

Evaluate and Identify Optimal Weapon Systems Using Fuzzy Multiple Criteria Decision Making

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Abstract— The weapon identification and selection issue is an important and strategic component and has a significant impact on the efficiency of defense system in US. The main purpose of this research is to develop a universal model and system to effectively assess, evaluate and identify the optimal weapons from a large collection of available weapon systems that have multiple criteria based on a fuzzy multiple criteria decision making (FMCDM) model. A simple but effective weight estimation method is adopted in this paper to make this selection more objective and reliable. There are some different weight estimation methods reported by researchers, however, most methods need a lot of mathematical operations and make the process very time consuming and even more complicated. In this paper, we utilized a weight estimation method based on the paired comparison matrix to simplify this estimation process. The evaluation and selection process can be significantly simplified and improved by using this method.

Keywords- *Optimal weapon systems; fuzzy multi-criteria decision making; similarity measure; decision matrix*

I. INTRODUCTION

One of the most important and critical issues related to the national defense is to correctly evaluate and assess the optimal weapons or weapon systems from a large collection of weapons to improve and enhance the overall performance and productivity of the national defense system. This evaluation and assessing issue becomes more important after September 11, 2001 since some enemy countries have defined US as their target and began to attack the US territory in an offensive way. In order to effectively protect our country from being attacked by any foreign country who has offensive weapons and effectively attack back those enemy countries, developing and building efficient models and systems to correctly evaluate and assess the optimal weapons or weapon systems is a prerequisite task to the US defense system. In this research, we will develop and build a fuzzy multiple criteria decision making model (FMCDM) to perform this evaluation and assessing task in a more efficient and reliable way. The FMCDM technique is based on multiple criteria decision making (MCDM) technique.

The MCDM technique can be divided into two major categories: crisp or classical and fuzzy MCDMs. In recent years, many researchers have attempted to use fuzzy MCDM methods for optimal equipment selection problems. Such as Lin and Yang using the AHP method to build a machine

selection model [1], Tabucanon et al. developed a decision support framework for selecting the most appropriate machines in flexible manufacturing systems (FMS) [2], Atmani and Lashkari developed a model for machine tool selection and operation allocation in FMS [3], Wang et al. presented a fuzzy multiple attribute decision making model to select the appropriate machines for FMS [4], Arslan et al. presented a multi-criteria weighted average (MCWA) method for machine tool selection [5]. Yurdakul proposed a model linking machine alternatives to manufacturing strategy for machine tool selection [6]. Ayag and Ozdemir used the fuzzy AHP technique to weight the machine tool alternatives under eight main and nineteen sub-criteria and then carried out benefit/cost ratio analysis by using both the fuzzy AHP score and procurement cost, of each alternative [7].

Some other researchers reported different methods to perform the optimal evaluations and estimations for various machine tools and equipments [8-13]. Although weapon evaluation and selection play an important role in the design of an effective defense system, however, the publications and researches on this subject are very limited [14-20].

Basically, correct evaluating and assessing of the optimal weapon systems can be defined as a decision making process. In recent years, different conventional decision making methods and models have been developed and adopted, such as the optimal estimation, linear programming and Karman filter. However, the fuzzy decision making model is a good candidate among those methods. As we know, one of the most useful aspects of fuzzy set theory is its ability to represent mathematically a class of decision problems called multiple objective decisions (MODs). This class of problems often involves many vague and ambiguous (and thus fuzzy) goals and constraint factors. The object of the fuzzy decision methodology is to obtain a decision, optimum in the sense that some set of goals is attained while observing (i.e. not violating) a simultaneous set of constraint factors.

The paper is organized as follows. The scope and objectives of this paper, combined with a technique review to FMCDM, are provided in section 1. The detailed description of the FMCDM model is described in section 2. The adopted method used to estimate the weight to the associated criteria or objectives is discussed in section 3. A case study with an example of evaluating and assessing the optimal weapon

system (missiles) is given in section 4. Section 5 provides the conclusion for the paper.

II. FUZZY MCDM MODEL

Normally, a triangular fuzzy number A can be defined by a triplet (a, b, c) shown in Fig.1a. An example of a fuzzy member of an equipment cost is shown in Fig.1b. The membership function is defined as (1).

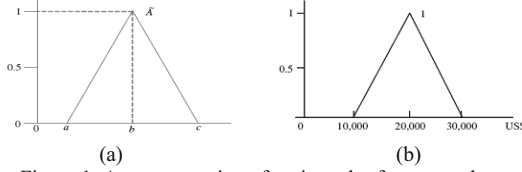


Figure 1. A representation of a triangular fuzzy member

$$\mu_A(x) = \begin{cases} 0, & x < a, \\ \frac{x-a}{b-a}, & a \leq x \leq b, \\ \frac{c-x}{c-b}, & b \leq x \leq c, \\ 0, & x > c. \end{cases} \quad (1)$$

The general multi-attribute decision making (MADM) model can be described as follows [11]:

- Let $X = \{X_i | i = 1, \dots, m\}$ denote a finite discrete set of m (≥ 2) possible alternatives (courses of action, candidates);
- Let $A = \{A_j | j = 1, \dots, n\}$ denote a finite set of n (≥ 2) criteria according to which the desirability of an alternative is to be judged,
- Let $\omega = (\omega_1, \omega_2, \dots, \omega_n)^T$ be the vector of weights, where $\sum_{j=1}^n \omega_j = 1$, $\omega_j \geq 0$, $j = 1, \dots, n$, and ω_j denotes the weight of criterion A_j ,
- Let $R = (r_{ij})_{m \times n}$ denote the $m \times n$ decision matrix, where r_{ij} (≥ 0) is the performance rating of alternative X_i with respect to criterion A_j .

In this section, we will introduce in details the algorithm based on the theory of fuzzy MCDM, which includes the following steps [11].

A. Representation of Fuzzy Requirements

When evaluating and assessing the optimal weapon system from a number of similar alternatives, a decision maker normally develops in his/her mind some sort of ambiguity. Representation of fuzzy requirements has been introduced in the beginning of this section.

B. Similarity Measure

In step A, the requirements of selecting optimal weapon systems have been described as the triangular fuzzy number with respect to different criteria. In this step, we will take the

requirement vector as the ideal weapon system, with the purpose to measure the similarity degree with the existing candidate weapon vectors, in which the specification values are known and determinate. As we know, a fuzzy number cannot be compared with a crisp one directly unless a non-fuzzy number has to be transformed into the form of fuzzy number firstly. For example, for a crisp number b , the form of its triangular fuzzy can be written as (2).

$$b = (b^L, b^M, b^U) \quad (2)$$

where $b^L = b^M = b^U$, and Similarity measure between two triangular fuzzy numbers can be calculated with (3) [21].

$$s(a, b) = \frac{a^L b^L + a^M b^M + a^U b^U}{\max[(a^L)^2 + (a^M)^2 + (a^U)^2, (b^L)^2 + (b^M)^2 + (b^U)^2]} \quad (3)$$

where two triangular fuzzy numbers are $a = (a^L, a^M, a^U)$ that represents the ideal number and $b = (b^L, b^M, b^U)$ that represents the real number, respectively.

Because there are various types of criteria for different weapon systems, in which some criteria, such as the missile launching distance, warhead and speed, are not suitable to be represented as a fuzzy number. Therefore these numbers can be expressed as crisp numbers.

C. Construction of Decision Matrix

Calculation result of the similarity measure between alternate weapon systems and the ideal weapon system can be concisely expressed in a matrix format, which is called decision matrix in MCDM problems, and in which columns indicate weapon criteria and rows alternate weapons. Thus, an element s_{ij} in the in Eq. (4) denotes the similarity degree to the ideal weapon of the i th weapon with respect to the j th criterion.

$$DM = \begin{bmatrix} s_{11} & s_{12} & s_{13} & \dots & s_{1n} \\ s_{21} & s_{22} & s_{23} & \dots & s_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ s_{m1} & s_{m2} & s_{m3} & \dots & s_{mn} \end{bmatrix} \quad (4)$$

D. Normalization

In order to eliminate the difference of dimension among different criteria, the operation of normalization is needed to transform various criteria dimensions into the non-dimensional criteria. Generally, the criteria of alternative weapons can be divided into two categories: the 'benefit' type attributes (the larger the better) and the 'cost' type attributes (the smaller the better). For example, the cost and weight belong to the 'cost' attributes, and the range and speed are 'benefit' attributes. In order to normalize those 'cost' attribute values to make them equivalent to the 'benefit' attributes (the larger the better), we developed a converting equation similar to [11] for those attribute values. The 'cost' attribute is calculated as (5):

$$x_{cj} = \frac{x_{j\max} - x_j}{x_{j\max}} \quad j = 1, 2, 3, \dots, m \quad (5)$$

For instance, the converted weapons' cost values are: $c_{cj} = (c_{j\max} - c_j)/c_{j\max}$, ($j=1, 2, \dots, 18$), and $c_{j\max} = 1200k$ in this study. Similar processing is performed for the weapons' weight attributes $w_{cj} = (w_{j\max} - w_j)/w_{j\max}$, where $w_{j\max} = 3700$ in this research.

Equations (6) and (7) are utilized to perform the normalization for the fuzzy attributes or criteria [11].

$$r_i = \left(\frac{a_i}{c_i^{\max}}, \frac{b_i}{b_i^{\max}}, \frac{c_i}{a_i^{\max}} \wedge 1 \right) \quad \text{for benefit criteria} \quad (6)$$

$$r_i = \left(\frac{a_i^{\min}}{c_i}, \frac{b_i^{\min}}{b_i}, \frac{c_i^{\min}}{a_i} \wedge 1 \right) \quad \text{for cost criteria} \quad (7)$$

where $(\bullet)^{\max}_i = \max\{(\bullet)_i\}$ and $(\bullet)^{\min}_i = \min\{(\bullet)_i\}$.

E. Rank of Alternate Weapons

The element s_{ij} in the decision matrix reflects the closeness degree of the ideal weapon with the i th alternate weapon with respect to the j th criterion. In this step, we can use the simple additive weighting (SAW) method, which is widely used in MCDM, to calculate the relative importance value with respect to all criteria, with which the ranking order of alternate weapons according to the relative importance value can be obtained. And we can consider the weapon with the highest relative importance value as the closest one to that of the decision maker requires. The relative importance value of i th alternate weapon can be calculated with (8).

$$U_i = \sum_{j=1}^n x_{ij} \omega_j \quad i = 1, 2, \dots, m \quad (8)$$

And the maximum of relative importance value can be written as (9).

$$U_{\max} = \max_i \sum_{j=1}^n x_{ij} \omega_j \quad i = 1, 2, \dots, m \quad (9)$$

III. ALGORITHM OF THE WEIGHT ASSIGNMENT

Compared with most MCDM methods, the FMCDM model reported by Bin Zhu et al. is one of the simplest and most effective methods [11]. A similarity measure method is utilized to build the decision matrix. However, one problem of this method is that the weight associated with each alternative is estimated or determined by the decision maker or an evaluation team based on their experience. Generally, this kind of weight estimation is acceptable for a small set of alternatives, such as 5 or less than 10. However, for a large set of alternatives, which is a popular situation, this weight estimation is not accurate and correct based only on the decision maker's experience.

A simple but effective weight estimation method is adopted in this paper to make this evaluation process more objective and reliable. There are some different weight estimation methods reported by researchers, such as Saaty who developed a paired comparison matrix and then an eigenvector that is equivalent to the weight for an associated alternative can be calculated based on that paired comparison matrix [22]. Yager multiplied the normalized eigenvector by the order of the system to obtain exponents for weighting the fuzzy criteria in a decision problem [23]. However, both methods need a lot of mathematical operations and therefore make the process very complicated and time consuming.

In this paper, we adopted a weight estimation method based on the paired comparison matrix to simplify this estimation process. The operational procedure is completed by the following steps:

1. List the degree of importance or importance level of each criterion relative to another criterion based on Table I [24].
2. Construct a paired comparison matrix W based on the importance levels in step 1. Each element w_{ij} in the matrix W is a ratio of the importance level of the i th criterion over to the j th criterion.
3. Add each row $\omega_i = \sum_{j=1}^n \omega_{ij}$; where $i = 1 \sim n$ and n is the total number of criteria.
4. Calculate the normalized weight factor for each criterion using $\omega_{ni} = \frac{\omega_i}{\omega_n}$; where $\omega_n = \sum_{i=1}^n \omega_i$.
5. These weight factors can be used to build the decision matrix based on the similarity measure method.

TABLE I. WEIGHT ASSIGNMENT TO A PAIRED COMPARISON CRITERIA

ImportanceValue	Definition
1	Equal Importance
3	Weak importanceof one over the other.
5	Strong importanceof one over the other.
7	Demonstrated importanceof one over the other.
9	Absolute domination of one over the other.
2, 4, 6, 8	Intermediate values between the two adjacent judgements..

In the following section, we will use an example to illustrate this weight estimation method.

IV. CASE STUDY

In this section, we use a group of weapon information [25-30], which is collected by Federation of American Scientists (FAS) and contains the updated missiles, as an example to illustrate the weight estimation method we adopted in this paper with the Fuzzy MCDM model we discussed in section 2 to evaluate and assess the optimal weapon systems (missiles) currently used in the U.S. defense system.

Based on the different target locations and launching methods, all missiles can be divided into four categories: Air-launched, Ground-launched, Ship-launched and Submarine-launched. In this study, we concentrate on the Air-launched guided missiles with the ground targets because this is a kind of popular missiles and widely utilized in the U.S. defense system. First let us create a specification table for those missile alternatives based on twelve (12) criteria, which is shown in Table II. The ‘cost’ type criteria such as weapon’s cost and weight have been converted to the ‘benefit’ type criteria in columns c3 and c7, respectively.

It can be found from Table II that some criteria contain vague and ambiguous (and thus fuzzy) definitions, such as Guidance, Propulsion, Platform and Fuse system. The reason for that is because those criteria cannot be determined or described by crisp variables, and some human-being-language related terminologies must be applied to define them. For instance, a guidance system of a missile can be evaluated as a *low* if only manual guidance system is adopted for that missile, and a *mid* can be used to describe a guidance system that contains passive radar homing system, and a *high* can be used for a guidance system that uses an Inertial Navigation System (INS) and Global Position System (GPS).

TABLE II. AIR-LAUNCHED GUIDED MISSILE ALTERNATIVES

Missile	c1	c2	c3	c4	c5	c6	c7	c8	c9	c10	c11	c12
AGM-12	L	10	0.518	1.8	W	P	0.988	L	970	13.6	18.0	48
AGM-45	M	28	0.895	2.0	M	G	0.973	L	145	10.0	8.0	36
AGM-62	L	16	0.696	2.5	W	M	0.984	L	825	11.3	12.5	45
AGM-65	M	12	0.875	0.9	M	M	0.986	M	125	8.2	12.0	28
AGM-78	M	65	0.635	2.0	M	G	0.750	M	223	15.0	13.5	39
AGM-84	H	60	0.603	0.7	S	G	0.604	M	488	15.0	13.5	36
AGM-86	H	600	0.122	0.7	M	P	0.500	M	1500	20.0	24.5	36
AGM-88	M	26	0.784	1.8	S	M	0.763	H	143	13.7	10.0	44
AGM-114	H	4	0.973	1.3	M	G	0.979	M	18	5.3	7.0	13
AGM-122	M	9	0.947	2.3	M	G	0.917	M	25	9.4	5.0	25
AGM-123	M	13	0.654	0.9	S	M	0.921	M	991	14.1	19.7	63
AGM-129	H	1620	0.000	0.9	M	P	0.000	H	290	20.8	27.8	122
AGM-130	H	35	0.212	0.8	M	M	0.625	H	2000	12.9	15.0	59
AGM-136	M	43	0.884	0.7	S	G	0.833	H	40	8.3	27.0	62
AGM-137	H	100	0.460	0.6	S	G	0.393	H	1000	14.0	30.0	100
AGM-142	H	43	0.189	1.2	M	M	0.150	H	750	15.8	21.0	68
AGM-154	H	60	0.595	0.7	M	G	0.765	H	500	14	13.0	106
AGM-158	H	200	0.392	0.9	S	G	0.417	H	1000	14	18.0	95

- c1: Guidance (L-low, M-mid, H-high)
- c2: Range (nautical miles)
- c3: Weight (pounds)
- c4: Speed (Mach)
- c5: Propulsion (W-weak, M-mid, S-strong)
- c6: Platforms (P-poor, M-mid, G-good)
- c7: Cost (US\$ thousands dollars - k)
- c8: Fuse system (L-low, M-mid, H-high)
- c9: Warhead (pounds)
- c10: Length (feet)
- c11: Diameter (inches)
- c12: Wingspan (inches)

The mapping relationships between some non-crisp parameters and fuzzy definitions for each missile should be indicated clearly. Table III shows an example of this kind of mapping for the Platform parameter.

TABLE III. MAPPING BETWEEN PLATFORM AND FUZZY DEFINITIONS

Missile	Platform Description	Fuzzy Definition
AGM-12	F-4, F-105	poor
AGM-45	F-4, F-16, F-105, A-4, A-6, A-7, B-2	good
AGM-62	F-18, F-4, A-4, A-7	mid
AGM-65	A-10, F-15E, F-16	mid
AGM-78	F-16C, EA-6B, EF-18G, F/A-18, F-4G, F-105G	good
AGM-84	A-6, F/A-18, S-3, P-3, B-52H, Ships	good
AGM-86	B-52H	poor
AGM-88	F-4, F-16C, F/A-18, EA-6B	mid
AGM-114	AH-1G, AH-64, MD-530, OH-58D, SH-60, HH-60 UH-60A, S-70 RAH-66, SA-342, F-4, F-5E, F-16 F/A-18, OV-10D	good
AGM-122	F-8, F-14, F-15, F/A-18, AH-1, AV-8B, OV-10 Fighters/Bombers	good
AGM-123	A-6E, A-7, F/A-18	mid
AGM-129	B-52H	poor
AGM-130	F-4E, F-15E, F-111	mid
AGM-136	B-52H, All Fighters and Bombers	good
AGM-137	All Fighters and Bombers	good
AGM-142	F-4, F-15, F-111, B-52H	mid
AGM-154	F-14, F-15, F-16, F-117, B-1B, F/A-18, AV-8B B-52H, All Other Fighter and Bombers	good
AGM-158	All Fighters and Bombers	good

Next we need to build the relative important levels for all criteria. This level is represented by a ratio between two or a paired of criteria. The ratio between the same criteria is 1 and a number represented in the intersection of a row and a column represents the importance ratio between that row and that column. For example, the number in the intersection cell of row c5 and column c4 is 2, which means that the criterion c5 (Propulsion of a missile) is 2 times more important than that of criterion c4 (Speed of the missile). A completed importance level of this example is shown in Table IV.

TABLE IV. RELATIVE IMPORTANT LEVEL OF ALL CRITERIA

	c1	c2	c3	c4	c5	c6	c7	c8	c9	c10	c11	c12
c1	1	2	3	5	2	5	6	6	4	8	8	8
c2	1/2	1	3	2	1	3	3	5	2	7	7	7
c3	1/3	1/3	1	1/2	1	2	3	5	1	5	5	5
c4	1/5	1/2	2	1	1	3	3	5	1/2	3	3	3
c5	1/2	1	1	1	1	3	4	3	1/2	3	3	3
c6	1/5	1/3	1/2	1/3	1/3	1	3	3	1/2	3	3	3
c7	1/6	1/3	1/3	1/3	1/4	1/3	1	3	1/2	3	3	3
c8	1/6	1/5	1/5	1/5	1/3	1/3	1/3	1	1/5	2	2	2
c9	1/4	1/2	1	2	2	2	2	5	1	5	5	5
c10	1/8	1/7	1/5	1/3	1/3	1/3	1/3	1/2	1/5	1	1	1
c11	1/8	1/7	1/5	1/3	1/3	1/3	1/3	1/2	1/5	1	1	1
c12	1/8	1/7	1/5	1/3	1/3	1/3	1/3	1/2	1/5	1	1	1

Table IV is exactly a paired comparison matrix $\mathbf{W}$ and the diagonal weight element $\omega_{ji} = 1/\omega_{ij}$.

Now let's calculate the overall weight for each row by adding each row $\omega_i = \sum_{j=1}^n \omega_{ij}$; where $i = 1 \sim n$ and $n=12$ is the total number of the criteria. The result of this calculation is shown in Table V.

TABLE V. THE OVERALL WEIGHT FOR EACH CRITERION

	c1	c2	c3	c4	c5	c6
ω_i	58.00	41.50	29.17	25.20	24.00	18.20
	c7	c8	c9	c10	c11	c12
ω_i	15.25	8.97	29.75	5.50	5.50	5.50

The total weight is obtained by adding all weights of criteria together, which is 266.54. The normalized weight for each criterion is shown in Table VI.

TABLE VI. THE NORMALIZED WEIGHT FOR EACH CRITERION

	c1	c2	c3	c4	c5	c6
$\hat{\omega}_i$	0.218	0.156	0.109	0.095	0.090	0.068
	c7	c8	c9	c10	c11	c12
$\hat{\omega}_i$	0.057	0.034	0.112	0.021	0.021	0.021

Now we can perform step 4 in section II to add these normalized weight for each criterion with all criteria to construct the ideal and criteria weight table, which is shown in Table VII.

TABLE VII. THE IDEAL MISSILE AND CRITERIA WEIGHT

Criterion	Ideal	Lower	Upper	Normalized Weight
c1	4	1	8	0.218
c2	600	4	1620	0.156
c3	0.9	0.0	1.5	0.109
c4	2.0	0.5	2.5	0.095
c5	4	1	8	0.090
c6	4	1	8	0.068
c7	0.9	0.0	1.5	0.057
c8	4	1	8	0.034
c9	1500	18	2200	0.112
c10	15.0	5.0	21.0	0.021
c11	15.0	5.0	30.0	0.021
c12	60	12	125	0.021

The vector of the ideal missile can be represented as the following form of the triangular fuzzy number (Table VII):

$$T = [(1 \ 4 \ 8), (4 \ 600 \ 1620), (0.0 \ 0.9 \ 1.5), (0.5 \ 2.0 \ 2.5), (1 \ 4 \ 8), (1 \ 4 \ 8), (0.0 \ 0.9 \ 1.5), (1 \ 4 \ 8), (18 \ 1500 \ 2200), (5.0 \ 15.0 \ 21.0), (5.0 \ 15.0 \ 30.0), (12 \ 60 \ 125)]$$

The corresponding vector of the criteria weight can be expressed as:

$$\omega = (0.218, 0.156, 0.109, 0.095, 0.090, 0.068, 0.057, 0.034, 0.112, 0.021, 0.021, 0.021)$$

The decision matrix, which can be calculated based on the similarity degree with respect to each criterion between the ideal missile and the alternatives, is shown in Table VIII by using (3) – (7). The relative importance value of i th alternate missile with respect to all criteria can be computed by (8), and the final calculating results are shown in Table IX.

TABLE VIII. DECISION MATRIX

Missile	c1	c2	c3	c4	c5	c6	c7	c8	c9	c10	c11	c12
AGM-12	0.1605	0.0075	0.4060	0.8571	0.1605	0.1605	0.7745	0.1605	0.5086	0.8069	0.7826	0.4882
AGM-45	0.3210	0.0209	0.7016	0.8333	0.3210	0.6420	0.7834	0.1605	0.0760	0.5933	0.3478	0.3662
AGM-62	0.1605	0.0119	0.5458	0.6667	0.1605	0.3210	0.7719	0.1605	0.4326	0.6705	0.5435	0.4577
AGM-65	0.3210	0.0089	0.6864	0.4286	0.3210	0.3210	0.7732	0.3210	0.0655	0.4865	0.5217	0.2848
AGM-78	0.3210	0.0484	0.4981	0.8333	0.3210	0.6420	0.5882	0.3210	0.1169	0.8900	0.5870	0.3967
AGM-84	0.6420	0.0447	0.4727	0.3333	0.6420	0.6420	0.4739	0.3210	0.2559	0.8900	0.5870	0.3662
AGM-86	0.6420	0.4471	0.0954	0.3333	0.3210	0.1605	0.3922	0.3210	0.7866	0.6833	0.6803	0.3662
AGM-88	0.3210	0.0194	0.8147	0.8571	0.6420	0.3210	0.5987	0.6420	0.0750	0.8129	0.4348	0.4475
AGM-114	0.6420	0.0030	0.7631	0.6190	0.3210	0.6420	0.7680	0.3210	0.0094	0.3145	0.3043	0.1322
AGM-122	0.3210	0.0067	0.7430	0.7246	0.3210	0.6420	0.7190	0.3210	0.0131	0.5577	0.2174	0.2543
AGM-123	0.3210	0.0097	0.5125	0.4286	0.6420	0.3210	0.7222	0.3210	0.5197	0.8366	0.8460	0.6408
AGM-129	0.6420	0.4576	0.0000	0.4286	0.3210	0.1605	0.0000	0.6420	0.1521	0.6571	0.5995	0.5383
AGM-130	0.6420	0.0261	0.1660	0.3810	0.3210	0.3210	0.4902	0.6420	0.6197	0.7654	0.8522	0.6001
AGM-136	0.3210	0.0320	0.6932	0.3333	0.6420	0.6420	0.6536	0.6420	0.0210	0.4925	0.6173	0.6306
AGM-137	0.6420	0.0745	0.3602	0.2857	0.6420	0.6420	0.3085	0.6420	0.5244	0.8307	0.5558	0.6567
AGM-142	0.6420	0.0320	0.1484	0.5714	0.3210	0.3210	0.1176	0.6420	0.3933	0.8650	0.7937	0.6916
AGM-154	0.6420	0.0447	0.4664	0.3333	0.3210	0.6420	0.6000	0.6420	0.2622	0.8307	0.5652	0.6195
AGM-158	0.6420	0.1490	0.3074	0.4286	0.6420	0.6420	0.3268	0.6420	0.5244	0.8307	0.7826	0.6912

TABLE IX. THE FINAL RESULT

AGM-12	AGM-45	AGM-62	AGM-65	AGM-78	AGM-84
0.3374	0.3864	0.3290	0.3271	0.3804	0.4368
AGM-86	AGM-88	AGM-114	AGM-122	AGM-123	AGM-129
0.4493	0.4010	0.4265	0.3684	0.4068	0.3684
AGM-130	AGM-136	AGM-137	AGM-142	AGM-154	AGM-158
0.4106	0.3816	0.4605	0.3881	0.4297	0.4864

The relative importance level of i th alternate missile can be calculated with Eq. (8) as:

$$U_i = \sum_{j=1}^n s_{ij} \omega_j \quad i = 1, 2, \dots m \quad (m = 12)$$

The maximum important level of missiles can be obtained as:

$$U_{\max} = \max_i \sum_{j=1}^n s_{ij} \omega_j \quad i = 1, 2, \dots m \quad (m = 12)$$

The missile that has the maximum important level can be found from Table IX, which is the **AGM-158** with a most important level of **0.4864**. The order that shows the top-10 closeness degree to the missiles that have the more important levels is:

AGM-158 > AGM-137 > AGM-86 > AGM-84 > AGM-154 > AGM-114 > AGM-130 > AGM-123 > AGM-88 > AGM-142

This is the optimal missile sequence estimated and evaluated based on the FMCDM system we developed in this paper. This evaluation and estimation is based on multiple

criteria and missile properties given by some references listed on our reference list.

One point to be noted from this assessing result is that the data we collected and used for this FMCDM system come from different reports issued by different agencies since 1993. Since the defense situation is always changing, therefore this result may not make very sense to today's situation. We just use these data as an example to illustrate the effectiveness and availability of our proposed method. The real and actual assessing result is dependant on the updated data.

V. CONCLUSION

Decision making is one of the most important and popular research and application topics in the national defense and security. To assess and evaluate the optimal weapon system such as missiles from a large group of alternatives that contain multiple criteria is a challenging, sometimes may be a headache task to decision makers in the defense system. A correct or optimal model and the associated algorithm are critical tools to complete this task. In this paper, a fuzzy multi-criteria decision making model is developed to help decision makers to correctly estimate weight factors for all criteria to make this process simpler and easier. To correctly predict and effectively protect our nation's safety, accurately evaluate and correctly assess the optimal weapon system is a prerequisite and critical task. In this paper, we used a collection of weapon information reported by different agencies in recent years with a target example to illustrate how to use FMCDM model to simplify this assessing process. The actual and more updated assessing result depends on the updated information reported by different sources in the future.

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