Chapter 31
Effectiveness Valuation of Electronic Countermeasure on Ground Air Defense and Anti-missile

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Abstract The effectiveness valuation of electronic countermeasure on ground air defense and anti-missile has turned into one of the hot subjects of present research. To the complexity and changefulness of the diverse random events deciding the competency matrix C and the fact that some criterions lack quantified representation in ADC method, innovation of the ADC method is proposed in the thesis. Through combination of qualitative and quantitative process, ADC method, analytic hierarchical process and Delphi method are used jointly to implement the effectiveness valuation of electronic countermeasure on ground aerial defense and anti-missile system. Availability A, dependability D, competency matrix C and the computational models of their sub models are set up respectively. It is proved that the model is in validity by example.

Keywords Analytic hierarchy process · Delphi method · Electronic countermeasure system · Effectiveness valuation · Improved ADC method

31.1 Introduction

As the electronic technology in air strikes and air defense against are extensive used in the field, electronic against becomes an important part of the modern war. As one of the important forces in ground to air defense, we air-defense unit of the ground will certainly put up drastic rivalry in electronic against conditions. So, how to evaluate the electronic against effectiveness is an important issue.

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31.2 Methodology

31.2.1 Improving Evaluation Methods

Currently, there are many methods to evaluate the effectiveness. But in all of the methods the ADC is more comprehensive, precise and its index is more clear which can reflects weapon system's physical advantages. There are also limitations in this method that every index must have a specific expression (AD A 109549 1981). As the ground to air defense electronic against system is complex and lack quantitative indexes, it is difficult to analyse its C matrix (Meng et al. 2003; Sang 2008; Li and Wang 2008).

So this article talks about how to ameliorate the ADC model, and its main part uses the improved ADC method to have a strict process and get an authentic outcome. In the premise of using as much analytical method as possible, calculate the weight by APH for some uncountable index and find out the point with Experts consult method to solve the calculation problem. Combining the quality and quantity can use the ADC to good advantage and can also make up its disadvantages, so that we can evaluate electronic against effectiveness effectively.

31.2.2 Building the Evaluation Index System of Ground to Air Defense Effect in Electronic Countermeasure Conditions

Combining with improved ADC model elements, the index system as follows: the evaluation of ground to air defense effect in electronic against conditions is decided by A, D, C three matrixes (AD A 109549 2010), A and D are decided by maintenance and reliability, C is decided by anti-jamming matrix C_1, the electronic reconnaissance capability matrix C_2, the anti-radiation missile resistance capability matrix C_3, the anti-stealth ability matrix C_4, the survival ability matrix C_5.

31.2.3 Building the Model of Effectiveness Valuation of Electronic Countermeasure

31.2.3.1 Analyzing the States of Electronic Countermeasure

Though ground to air defense electronic against systems are different in theory, function and structure, but the typical electronic against process is: Firstly, reconnaissance equipment such as satellite, radar and photoelectricity equipment reconnoitre the radiation source. Secondly, the Data-Processing-Center find out its

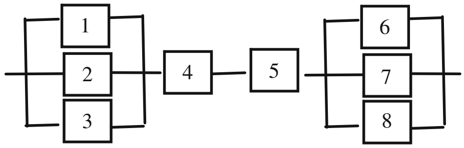

Fig. 31.1 Reliability chart of electronic countermeasure system

position and radiation source recognition system identify and pick up features such as the working frequency. Thirdly, our ground to air defense electronic against systems takes soft killing or hard killing according to the obtained information. Soft against methods include radar jamming equipment and photoelectricity jamming equipment. Hard killing methods are launching missiles to against ARM.

According to its typical process, building elementary model can find out system's reliable frame as Fig. 31.1, and it can also discover system's original state as Table 31.1.where:

1 -Equipment of radar reconnaissance;
2 -Equipment of photoelectricity reconnaissance;
3 -Equipment of secondary plane reconnaissance;
4 -Center of data processing;
5 -System of radiation sources identifies;
6 -Equipment of radar disturbing;
7 -Equipment of photoelectricity disturbing;
8 -Equipment of hard destroys.

Explanation: the number in the picture shows the serial number of each part.

31.2.3.2 Building Evaluation Model

The basic model of ADC mean is:

$$E_s = A^T[D][C] \tag{31.1}$$

Table 31.1 Work state of electronic countermeasure system

Order	State
1	All of the parts are normal
2	Part 1 conk out, others are normal
3	Part 2 conk out, others are normal
4	Part 3 conk out, others are normal
5	Part 6 conk out, others are normal
6	Part 7 conk out, others are normal
7	Part 8 conk out, others are normal
8	The system conk out

E_s —system's effectiveness vector;
A^T —availability vector;
C —competency matrix
D —dependability matrix

(1) *the sub models of* availability A

Electronic countermeasure system is made up of eight parts. The availability level of each part can be got by the formula (Yan et al. 2008):

$$A_i = {}^{MTBF_i}/_{MTBF_i + MTTR_i} \quad (i = 1, 2, \ldots, 8)$$

where:

i-number in Fig. 31.1.

Combining eight states in Table 31.1, availability A of electronic countermeasure system can be got by the calculable models of combined system.

$$A = (a_1\, a_2\, a_3\, a_4\, a_5\, a_6\, a_7\, a_8)$$
$$a_1 = \prod_{i=1}^{8} A_i \quad a_2 = (1 - A_1)\prod_{i=2}^{8} A_i \quad a_3 = (1 - A_2)\prod_{i=1,\neq 2}^{8} A_i \quad a_4 = (1 - A_3)\prod_{i=1,\neq 3}^{8} A_i$$
$$a_5 = (1 - A_6)\prod_{i=1,\neq 6}^{8} A_i \quad a_6 = (1 - A_7)\prod_{i=1,\neq 7}^{8} A_i \quad a_7 = (1 - A_8)\prod_{i=1}^{7} A_i \quad a_8 = 1 - \sum_{i=1}^{7} a_i \tag{31.2}$$

(2) *the sub models of dependability D*

The factors of D are decided by dependability level. The dependability level's expression of each parts in electronic against system is

$$R_i = \exp(-\lambda_i \mathrm{t}) \quad (i = 1, 2, \ldots, 8)$$

where:

λ_i is the parts' invalidation possibility, and can be got by: $\lambda_i = 1/MTBF_i$

State transfer probability d_{11}–d_{88} can be got by system's original state and every part's dependability. The d_{11} means the probability that system runs normally from beginning to the end. The d_{12} means the probability that system runs normally at beginning but radar reconnaissance equipment conk out at last. It can be got by

$$d_{12} = (1 - R_1)\prod_{i=2}^{8} R_i$$

In the same way dependability D can be found out by:

$$D = D(t) = \begin{cases} d_{ij}, & i \leq j \\ 0 & i > j \end{cases} \quad (i, j = 1, 2, \ldots, 8) \tag{31.3}$$

(3) *the sub models of competency matrix C*

Competency matrix C is determined by anti-jamming matrix C_1, the electronic reconnaissance capability matrix C_2, the anti-radiation missile resistance capability matrix C_3, the anti-stealth ability matrix C_4, the survival ability matrix C_5.

a. anti-jamming Capability C_1

Anti-jamming capability can be expressed by the change of radar maximum detection distance in jamming conditions. If there is no jamming, the maximum detection distance of radar (Schrick 2008) that it can be denoted by R_{max} is

$$R_{\max} = \left[\frac{p_t G_t^2 \lambda^2 \sigma}{(4\pi)^3 K T_0 \Delta f_r F_n L (S/_N)_{\min}}\right]^{\frac{1}{4}} \tag{31.4}$$

where:

P_t —radio power;
G_t —antenna gain;
λ —wavelength;
σ —RCS;
K —Boltzmann constant;
T_0 —receiver noise temperature, it can be denotation by 290 K;
Δf_r —receiver bandwidth;
L —the loss factor of system;
F_n —noise coefficient;
$(S/N)_{min}$ —minimum SNR

Radar maximum detection distance in jamming conditions (Yan and Zhang 2009) is

$$R'_{\max} = \frac{1}{3}\sqrt{\frac{R_j}{\theta_{0.5}}}\sqrt{\frac{\pi P_t G_t \sigma K \Delta f_j}{K \gamma_j P_j G_j \Delta f_r}} \tag{31.5}$$

where:

r_j —polarization loss, $r_j = 0.5$;
P_j —jamming power;
G_j —interference machine lord disc plus;
Δf_j —jamming signal bandwidth.

C_1 can be got by it:

$$C_1 = 1 - \overline{C_1} = 1 - {(R_{\max} - R'_{\max})}\Big/{R_{\max}} \times 100\% \tag{31.6}$$

b. The electronic reconnaissance capability matrix C_2

C_2 is mainly decided by anti-signal intercepted capability N_1 and anti-signal analysis capability N_2, where:

$$N_1 = 1 - K_1 P_1 \quad K_1 = \frac{\theta_t}{\theta_{t0}} \frac{\Delta f}{\Delta F} \frac{R_t}{R_{to}} \tag{31.7}$$

K_1 —reconnaissance relative cover coefficient;
P_1 —intercept probability;
θ_t —actual cover range in the detectable orientation of system;
θ_{t0} —expected or demanded by campaign mission cover range in the detectable orientation;
Δf_t —actual cover range in the detectable frequency orientation of system (Ribeiro 2006);
ΔF_t —expected or demanded by campaign mission cover range in the detectable frequency;
R_t —actual reconnaissance distance of system;
R_{t0} —expected or demanded by campaign mission reconnaissance distance (Zhou and Tao 2007)

$$N_2 = P_2 \rho \tag{31.8}$$

where:
P_2 —signal processing probability;
ρ —recognition confidence

we can get:

$$C_2 = \omega_1 N_1 + \omega_2 N_2 \tag{31.9}$$

where:
$\omega_1 \omega_2$ are decided by experts, $\omega_1 = 0.43$, $\omega_2 = 0.57$.

c. The anti-radiation missile resistance capability matrix C_3 (Liu 2010)*, the anti-stealth ability matrix C_4*

Because of the complexity and changefulness of the diverse random events deciding the competency matrix C_3, C_4, and the fact that some criterions lack quantified representation in ADC method, innovation of the method is proposed in the thesis. Through combination of qualitative and quantitative process with ADC method, hierarchical analytic process and Delphi method are used jointly to implement the effectiveness valuation of electronic countermeasure. And they can be broken up to index system in Table 31.2 (Ti 2005a).

The weight of each index can be decided by hierarchical analytic process and every index's relative importance can be shown by using ratio build judge matrix 1–9. Taking the anti-stealth ability matrix C_4 for an example: assuming that the sub model's tactics measure and techniques ability constitute the matrix of remark collection:

Table 31.2 The standard of grade

Index	Subindex	The standard of grade (point)			
		0.75–1	0.5–0.75	0.25–0.5	0–0.25
Anti-radiation missile resistance capability (Wu et al. 2010)	Concealment distance (km)	>300	200–300	100–200	<100
	Warning time (Chrazanowski)	>60 s	45–60 s	20–45 s	<20 s
	Jamming and inveiglement capability	Very good	Good	Not bad	Bad
	Attack and against ability	Very good	Good	Not bad	Bad
The anti-stealth ability (Ti 2005b)	Meter wave band radar	Most sensitive	More sensitive	Sensitive	Not sensitive
	Anti-stealth drilling	Most continual	More continual	Continual	Not continual
	Radar web	Very good	Good	Not bad	Bad
	Increase aperture multiplication of radar power	>30	20–30	10–20 s	<10
	Increase the number of impulses dealed with phasic parameter	>100	80–100	50–80	<50

$$T = (t_{mn})_{2\times 2}\begin{bmatrix} 1 & 3.03 \\ 0.33 & 1 \end{bmatrix} \tag{31.10}$$

The eigenvector of judge matrix can be calculated by "addition method" according to expression (31.10).

$$\omega_m = \frac{1}{2}\sum_{n=1}^{2}\frac{t_{mn}}{\sum_{k=1}^{2} t_{kn}}$$

And the weight can be got as:

$$\omega = (\omega_1, \omega_2)^{\mathrm{T}} = (0.66, 0.34)^{\mathrm{T}}.$$

Then ten experts mark basing on Table 31.2, and calculate the average figure. At last it can be got by linearity addition method:

$$C_4 = \sum_{m=1}^{2}\omega_m\left[\sum_{k=1}^{m_n}\omega_{mk}\times F_{mk}\right] \tag{31.11}$$

where:
m_n —the number of sub index;
ω_m —the weight of the third layer index;
ω_{mk} —the weight of sub index's coefficient;
F_{mk} —the sub index point given by experts.

d. the survival ability C_5

The survival ability can be showed by survival probability. In order to improve survival ability, we usually assume that there are m information centers which are redundancies of each other. So the survival probability is

$$C_5 = P_{cam} = 1 - \prod_{k=1}^{m} p_k = 1 - \prod_{k=1}^{m} \left(\prod_{i=0}^{Q} p_{ik} \right) \tag{31.12}$$

where:
K —the number of ruined center;
P_{0k} —the probability of raided on the center;
$P_{1k}, P_{2k}, \ldots, P_{Qk}$ —the probability of destroying the center after all effective against measures are taken.

(4) *Calculating system's effectiveness Es*

As analyzed above, the formula can be got:

$$C = \prod_{k=1}^{5} C_K \tag{31.13}$$

and formula (31.1)can be changed to

$$E_S = AD \prod_{k=1}^{5} C_K \tag{31.14}$$

The improved ADC method which can evaluate the effectiveness of electronic countermeasure on ground air defense and anti-missile can be got by joining formulae (31.2)–(31.6), (31.9), (31.11), (31.12) to formula (31.14).

31.3 The Example

The effectiveness of two supposed typical ground air defense and anti-missile systems in electronic against conditions which can be evaluated by the model have been got. System 2 is partly advanced to system 1 by improving reliability level and radar's anti-stealth ability of every part in System 2. The numerical value of each parameter of 2 systems above can be got from figure Tables 31.3 and 31.4.

Table 31.3 Reliability parameter

	$MTTR_1$	$MTTR_2$	$MTBF_1$	$MTBF_2$
Radar	25	13	180	300
Photoelectricity equipment	10	10	200	600
Satellite	50	30	300	1470
Date center	30	20	200	980
Radiosource recognition system	21	20	300	500
Radar jamming equipment	26	20	300	410
Photoelectricity jamming equipment	10	7	400	470
Hard killing methods	40	20	180	650

Elucidation: in Table 31.4, the number which follows every index is its weight; other numbers in Table 31.4 are points.

From Table 31.3:

$$A_1 = [0.4279 \quad 0.0595 \quad 0.0214 \quad 0.0713 \quad 0.0371 \quad 0.0107 \quad 0.0951 \quad 0.277]$$

$$D_1 = \begin{bmatrix} 0.6392 & 0.0041 & 0.0720 & 0.0168 & 0.0002 & 0.0008 & 0.0001 & 0.2668 \\ 0 & 0.6943 & 0.0028 & 0.0513 & 0.0014 & 0.0003 & 0.0002 & 0.2497 \\ 0 & 0 & 0.7101 & 0.0082 & 0.0312 & 0.0051 & 0.0001 & 0.2453 \\ 0 & 0 & 0 & 0.7452 & 0.0362 & 0.0014 & 0.0006 & 0.2166 \\ 0 & 0 & 0 & 0 & 0.7642 & 0 & 0.0012 & 0.2346 \\ 0 & 0 & 0 & 0 & 0 & 0.8013 & 0.0004 & 0.1983 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.8537 & 0.1463 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_2 = [0.7934 \quad 0.0012 \quad 0.0132 \quad 0.0162 \quad 0.0387 \quad 0.0118 \quad 0.0245 \quad 0.101]$$

$$D_2 = \begin{bmatrix} 0.7421 & 0.0052 & 0.0810 & 0.0170 & 0.0004 & 0.0009 & 0.0002 & 0.1532 \\ 0 & 0.7841 & 0.0032 & 0.0812 & 0.0040 & 0.0006 & 0.0001 & 0.1268 \\ 0 & 0 & 0.8021 & 0.0044 & 0.0923 & 0.0061 & 0.0004 & 0.0947 \\ 0 & 0 & 0 & 0.8428 & 0.0060 & 0.0998 & 0 & 0.0514 \\ 0 & 0 & 0 & 0 & 0.8690 & 0.0091 & 0.0760 & 0.0459 \\ 0 & 0 & 0 & 0 & 0 & 0.9215 & 0.0410 & 0.0375 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.9705 & 0.0295 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

From Table 31.4: $C_{41} = 0.664$; $C_{42} = 0.814$.

To predigest the problem, these parameters of system1 and system 2 such as anti-jamming C_1, the electronic reconnaissance resistance capability C_2, anti-radiation missile resistance capability C_3, the survival ability C_5 can be supposed to equal to 1.

So it can be got that: $E_{S1} = 0.426$; $E_{S2} = 0.603$.

According to the analysis of result, the conclusion can be made that the effectiveness of electronic countermeasure can be strengthened obviously with

Table 31.4 Points given by experts to the anti-stealth ability of radar

Sub index	The third layer index	System 1	System 2
Tactics measure 0.66	Meter wave band radar 0.313	0.62	0.84
	Anti-stealth drilling 0.227	0.87	0.94
	Radar web 0.460	0.74	0.89
Techniques ability 0.34	Increase aperture multiplication of radar power 0.461	0.63	0.88
	Increase the number of impulses dealed with phasic parameter 0.327	0.75	0.82

radar's anti-stealth ability and the reliability of system2's improving. The result is accordant with practice (Yan et al. 2007; Chin 1998; Packer 2003; Whatmore 2005; Hall and Betts 1994; Rius et al. 1993). And it is fully proved that the improved ADC method is in validity to evaluate the effectiveness of electronic countermeasure on ground air defense and anti-missile.

31.4 Conclusion

In conclusion, the improved ADC model is used to evaluate the effectiveness of electronic countermeasure on ground air defense and anti-missile, and it is proved by example that the model is in validity (Volakis 1994; Zhang et al. 2000; Levison and Badler 1994; Badler et al. 2006). Currently, the model has been used to evaluate C^4ISR air defense systems, and a synthetically effectiveness valuation software has been developed. So the improved ADC model is proved to be worthful.

References

A methodology to find overall system effectiveness in a multicriterion environment using surface to air missile weapon systems as an example. AD A109549, (1981)

A methodology to find overall system effectiveness in a multicriterion environment using surface to air missile weapon systems as an example. AD A109549, (2010)

Badler N, Bindiganavale R, Allbeck J, Schuler W, Zhao L, Palmer M (2006) Parameterized action representation for virtual human agents. In: Cassell J (ed) Embodied conversational agents. MIT Press, Cambridge, pp 256–284

Chin HH (1998) Intelligent simulation support system: used in electronic warfare simulator. American Institute of Aeronautics and Astronautics, Washington (AIAA-92-4811) Sep 1998

Chrazanowski EJ (1990) Radar active countermeasure. Artech House, Norwood, MA

Hall DR, Betts FC (1994) An air-to-air situationally interactive combat model (SICM). In: NAECON, pp 960–967

Levison L, Badler N (1994) How animated agents perform tasks: connecting planning and manipulation through object-specific reasoning. Department of Computer and Information Science, University of Pennsylvania, Philadelphia

Li Z, Wang S (2008) Several ways of effectiveness valuation to weapon. J Univ Navy Force Eng 90(1):97–99 (in Chinese)

Liu Y (2010) Mathematics model of effectiveness for electronic recce equipment. J UEST Chin 24(3):304–306 (in Chinese)

Meng Q, Zhang J, Song B (2003) Effectiveness valuation of fish torpedo. Publishing company of national defence industry, Beijing (in Chinese)

Packer RJ (2003) Computer modelling of advanced radar techniques: the advanced radar simulator. In: IEE colloquium on electronic warfare systems

Ribeiro RA (2006) Fuzzy multiple attribute decision making: a review and new preference elicitation techniques. Fuzzy Sets Syst 78(2):155–18

Rius JM et al (1993) High-frequency RCS of complex radar target in real time. IEEE Antennas Propag 41(9):1308E–1319E

Sang W (2008) The study on ways of effectiveness valuation of electronic countermeasure. Tech Electron Countermeasure 24:34–41 (in Chinese)

Schrick G (2008) Interception of LPI Radar Singles. In: IEEE international conference on radar

Ti N (2005a) Formulas for measuring radar ECCM capability. IEE Proc, 132(3):198–200, July 2009

Ti N (2005b) Rader ECCMs new area: anti-stealth and anti-ARM. IEEE Trans Aerosp Rev 31(3):1120–1127

Volakis JL (1994) XPATCH: a high-frequency electromagnetic scattering prediction for complex three dimensional objects. IEEE Antennas Propag Mag 36(1):65–69

Whatmore L (2005) The evaluation of radar effectiveness using the generic ECM ES model. In: IEE colloquium on computer modeling and simulation of radar systems

Wu X, Hui Zhang, Wang S (2010) The study on technic measure of aerial defence radar to confront anti-radiation missile. Electron Countermeasure Spacefl 22(1):10–13 (in Chinese)

Yan Y, Zhang Q (2009) The effectiveness evaluation of the C^4ISR system based on the improved ADC method. J Univ Air Force Eng 34(1):32–35 (in Chinese)

Yan Y, Lei Y, Zhang Q (2007) The design of the C^4ISR system effect valuation software. Arith Tech Aviat 37(1):4–7 (in Chinese)

Yan Y, Lei Y, Zhang Q (2008) Research on reliability of the efficiency evaluation of the C^4ISR system based on ADC method. Firepower Command Control 33(1):21–24 (in Chinese)

Zhang Y, Volz R, Sehgal A (2000) Generating Petri net driven graphical simulation tool for automated systems. In: Proceedings of the American nuclear association 2000 annual meeting, pp 140–147

Zhou S, Tao B (2007) Mathematical simulation of using decoying and killing missiles to counter anti-radiation missiles. (1): ADA320857