact values of the targets are shown in Figure 5.

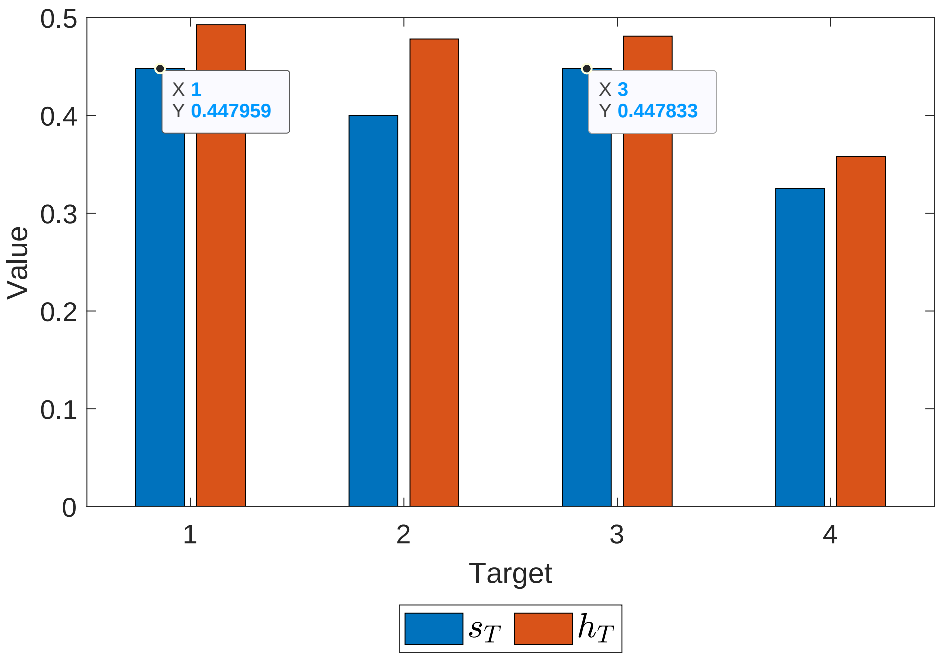

Figure 4. The score values and exact values for the targets under the G-AGSC$_{g_\lambda}$ operator.

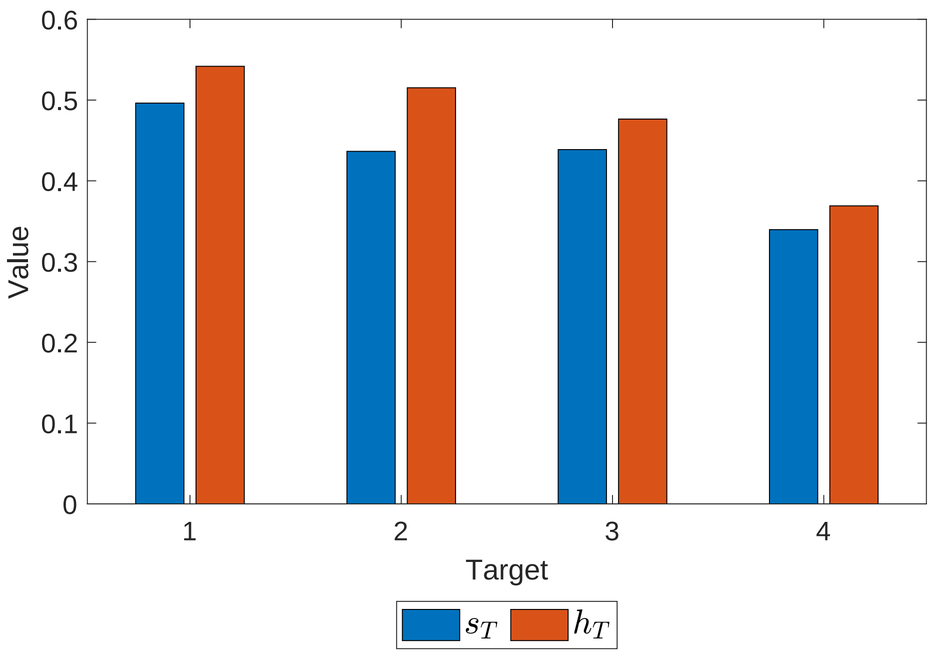

Figure 5. The score values and exact values for the targets under the G-GGSC$_{g_\lambda}$ operator.

According to the ranking rules, the ranking result of the targets is apparently the same as the method with the G-AGSC$_{g_\lambda}$ operator:

$$T1 > T3 > T2 > T4 \tag{36}$$

5.2. Comparative Analysis

5.2.1. Comparison with Existing Methods in the Tradtional Index System

Firstly, the threat evaluation results of the proposed methods and the IFS method in [32] and GIFSS method in [20] are compared under the traditional index system which only considers the relative kinematics between the defending assets and targets. The score values of the targets under the proposed methods and comparison methods are shown in Figure 6.

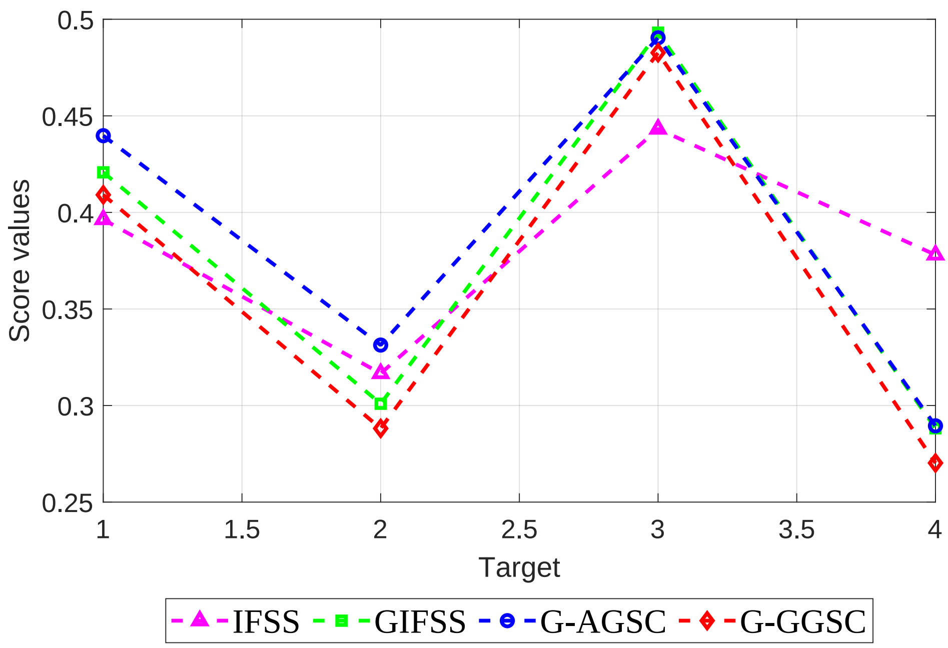

Figure 6. The score values of the targets under different methods in the tradtional index system.

The ranking results of the proposed methods and comparison methods are shown in Table 6.

Table 6. Ranking results of the targets under different methods in the tradtional index system.

	Method	Ranking Results
Comparison methods	IFSS	$T3 > T1 > T4 > T2$
	GIFSS	$T3 > T1 > T2 > T4$
Proposed methods	G-AGSC	$T3 > T1 > T2 > T4$
	G-GGSC	$T3 > T1 > T2 > T4$

It is clear that the ranking results of the targets under the proposed methods in the tradtional index system are consistent with the GIFSS method, which verifies the effectiveness of the proposed methods. Analyzing the generalized parameter matrix given by the experts for each target and comparing target 2 and target 4, the expert provided an assessment that the threat of target 2 is greater than that of target 4, whereas as the IFS method does not include the generalized parameter matrix given by the expert, the ranking result is that the threat of target 4 is greater than the threat of target 2, which is not consistent with the results of the other algorithms.

5.2.2. Comparison with Existing Methods in the Proposed Index System

The score values of the targets under the proposed methods and comparison methods are shown in Figure 7.

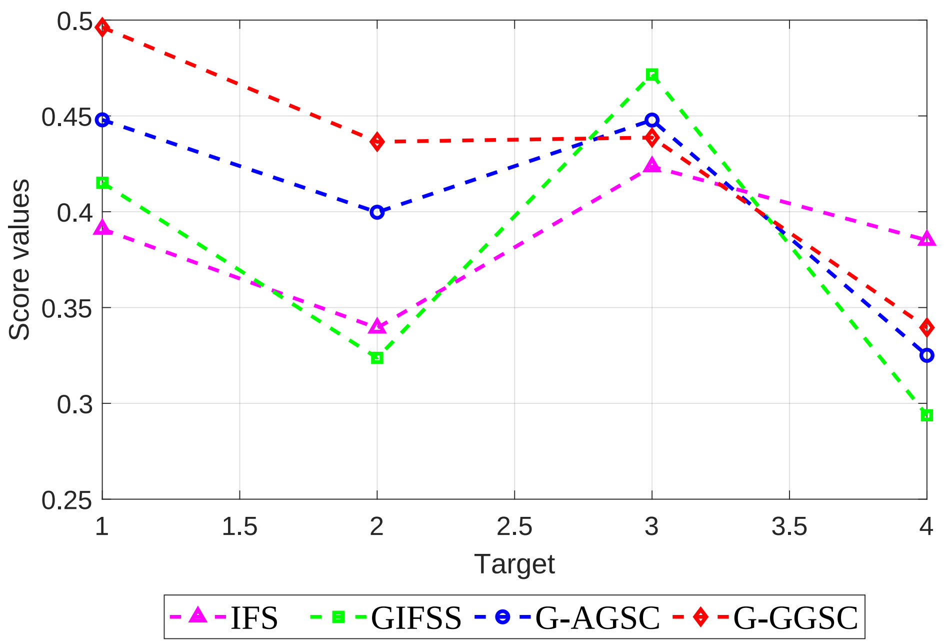

Figure 7. The score values of the targets under different methods in the proposed index system.

The ranking results of the proposed methods and comparison methods are shown in Table 7.

Table 7. Ranking results of the targets under different methods in the proposedindex system.

	Method	Ranking Results
Comparison methods	IFSS	$T3 > T1 > T4 > T2$
	GIFSS	$T3 > T1 > T2 > T4$
Proposed methods	G-AGSC	$T1 > T3 > T2 > T4$
	G-GGSC	$T1 > T3 > T2 > T4$

Referring to the initial target threat index, Table 2, among all targets, the interceptor has the fastest speed relative to target 3, and the relative distance is close to target 1, which means that target 3 is most likely to be intercepted first. Therefore, compared with the evaluation results in the traditional index system, each method reduces the threat score value of target 3. However, in terms of the ranking results, the comparison methods are consistent with the previous ranking results, whereas the ranking results of the two proposed algorithms are different. This is because, on the one hand, the aggregation operator based on the fuzzy measure and the Choquet integral can not only reflect the preference of decision-makers for each independent index but can also consider the correlation between indexes, which is more general and applicable for MCDM problems, such as this example. On the other hand, by introducing the Shapley index, it can reflect the overall average contribution of each index and index set to the entire index system, which is more reasonable and more in line with the overall evaluation and perception of decision-makers for the targets.

6. Conclusions

In this paper, a new threat evaluation index system was proposed by introducing the kinematics relative to the interceptors into the traditional threat evaluation index system, the idea of which originates from the notion that the more likely the target will be intercepted, the smaller the threat of the target. Then, two new aggregation operators for GIFSS named the G-AGSC$_{g_\lambda}$ operator and the G-GGSC$_{g_\lambda}$ operator were proposed, by employing λ-Shapley fuzzy measures instead of independent addable functions to weigh each index and the index sets, which can not only reflect the correlation between the indexes but can also indicate the overall average contribution of each index and index set to the whole index system. The proposed methods can overcome the limitations of existing IFS and GIFSS methods, and the effectiveness and superiority are verified by the numerical simulation and comparison.

Our future work may concentrate on how to determine the fuzzy measures of each index and index set more objectively and scientifically according to the problem characteristics, target characteristics and decision-maker's preference.

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Abbreviations

The following abbreviations are used in this manuscript:

TE	Threat evaluation
TI	Threat indexes
IFS	Intuitionistic fuzzy set
IFV	Intuitionistic fuzzy value
SS	Soft set
GIFSS	Generalized intuitionistic fuzzy soft set
MCDM	Multiple criteria decision making

References

1. Paradis, S.; Benaskeur, A.; Oxenham, M.; Cutler, P. Threat Evaluation and Weapons Allocation in Network-Centric Warfare. In Proceedings of the 7th International Conference on Information Fusion, Philadelphia, PA, USA, 25–28 July 2005; Volume 2, p. 8. [CrossRef]
2. Lee, H.; Choi, B.J.; Kim, C.O.; Kim, J.S.; Kim, J.E. Threat Evaluation of Enemy Air Fighters via Neural Network-Based Markov Chain Modeling. *Knowl. Based Syst.* **2017**, *116*, 49–57. [CrossRef]
3. Naseem, A.; Shah, S.T.H.; Khan, S.A.; Malik, A.W. Decision support system for optimum decision making process in threat evaluation and weapon assignment: Current status, challenges and future directions. *Annu. Rev. Control* **2017**, *43*, 169–187. [CrossRef]
4. Matawale, C.R.; Panigrahi, S.; Sahu, S.K.; Datta, S.; Mahapatra, S.S. Fuzzy-TOPSIS for Appropriate Site Selection for Establishing a Thermal Power Plant. *Appl. Mech. Mater.* **2014**, *619*, 385–389. [CrossRef]
5. Wang, L.; Liu, Z.G.; Wang, W. Aerial Targets Threat Evaluation Method. In Proceedings of the 2nd Annual International Conference on Electronics, Electrical Engineering and Information Science (EEEIS 2016), Xi'an, China, 4–6 December 2016. [CrossRef]
6. Yang, Y.; Yu, L.; Zhou, Z.; Ruan, C. Air target threat evaluation based on RS-TOPSIS. *J. Beijing Univ. Aeronaut. Astronaut.* **2018**, *44*, 1001. [CrossRef]
7. Lei, Y.J.; Wang, B.S.; Wang, Y. Techniques for threat assessment based on intuitionistic fuzzy reasoning. *Dianzi Yu Xinxi Xuebao/J. Electron. Inf. Technol.* **2007**, *29*, 2077–2081.
8. Xu, Y.; Wang, Y.; Miu, X. Multi-attribute decision making method for air target threat evaluation based on intuitionistic fuzzy sets. *Syst. Eng. Electron. J.* **2012**, *23*, 891–897. [CrossRef]

9. Zhang, Z.; Kong, W.; Liu, P.; Shi, J.; Lei, Y.; Zou, J. Assessment and sequencing of air target threat based on intuitionistic fuzzy entropy and dynamic VIKOR. *J. Syst. Eng. Electron.* **2018**, *29*, 305. [CrossRef]
10. Johansson, F.; Falkman, G. A Comparison between Two Approaches to Threat Evaluation in an Air Defense Scenario. In *Modeling Decisions for Artificial Intelligence*; Torra, V., Narukawa, Y., Eds.; Springer: Berlin/Heidelberg, Germany, 2008; pp. 110–121.
11. Johansson, F.; Falkman, G. A Bayesian Network Approach to Threat Evaluation with Application to an Air Defense Scenario. In Proceedings of the IEEE International Conference on Information Fusion, Cologne, Germany, 30 June–3 July 2008. [CrossRef]
12. Wang, Y.; Sun, Y.; Li, J.Y.; Xia, S.T. Air Defense Threat Assessment Based on Dynamic Bayesian Network. In Proceedings of the 2012 International Conference on Systems and Informatics (ICSAI2012), Yantai, China, 19–20 May 2012. [CrossRef]
13. Molodtsov, D. Soft set theory—First results. *Comput. Math. Appl.* **1999**, *37*, 19–31. [CrossRef]
14. Maji, P.K.; Biswas, R.R.A.R. Intuitionistic fuzzy soft sets. *J. Fuzzy Math.* **2001**, *9*, 677–692.
15. Maji, P.K.; Roy, A.R.; Biswas, R. On intuitionistic fuzzy soft sets. *J. Fuzzy Math.* **2004**, *20*, 669–684.
16. Maji, P.K. More on Intuitionistic Fuzzy Soft Sets. In Proceedings of the International Workshop on Rough Sets, Fuzzy Sets, Data Mining, and Granular-Soft Computing, Delhi, India, 15–18 December 2009.
17. Agarwal, M.; Hanmandlu, M.; Biswas, K. Generalized Intuitionistic Fuzzy Soft Set and Its Application in Practical Medical Diagnosis Problem. In Proceedings of the FUZZ-IEEE 2011, IEEE International Conference on Fuzzy Systems, Taipei, Taiwan, 27–30 June 2011; pp. 2972–2978. [CrossRef]
18. Agarwal, M.; Biswas, K.K.; Hanmandlu, M. Generalized intuitionistic fuzzy soft sets with applications in decision-making. *Appl. Soft Comput. J.* **2013**, *13*, 3552–3566. [CrossRef]
19. Wu, H.; Su, X.Q. Threat assessment of aerial targets based on group generalized intuitionistic fuzzy soft sets. *Control Decis.* **2015**, *30*, 1462–1468. [CrossRef]
20. Feng, J.; Zhang, Q.; Hu, J.; Liu, A. Dynamic assessment method of air target threat based on improved GIFSS. *J. Syst. Eng. Electron.* **2019**, *30*, 525–534. [CrossRef]
21. Garg, H.; Arora, R. Generalized and group-based generalized intuitionistic fuzzy soft sets with applications in decision-making. *Appl. Intell.* **2018**, *48*, 343–356. [CrossRef]
22. Choquet, G. Theory of capacities. *Ann. L'Institut Fourier.* **1953**, *5*, 131–295. [CrossRef]
23. Tan, C.; Chen, X. Intuitionistic fuzzy Choquet integral operator for multi-criteria decision making. *Expert Syst. Appl.* **2010**, *37*, 149–157. [CrossRef]
24. Xu, Z. Choquet integrals of weighted intuitionistic fuzzy information. *Inf. Sci.* **2010**, *180*, 726–736. [CrossRef]
25. Sugeno, M. Theory of Fuzzy Integrals and Its Application. Ph.D. Thesis, Tokyo Institute of Technology, Tokyo, Japan, 1974.
26. Grabisch, M. k-order additive discrete fuzzy measures and their representation. *Fuzzy Sets Syst.* **1997**, *92*, 167–189. [CrossRef]
27. Tan, C. A multi-criteria interval-valued intuitionistic fuzzy group decision making with Choquet integral-based TOPSIS. *Expert Syst. Appl. Int. J.* **2011**, *38*, 3023–3033. [CrossRef]
28. Meng, F.; Zhang, Q.; Cheng, H. Approaches to multiple-criteria group decision making based on interval-valued intuitionistic fuzzy Choquet integral with respect to the generalized -Shapley index. *Knowl. Based Syst.* **2013**, *37*, 237–249. [CrossRef]
29. Qu, G.H.; Zhang, H.P.L. Group decision making based on λ-Shapley Choquet integral novel intuitionistic fuzzy TOPSIS method. *Syst. Eng. Theory Pract.* **2016**, *36*, 726–742. [CrossRef]
30. Zadeh, L. Fuzzy sets, information and control. *Inf. Control* **1965**, *8*, 353–388. [CrossRef]
31. Atanassov, K.T. Intuitionistic fuzzy sets. *Fuzzy Sets Syst.* **1986**, *20*, 87–96. [CrossRef]
32. Xu, Z. Intuitionistic preference relations and their application in group decision making. *Inf. Sci.* **2007**, *177*, 2363–2379. [CrossRef]
33. Xu, Z.; Yager, R. Some Geometric Aggregation Operators Based on Intuitionistic Fuzzy Sets. *Int. J. Gen. Syst.* **2006**, *35*, 417–433. [CrossRef]
34. Li, S.; Peng, X.Q.; Li, Y.X. Choquet integrals of weighted generalized and group generalized intuitionistic fuzzy soft sets. *Soft Comput.* **2020**, *24*, 745–760. [CrossRef]
35. Liu, X.; Han, Y.; Qiu, H.; Zheng, Z. Threat Evaluation in Air Defense Based on Improved KPCA-TOPSIS. In Proceedings of the 2018 IEEE CSAA Guidance, Navigation and Control Conference (GNCC), Xiamen, China, 10–12 August 2018. [CrossRef]
36. Zhang, Q.; Hu, J.; Feng, J.; Liu, A. Air multi-target threat assessment method based on improved GGIFSS. *J. Intell. Fuzzy Syst.* **2019**, *36*, 4127–4139. [CrossRef]
37. Shaferman, V.; Oshman, Y. Cooperative Interception in a Multi-Missile Engagement. In Proceedings of the 2009 AIAA Guidance, Navigation, and Control Conference, Chicago, IL, USA, 10–13 August 2009.
38. Chen, T.; Xu, S. Double line-of-sight measuring relative navigation for spacecraft autonomous rendezvous. *Acta Astronaut.* **2010**, *67*, 122–134. [CrossRef]
39. Chen, T.; Xu, S. Approach Guidance with Double-Line-of-Sight Measuring Navigation Constraint for Autonomous Rendezvous. *J. Guid. Control Dyn.* **2012**, *34*, 678–687. [CrossRef]
40. Liu, Y.; Qi, N.; Shan, J. Cooperative Interception with Double-Line-of-Sight-Measuring. In Proceedings of the 2013 AIAA Guidance, Navigation, and Control Conference, Boston, MA, USA, 19–22 August 2013.
41. Shapley, L. A value for n-person games. In *Annals of Mathematics Study*; Princeton University Press: Princeton, NJ, USA, 1953.
42. Marichal, J.L.; Kojadinovic, I.; Fujimoto, K. Axiomatic characterizations of generalized values. *Discret. Appl. Math.* **2007**, *155*, 26–43. [CrossRef]