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The Projection Effectiveness Evaluation Via HMADM for the Electronic Warfare System under Complex Electromagnetism Environment

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ABSTRACT: The projection effectiveness evaluation algorithm based on hybrid multiple attribute decision making (HMADM) for the electronic warfare (EW) system under complex electromagnetism environment is investigated. First, the evaluation hierarchy structure of the EW system under complex electromagnetism environment is put forward and classified into three levels. Then, the model of hybrid multiple attribute decision making of the EW system under complex electromagnetism environment is given, where the attributes of the evaluated EW systems under complex electromagnetism environment are classified into an accurate scalar and a qualitative language. And then, the analytic hierarchy process (AHP) method is proposed to determine the weight of the hybrid multiple attributes' in the EW system under complex electromagnetism environment. Based on the above results, the projection effectiveness evaluation algorithm based on HMADM is proposed. Finally, an example of three EW systems under complex electromagnetism environment and its simulation results show that the proposed projection effectiveness evaluation algorithm based on HMADM for the EW system under complex electromagnetism environment is simple and effective.

KEYWORDS: Effectiveness evaluation; Electronic warfare (EW); Complex electromagnetism environment; Hybrid multiple attribute decision making (HMADM); Projection algorithm.

INTRODUCTION

The EW equipments become more and more important in modern battles. With the fast development of the new technologies, the EW equipments become more and more complex, pregnable and damageable such that it is difficult to evaluate the performance and effectiveness of the EW equipments. Fuzzy-AHP in effectiveness evaluation of EW is investigated to calculate the influence degree of each ingredient in [1]. According to its characteristics of insufficient information and uncertainty, the EW system operation effectiveness is evaluated by using the method of grey hierarchy evaluation in [2]. The effectiveness of instructed EW system is calculated by using analytic hierarchy process, the weighted coefficient of each guideline is defined, and the effectiveness of instructed EW system is calculated in [3]. An effectiveness evaluation index system of airborne EW system is built, which can reflect the airborne EW system capacity generally and impersonally in [4]. With the adoption of the grey system theory and AHP, the evaluation model of the reconnaissance capabilities of the EW reconnaissance troops based on the multilevel grey theory is created in [5].

As one of important EW equipments, the EW system under complex electromagnetism environment plays an important role in the modern information battle. Therefore, the effectiveness evaluation problem of the EW system under complex electromagnetism environment has become a popular topic in the investigation of modern battle theory. Thus the projection effectiveness evaluation of the EW system under complex electromagnetism environment is investigated in this paper. And the effectiveness evaluation example of three EW systems under complex electromagnetism environment is designed by using this method and the simulation result shows that the proposed method is effective and simple for effectiveness evaluation of the EW system under complex electromagnetism environment.

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THE HIERARCHICAL STRUCTURE OF THE EW SYSTEM UNDER COMPLEX ELECTROMAGNETISM ENVIRONMENT

According to the typical features of the EW system under complex electromagnetism environment, some important factors which are related with the performances of the EW system under complex electromagnetism environment can be found out and can be classified into three levels.

The first level for the EW system under complex electromagnetism environment can be denoted by A. The second level of the EW system under complex electromagnetism environment includes scouting and detecting ability C1, command and control ability C2, communicating and safeguarding ability C3, and electromagnetism environment C4.

Two specifications for every component of the second level are included in the third level of the EW system under complex electromagnetism environment. The third level of scouting and detecting ability C1 includes scouting and detecting method C11 and scouting and detecting range C12. The third level of command and control ability C2 includes ability of auxiliary decision C21 and decision delay C22. The third level of communicating and safeguarding ability C3 include covering range C31 and communicating capacity C32. The third level of battlefield electromagnetism environment C4 includes quality of electromagnetism radiant point C41 and density of electromagnetism signal C42.

Based on the above analysis of the EW system under complex electromagnetism environment, we can give its hierarchy structure with three levels in Figure. 1 [6-8].

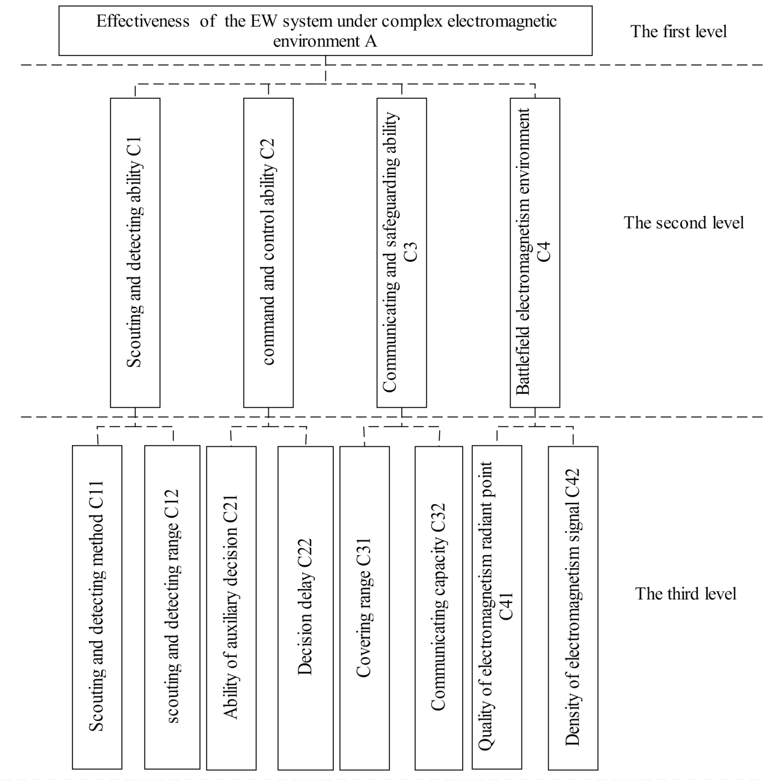

Figure 1. The hierarchy structure of the EW system under complex electromagnetism environment.

MODEL OF HMADM

Based on the above analysis, we can know that the specification system for the effectiveness evaluation of the EW system under complex electromagnetism environment includes the scouting and detecting method C11, scouting and detecting range C12, auxiliary decision ability C21, decision delay C22, covering range C31, communicating capacity C32, quality of electromagnetism radiant point C41 and density of electromagnetism signal C42 ($n=8$), where C12 and C22 are quantity and presented by accurate scalars, and other specifications are quality and presented by fuzzy languages. Moreover, the specifications can also be classified into two kinds: the benefit specification and the cost specification, where the benefit specification means that the bigger the value of specification is, the bigger the effectiveness of the EW system under complex electromagnetism environment is, and the cost specification means that the smaller the value of specification is, the bigger the effectiveness of the EW system under complex electromagnetism environment is.

In [9], the model of HMADM is established as follows:

Step 1. Assume that there are m EW systems under complex electromagnetism environment to be evaluated and there are n attributes for every EW system under complex electromagnetism environment.

Step 2. Denote the set of the evaluated EW systems under complex electromagnetism environment by $X=\{x_1,x_2,\cdots,x_m\}$ and denote the set of attributes in the third level of the EW system under complex electromagnetism environment by $U=\{u_1,u_2,\cdots,u_n\}$, respectively.

Step 3. Determine the attributes' values $a_{ij}(i=1,2,\cdots,m,j=1,2,\cdots,n)$ in every EW system under complex electromagnetism environment in the third level.

Step 4. Compute the attribute matrix in the following form:

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \tag{1}$$

where $a_{ij}(i=1,2,\cdots,m,j=1,2,\cdots,n)$ can be an accurate (quantitative) scalar or a qualitative language.

If the specification is a qualitative language which is presented by

$$S_j=\{s_k \mid k=1,2,\cdots,p\} \tag{2}$$

where p presents the number of the evaluated language for the qualitative specification u_i, s_k presents the evaluated language for the qualitative specification u_i (s_1 is the lower limitation of the evaluated language, s_n is the upper limitation of the evaluated language), S_i presents the set of the evaluated languages for the quality specification u_i. In order to evaluate the EW system under complex electromagnetism environment qualitatively, the evaluated language can be changed into the following fuzzy interval number:

$$s_k \to a_{ij}=[a_{ij}^l,a_{ij}^u]=\frac{1}{p}[k-1,k] \tag{3}$$

Step 5. Normalize the above attribute matrix A into the following matrix B:

$$B=\begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ b_{m1} & b_{m2} & \cdots & b_{mn} \end{bmatrix} \tag{4}$$

where the quantitative specification is presented by an accurate scalar a_{ij}, and normalized as follows

$$b_{ij}=\begin{cases} a_{ij}/\max\limits_i a_{ij}, & a_{ij} \text{ is a benefit specification} \\ \min\limits_i a_{ij}/a_{ij}, & a_{ij} \text{ is a cost specification} \end{cases} \tag{5}$$

where the qualitative specification is presented by a fuzzy interval number $a_{ij}=[a_{ij}^l,a_{ij}^u]$, and normalized as follows

$$b_{ij}=[b_{ij}^l,b_{ij}^u]=\begin{cases} [a_{ij}^l/\max\limits_i a_{ij}^l, a_{ij}^u/\max\limits_i a_{ij}^u], & a_{ij} \text{ is a benefit specification} \\ [\min\limits_i a_{ij}^l/a_{ij}^l, \min\limits_i a_{ij}^u/a_{ij}^u], & a_{ij} \text{ is a cost specification} \end{cases} \tag{6}$$

DETERMINATION OF THE HYBRID MULTIPLE ATTRIBUTES' WEIGHTS BY AHP

AHP is a decision making support tool which requires the establishment of a hierarchy of criteria to achieve the goal of the decision problem. AHP provides a rational framework for decision making by breaking down the process into components with respect to an overall goal. The detail algorithm of AHP is listed as follows [6-8]:

Step 1. Establish the hierarchy structure of the effectiveness evaluation system with the ladder structure.

Step 2. Establish the pair-wise judgment matrix by comparing the attributes in the hierarchy structure of the effectiveness evaluation system. According to the set {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9} in Table 1, we can obtain their attributes' intensity of importance and the corresponding judgment matrices.

Table 1. Comparison scale.

Definition	**Intensity of Importance**	**Explanation**
Equal importance	1	Two activities contribute equally to the objective
Weak importance of one over another	3	Experience and judgment slightly favor one activity over another
Essential or strong importance	5	Experience and judgment strongly favor one activity over another
Demonstrated importance	7	An activity is strongly favored and its dominance demonstrated in practice
Absolute importance	9	The evidence favoring one activity over another is of the highest possible order of affirmation
Intermediate values between the two adjacent judgments	2 , 4, 6, 8	When compromise is needed
Reciprocals of above nonzero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

Step 3. Extract the relative importance by the previous pairwise comparisons. Calculate the corresponding maximum left eigenvector of the judgment matrix is approximated by using the geometric mean of each row and the numbers are normalized by dividing them with their sum.

Step 4. Test the consistency of the relative importance. The pairwise comparisons in a judgment matrix are considered to be adequately consistent if the corresponding consistency ratio (C.R.) is less than 10%.

Step 5. Calculate the relative weight $w_1, w_2, \cdots, w_n$ of the attributes in the third level and test its consistency.

THE PROJECTION ALGORITHM VIA HMADM

On the view of the vector projection, the projection algorithm regards the decision making scheme as a vector. Thus there is an angle between the decision making scheme $b_i (i = 1, 2, \cdots, m)$ and the desired scheme b^* , and the effectiveness evaluation order can be obtained from the projection of the decision making scheme on the desired scheme. The detail steps of the projection algorithm for the effectiveness evaluations of EW systems under complex electromagnetism environment can be listed as follows [9].

Step 1. Normalized the weight matrix by

$$Y = (y_{ij})_{m\times n} = (w_j \times b_{ij})_{m\times n} \tag{7}$$

where w_i , $j = 1, 2, \cdots, n$, are the weight of the attributes in the third level of the EW system under complex electromagnetism environment, and b_{ij} ($i = 1, 2, \cdots, m, j = 1, 2, \cdots, n$) are the elements of the normalized matrix B .

Step 2. Determine the desired effectiveness value y^* of the EW system under complex electromagnetism environment by

$$y^* = \{y_1^*, y_2^*, \cdots, y_n^*\} = \begin{cases} (\max_i y_{ij} \quad j \in I) or (\min_i y_{ij} \quad j \in J), \quad u_j \text{ is an accurate scalar} \\ ([\max_i y_{ij}^l, \max_i y_{ij}^u] \quad j \in I) or ([\min_i y_{ij}^l, \min_i y_{ij}^u] \quad j \in J), u_j \text{ is a qualitative language} \end{cases} \tag{8}$$

where I presents the set of the benefit specifications and J presents the set of the cost specifications.

Step 3. Calculate the projection value p_i by

$$p_i = \frac{\sum_{j=1}^{h} y_j^* y_{ij} + \sum_{j=h+1}^{n} [y^{*l}_j y_{ij}^l + y^{*u}_j y_{ij}^u]}{\sqrt{\sum_{j=1}^{h} (y_j^*)^2 + \sum_{j=h+1}^{n} [(y^{*l}_j)^2 + (y^{*u}_j)^2]}}, \ i = 1, 2, \cdots, m \tag{9}$$

where h presents the number of the accurate scalars.

Step 4. By using (9), we can obtain the projection p_i of every EW system under complex electromagnetism environment on the desired EW system. According to the values p_i , $i = 1, 2, \cdots, m$, we can give the effectiveness evaluation order of EW systems under complex electromagnetism environment, where the bigger the value p_i is , the better the effectiveness order of EW systems under complex electromagnetism environment is.

A NUMERICAL EXAMPLE

Based on the evaluation hierarchy structure of the EW system under complex electromagnetism environment in Figure. 1, and the projection effectiveness evaluation method via HMADM for the EW system under complex electromagnetism environment, we will calculate the effectiveness evaluation of three EW systems under complex electromagnetism environment. The detail step can be given as follows.

Step 1. Assume that the experts give the relative importance of the criteria in the pair-wise judgment matrices of the EW system under complex electromagnetism environment. The corresponding pair-wise judgment matrix among scouting and detecting ability C1, command and control ability C2, communicating and safeguarding ability C3, and battlefield electromagnetism environment C4 can be given by the following Table 2. And the weight vector of C1, C2, C3 and C4 is $\lceil 0.553 \quad 0.1313 \quad 0.2704 \quad 0.0454 \rceil^T$, $C.R. = 0.0883 < 0.1$ shows that the relative importance of the pair-wise judgment matrix is consistent.

Table 2. The pair-wise judgment matrix among C1, C2, C3 and C4.

A	C1	C2	C3	C4	W_A
C1	1	5	3	7	0.553
C2	0.2	1	0.3333	5	0.1313
C3	0.3333	3	1	6	0.2704

C4	0.1429	0.2	0.1667	1	0.0454
$\lambda_{\max} = 4.2359$		$C.I. = 0.0786$		$C.R. = 0.0883 < 0.1$	

The corresponding pair-wise judgment matrix between scouting and detecting method C11, and scouting and detecting range C12 can be given by Table 3. And the weight vector of C11 and C12 is $\lceil 0.3333 \quad 0.6667 \rceil^T$, $C.R. = 0 < 0.1$ shows that the relative importance of the pair-wise judgment matrix is consistent.

Table 3. The pair-wise judgment matrix between C11 and C12.

C1	C11	C12	W_{C1}
C11	1	0.5	0.3333
C12	2	1	0.6667

The corresponding pair-wise judgment matrix between ability of auxiliary decision C21, and decision delay C22 can be given by can be given by Table 4. And the weight vector of C21 and C22 is $\lceil 0.25 \quad 0.75 \rceil^T$, $C.R. = 0 < 0.1$ shows that the relative importance of the pair-wise judgment matrix is consistent.

Table 4. The pair-wise judgment matrix between C21 and C22.

C2	C21	C22	W_{C2}
C21	1	0.3333	0.25
C22	3	1	0.75

The corresponding pair-wise judgment matrix between covering range C31 and communicating capacity C32 can be given by Table 5. And the weight vector of C31 and C32 is $\lceil 0.6667 \quad 0.3333 \rceil^T$, $C.R. = 0 < 0.1$ shows that the relative importance of the pair-wise judgment matrix is consistent.

Table 5. The pair-wise judgment matrix between C31 and C32.

C3	C31	C32	W_{C3}
C31	1	2	0.6667
C32	0.5	1	0.3333

The corresponding pair-wise judgment matrix between quality of electromagnetism radiant point C41 and density of electromagnetism signal C42 can be given by Table 6. And the weight vector of C41 and C42 is $\lceil 0.8333 \quad 0.1667 \rceil^T$, $C.R. = 0 < 0.1$ shows that the relative importance of the pair-wise judgment matrix is consistent.

Table 6. The pair-wise judgment matrix between C41 and C42.

C4	C41	C42	W_{C4}
C41	1	5	0.8333

C42	0.2	1	0.1667

From Table 2, we can know that the weight vector of C1, C2, C3 and C4 $w_A = [0.553 \quad 0.1313 \quad 0.2704 \quad 0.0454]^T$ can be shown by Figure. 2. From Figure. 2, we can directly find that the order of the relative importance among C1, C2, C3 and C4 is "C1»C3»C2»C4", where "»" implies that the former is more important than the later.

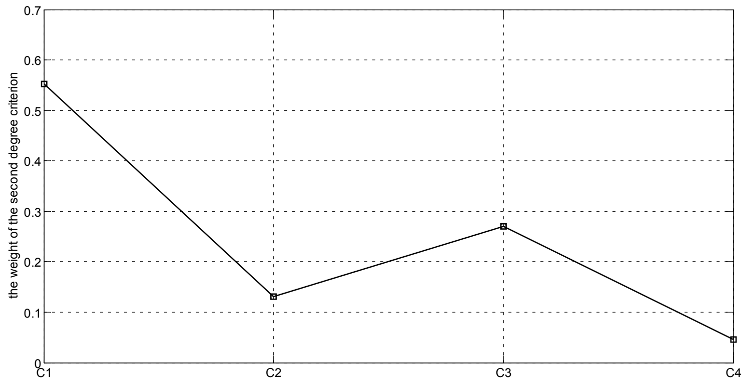

Figure 2. The relative importance among C1, C2, C3 and C4.

Step 2. We can obtain the weight vector of the components in the third level as

$$w = [0.1843 \quad 0.3687 \quad 0.0328 \quad 0.0984 \quad 0.1802 \quad 0.0901 \quad 0.0378 \quad 0.0076]^T$$

which is shown in Figure. 3. From Figure. 3, we can directly know that the order of the relative importance among the components in the third level as "C12»C11»C31»C32»C22 »C41» C21» C42".

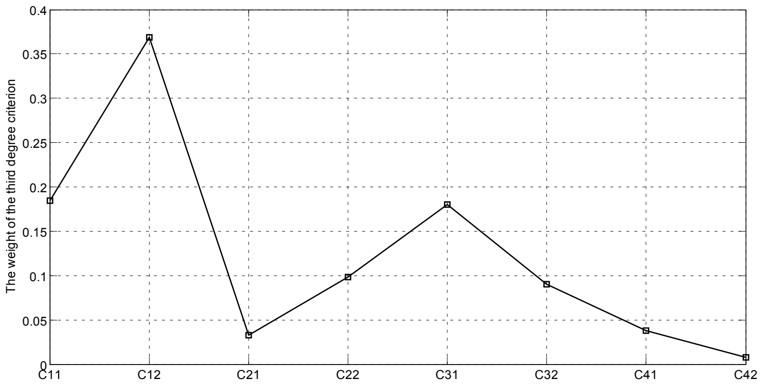

Figure 3. The relative importance among C11, C12, C31, C32, C41 and C42.

Step 3. Assume that we can't know the sufficient information of the specifications C11, C21, C22, C31, C32, C41 and C42 and we only know that these specifications belong to {very important, important, relative important, common}, and they are denoted by {1, 2, 3, 4}. Thus we determine the performance specifications for three EW systems in Table 7, where the specification C22 is cost, and the other specifications are efficient.

Table 7. The performance specifications for three EW systems.

	C1		C2		C3		C4	
	C11	C12	C21	C22	C31	C32	C41	C42
x_1	1	50	2	3	1	3	3	1
x_2	2	40	3	2	2	2	1	1

x_3	3	35	1	2	3	1	2	2

Step 4. According to Table 6, we can obtain the decision making matrix A in (1) as

$$A=\begin{bmatrix} [0.75,1] & 50 & [0.5,0.75] & [0.25,0.5] & [0.75,1] & [0.25,0.5] & [0.25,0.5] & [0.75,1] \\ [0.5,0.75] & 40 & [0.25,0.5] & [0.5,0.75] & [0.5,0.75] & [0.5,0.75] & [0.75,1] & [0.75,1] \\ [0.25,0.5] & 35 & [0.75,1] & [0.5,0.75] & [0.25,0.5] & [0.75,1] & [0.5,0.75] & [0.5,0.75] \end{bmatrix}$$

Step 5. From (4), we can obtain the normalization matrix B associated with the decision making matrix A as

$$B=\begin{bmatrix} [1,1] & 1 & [0.667,0.75] & [1,1] & [1,1] & [0.333,0.5] & [0.333,0.5] & [1,1] \\ [0.667,0.75] & 0.8 & [0.333,0.5] & [0.5,0.667] & [0.667,0.75] & [0.667,0.75] & [1,1] & [1,1] \\ [0.333,0.5] & 0.7 & [1,1] & [0.5,0.667] & [0.333,0.5] & [1,1] & [0.667,0.75] & [0.667,0.75] \end{bmatrix}$$

Step 6. From (7), we can obtain the normalized form of the weight matrix Y as

$$Y=\begin{bmatrix} [0.1843,0.1843] & 0.3687 & [0.0219,0.0246] & [0.0984,0.0984] & [0.1802,0.1802] & [0.03,0.0451] & [0.0126,0.0189] & [0.0076,0.0076] \\ [0.1229,0.1382] & 0.295 & [0.0109,0.0164] & [0.0492,0.0656] & [0.1201,0.1351] & [0.0601,0.0676] & [0.0378,0.0378] & [0.0076,0.0076] \\ [0.0614,0.0921] & 0.2581 & [0.0328,0.0328] & [0.0492,0.0656] & [0.0601,0.0901] & [0.0901,0.0901] & [0.0252,0.0284] & [0.0051,0.0057] \end{bmatrix}$$

Step 7. From (8), we can obtain the desired effectiveness value $y*$ as follows:

$$y^*=[[0.1843,0.1843]\ 0.3687\ [0.0328,0.0328]\ [0.0492,0.0656]\ [0.1802,0.1802]\ [0.0901,0.0901]\ [0.0378,0.0378]\ [0.0076,0.0076]]$$

Step 8. From (9), we can obtain the projection vector of three EW systems under complex electromagnetism environment as

$$P=[p_1,p_2,p_3]=[0.5317,0.4129,0.3262]$$

Thus we can give the projections and the order for the effectiveness evaluations of EW systems in Table 8 and Figure. 4.

Table 8. The projections and the order for the effectiveness evaluations of three EW systems.

Evaluation \ System	x_1	x_2	x_3
Projection	0.5317	0.4129	0.3262
Order	1	2	3

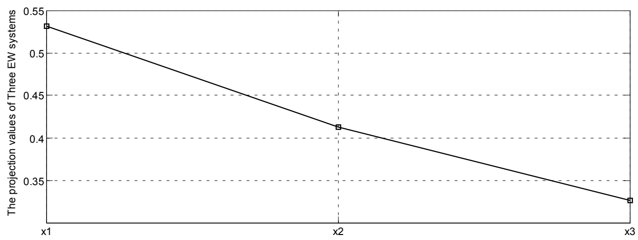

Figure 4. The projection values for the effectiveness evaluations of three EW systems.

CONCLUSION

The evaluating scheme of the quantitative specifications and the qualitative specifications for the EW system under complex electromagnetism environment is established. Based on the above results, the projection algorithm based on hybrid multiple attribute decision making is given for the effectiveness evaluation of the EW system under complex electromagnetism environment. Finally, a numerical example of three EW systems under complex electromagnetism environment and its simulation results show that the proposed projection algorithm based on hybrid multiple attribute decision making is simple and effective to evaluate the effectiveness of the EW system under complex electromagnetism environment.

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