Performance Evaluation of Radar against Complicated E.M. Environment Based on AHP

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Abstract. The performance of current radars is degraded in complicated E.M. environment and there is no uniform method to make evaluation to the performance degradation till now. Aiming at certain 3D radar in specific combat scenario, the paper provided the specification system for performance evaluation of radar against complicated E.M. environment, established the evaluation model and conducted normalization processing to specifications through AHP and made quantitative evaluation. The simulation results indicate that the established model by that method is effective and feasible and the evaluation result can provide reference for performance evaluation of radar against complicated E.M. environment.

Keywords. Complicated E.M. environment; performance evaluation; AHP.

1. Introduction
In modern warfare, various firepower strike weapons have to conduct increasingly high dependence on the sensors. In the sensors, the radar is significant for accuracy of firepower strike weapons. The corresponding jamming techniques to radars also gain certain development. That made the E.M. environment of battle field more and more complicated and the radar operation environment more and more severe, which leads to serious function degradation of radar as “eye” of platform. The evaluation to radar performance against complicated E.M. environment is to integrate multiple specification evaluations and consider weighting factors so as to obtain the comprehensive evaluation specifications, which indicate the overall situation of the object under evaluation against complicated E.M. environment.

Till now the researches on radar performance against jamming have already obtain certain achievements [1-8]. But there is few guidance and method for combat performance execution of radar in complicated E.M. environment, esp. The performance evaluation of radar in complicated E.M. environment is obviously inadequate.

2. Specifications System of Performance Evaluation of Radar against Complicated E.M. Environment
Specifications system of performance evaluation of radar against complicated E.M. environment involves 4 levels including target level, strategy level, criteria level and parameter level as well as 5 dimensions including time domain, space domain, energy domain, tactics and probability covering qualitative specifications and quantitative specifications. The system established in this paper is shown in figure 1.
The definition of specification system is as follows. (1) Target level is the performance of radar against complicated E.M. environment. (2) Strategy level involves active jamming and passive jamming in the complicated E.M. environment. It consists of strategies against passive jamming, against deception jamming and against suppression jamming. (3) Criteria level: The evaluation criteria for performance against complicated E.M. environment include power criteria, time criteria, space criteria, probability criteria and tactic criteria. The criteria of power and probability mainly aim at passive jamming, suppression jamming and transponding jamming. The tactic criteria mainly indicates the procedure of mutual gaming between us and enemy and aims at the performance of 2 core specifications including radar performance and accuracy against the complicated E.M. environment. The time criteria mainly indicates radar reaction time in complicated E.M. environment including initial detection time of target and stable track generation time. The space criteria mainly refers to radar space coverage. Radar operation sectors may be decreased under suppression jamming. (4) Specification level: the complicated environment faced by radar mainly involves passive jamming, deception jamming and suppression jamming. The specifications against passive jamming mainly include improvement factor against clutter. The specifications against deception jamming mainly include improvement factor against jamming, improvement factor of effective interception probability, improvement factor of interception time and improvement factor of average track generation time etc. The specifications against suppression jamming mainly include improvement factor against jamming, improvement factor of self-defense range, improvement factor of range measurement accuracy, improvement factor of azimuth measurement accuracy, improvement factor of elevation measurement accuracy, improvement factor of effective interception probability, improvement factor of interception time, improvement factor of average track generation time and improvement factor of sector loss etc.

Improvement factor against clutter is as follows:

\[ I_{eif} = \frac{(S/J)_j}{(S/J)_n} \]  

where \((S/J)_j\) is radar SNR after employment of ECCM measures and \((S/J)_n\) is SNR before employment of ECCM measures.
Improvement factor of self-defense range is as follows.

\[ \frac{R' - R}{R} \] (2)

where \( R \) is the radar self-defense range under jamming and \( R' \) is the self-defense range after employment of ECCM measures.

Improvement factor of range measurement accuracy is as follows.

\[ \frac{Ed - Ed'}{Ed} \] (3)

where \( Ed \) is the range measurement accuracy before employment of ECCM measures. \( Ed' \) is the range measurement accuracy after employment of ECCM measures.

Improvement factor of azimuth measurement accuracy is as follows.

\[ \frac{Ep - Ep'}{Ep} \] (4)

where \( Ep \) is the azimuth measurement accuracy before employment of ECCM measures. \( Ep' \) is the azimuth measurement accuracy after employment of ECCM measures.

Improvement factor of elevation measurement accuracy is as follows.

\[ \frac{Et - Et'}{Et} \] (5)

where \( Et \) is the elevation measurement accuracy before employment of ECCM measures. \( Et' \) is the elevation measurement accuracy after employment of ECCM measures.

Improvement factor of effective interception probability is as follows.

\[ \frac{Epb - Epb'}{Epb} \] (6)

where \( Epb \) is the interception probability before employment of ECCM measures. \( Epb' \) is the interception probability after employment of ECCM measures.

Improvement factor of interception time is as follows.

\[ \frac{Ect - Ect'}{Ect} \] (7)

where \( Ect \) is the interception time before employment of ECCM measures. \( Ect' \) is the interception time after employment of ECCM measures.

Improvement factor of track generation time is as follows.

\[ \frac{Ett - Ett'}{Ett} \] (8)

where \( Ett \) is the average track generation time before employment of ECCM measures. \( Ett' \) is the track generation time after employment of ECCM measures.

Improvement factor of sector loss is as follows.

\[ \frac{Es - Es'}{Es} \] (9)

where \( Es \) is the factor loss before employment of ECCM measures and \( Es' \) is the factor loss after employment of ECCM measures.

3. Performance Evaluation of Radar against Complicated E.M. Environment Based on AHP

The complicated E.M. environment consists of passive jamming and active jamming. Performance evaluation of radar against complicated E.M. environment should be conducted in 4 phases. Phase 1 mainly investigates the specifications performance of radar under the environment without background. Phase 2 mainly investigates radar performance under complicated E.M. environment without
employment of ECCM measures. Phase 3 mainly investigates radar performance under complicated E.M. environment with employment of ECCM measures. Phase 4 is that the radar performance decreases to same as phase 2 with employment of ECCM measures under more complicated E.M environment and relevant middle procedure. In phase 1, the basis of each radar specification is determined such as interception time, interception probability, performance and accuracy etc. In phase 2, the degradation degree of each radar specification is determined. In phase 3, the improvement degree of radar specifications corresponding to phase 2 and degradation degree of radar specifications corresponding to phase 1 are determined. In phase 4, the degradation degree of radar against the complicated E.M. environment of different strength is determined. This paper mainly discusses the first 3 phases. Performance evaluation of radar against complicated E.M. environment is the result obtained by comprehensive integration of each specification with weighting calculation. For different radars and different scenarios, the weighting of each specification is also different. The core is to determine the importance degree of each specification in the whole specification system so as to decide the weighting of each specification. Based on AHP, this paper established the model and evaluated the performance of certain radar against complicated E.M. environment in specific scenario.

3.1. Normalization Processing of Specifications

The unit and classification of each evaluation specification for radar against complicated E.M. environment is not the same and normalization processing should be conducted according to the difference. The improvement factors of anti-clutter, self-defense range, range measurement accuracy, azimuth measurement accuracy, elevation measurement accuracy and effective interception probability should be as high as possible. The improvement factors of interception time, average track generation time and sector loss should be as low as possible. The normalization is conducted according to equations (1)-(9). Typical battlefield scenario of radar against complicated E.M. environment is shown in figure 2.

![Figure 2](image_url)

**Figure 2.** Typical battlefield scenario of radar against complicated E.M. environment.

The strategy level and criteria level are qualitative parameters without normalization processing. Their weighting is decided in 0-1 as per expert experience.

3.2. Determination of Fuzzy Distribution Weighting

At first, the factors set influencing evaluation object is established as \( F = (f_1, f_2, \ldots, f_n) \). The factor \( f_i \) (\( i=1, 2, \ldots, n \)) is the specification of each level in specification system of radar performance evaluation.
against complicated E.M. environment. The weighting corresponding to each specification is not the same. For specific specification fi, its weighting is determined as wi and its determined weighting set is W= (w1, w2, ......wn), \( \sum_{i=1}^{n} w_i = 1 \), i=1, 2, ...... n. x.

For specific combat scenario, the sum of weighting of anti-passive jamming, anti-deception jamming and anti-suppression jamming involve in strategy level is 1 according to expert experience. The sum of weighting of power, tactics, probability, time and space involved in criteria level is 1 according to expert experience. The sum of weighting of 9 specifications involved in specification level is 1 according to normalization to all or partial of 9 specifications.

3.3. Evaluation by 3-scale Method

The fuzzy judgment matrix A=(a_{ij})_{n×n} is established through 3-scale method [9]. The fuzzy matrix A is converted into fuzzy complementary judgment matrix B=(b_{ij})_{n×n}. Where \( b_{ij} = \frac{b_i-b_j}{2^n} + 0.5 \) and \( b_i = \Sigma_{j=1}^{n} a_{ij} \). After eigenvalue decomposition to fuzzy complementary judgment matrix, the eigenvector if maximum eigenvalue is obtained as C=(c_i)_{n}. The weighting vector obtained at last is \( w_i = \frac{c_i}{\Sigma_{i=1}^{n} c_i} \).

For step 1, evaluation of specification level is R=W· V. where W= (w1, w2, ......wn) is the weighting matrix of specifications. V is the normalized fuzzy value matrix of specification level. The obtained result R is the evaluation result of specification level.

For step 2, evaluation of criteria level is S=R· C. where C is the weighting matrix of criteria level. The obtained results include s1 (evaluation result against passive jamming), s2 (evaluation result against deception jamming) and s3 (evaluation result against suppression jamming).

For step 2, evaluation of strategy level is T=S· B=s1· b1+s2· b2+s3· b3. where S and B are both 1D vector. b1 is the weighting value against passive jamming. b2 is the weighting value against deception jamming and b3 is the weighting value against suppression jamming. Thus the evaluation result of radar performance against complicated E.M. environment is achieved.

4. Simulated Calculation

The fuzzy judgment matrix established through 3-scale method is as follows.

\[
A = \begin{bmatrix}
0.5 & 1 & 1 & 1 & 1 \\
0 & 0.5 & 1 & 1 & 1 \\
0 & 0 & 0.5 & 1 & 1 \\
0 & 0 & 0 & 0.5 & 1 \\
0 & 0 & 0 & 0 & 0.5
\end{bmatrix}
\]

It is converted into fuzzy complementary judgment matrix as follows.

\[
B = \begin{bmatrix}
0.5 & 0.6 & 0.7 & 0.8 & 0.9 \\
0.4 & 0.5 & 0.6 & 0.7 & 0.8 \\
0.3 & 0.4 & 0.5 & 0.6 & 0.7 \\
0.2 & 0.3 & 0.4 & 0.5 & 0.6 \\
0.1 & 0.2 & 0.3 & 0.4 & 0.5
\end{bmatrix}
\]

The maximum eigenvalue is as follows.

\( \lambda_{\text{B}}=0.28 \)

The eigenvector of fuzzy complementary judgment matrix is as follows.

\[
C = \begin{bmatrix}
0.61 \\
0.52 \\
0.43 \\
0.33 \\
0.24
\end{bmatrix}
\]
According to practical situation, the parameters weighting of strategy level are as follows. Weighting of anti-passive jamming, anti-deception jamming and anti-active jamming are all 0.5. The parameters weighting of strategy level is shown in table 1.

| Criteria level | Weighting | Parameter level | Weighting | Specification ambiguity value 1 | Specification ambiguity value 2 |
|----------------|-----------|-----------------|-----------|-------------------------------|-------------------------------|
| Power          | 0.29      | Improvement factor against clutter | 1         | 1.1                           | 1.25                          |
|                |           | Improvement factor of self-defense range | 0.25     | 0.25                          | 0.5                           |
|                |           | Improvement factor of range measurement accuracy | 0.25     | 0.47                          | 0.76                          |
| Tactics        | 0.25      | Improvement factor of azimuth measurement accuracy | 0.25     | 0.6                           | 0.96                          |
|                |           | Improvement factor of elevation measurement accuracy | 0.25     | 0.5                           | 0.94                          |
| Probability    | 0.2       | Improvement factor of effective interception probability | 1         | 0.25                          | 0.5                           |
| Time           | 0.15      | Improvement factor of interception time | 0.5       | 0.23                          | 0.4                           |
|                |           | Improvement factor of track generation time | 0.5       | 0.33                          | 0.55                          |
| Space          | 0.11      | Improvement factor of sector loss | 1         | 0.65                          | 0.68                          |

In order to compare the radar ECCM effect, combined with the achievement effect, employment of the ambiguity value of each specification is classified into common ECCM mode and advanced ECCM mode, and the weighting is decided as per expert experience. According to calculation, the quantization specification of that radar against jamming in specific scenario for common ECCM and advanced ECCM are 0.3 and 0.625 separately.

5. Conclusion
Aiming at performance evaluation of certain 3D radar against complicated E.M. environment in specific scenario, this paper employs AHP to provide one solution for evaluation of radar performance against complicated E.M. environment. This paper establishes the specification system and constructs the evaluation method through evaluation models and 3-scale method, and conducts quantization and provides reasonable evaluation result. Through simulated calculation and combined with analysis to practical example, that method is proved to be effective and feasible and able to provide one solution for evaluation of radar performance against complicated E.M. environment. That method can also be employed for radar performance evaluation against complicated E.M. environment in other combat scenarios.

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