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Research on the Configuration Quantity Issues of Decoy Based on Cost-Effectiveness Ratio

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Abstract

With the continuous application of new technologies in reconnaissance and attack, display falsity plays a more important role in improving the survivability of targets, and the number of decoys plays a crucial role in the camouflaging effect. Based on the concept of cost-effectiveness ratio, according to the newly formulated Johnson criterion and the view of discovery and destruction, this paper proposes to take the identification probability as the probability of being destroyed and uses mathematical formulas to calculate the cost of a single use decoy. On this basis, a cost-effectiveness ratio model is established, with the product of the increase in the survival probability of the target and the cost of the target as the benefit, and the sum of the product of the probability of being destroyed and the cost of the decoy and the cost of a single use as the consumption cost. The model is calculated and analyzed, and the number of decoys that conform to the actual situation is obtained.

Keywords

Decoy, Configuration Quantity, Cost-Effectiveness Ratio

1. Introduction

The rapid development of science and technology, especially the application of emerging technologies in reconnaissance, surveillance and precision guidance, has made information warfare highly transparent for the side with high technology. Camouflage protection, as the main means to counter enemy reconnaissance, surveillance and precision guidance and an important method to enhance the survivability of military targets, has always been highly valued [1] [2]. With more high-tech applications in reconnaissance and surveillance, the development and application of concealment camouflage technology have lagged behind relatively. Under such circumstances, display falsity has played an increasingly significant role [3] [4]. One of the functions of display falsity is to deploy a certain number of decoys around targets to improve their survivability [5].

Reference [6] conducted an in-depth study on the cost-effectiveness ratio model of decoy in the entrance of protective engineering, proposed to take the increased value of the survival probability of protective engineering as the combat effectiveness index, and the value of all targets and decoys as the cost to establish the cost-effectiveness ratio model. The model was analyzed, solved, and optimized, and conclusions were drawn through specific examples. This reference has a good reference value for display falsity of protective engineering entrance, but lacks generality. Reference [7] comprehensively considers various factors such as the value ratio of target and decoy, identification probability, and the probability of hitting and destroying, etc., using nonlinear multi-objective programming to determine the weight coefficient of the cost and survival capability evaluation index of the decoy, established a decoy allocation quantity model based on multi-objective decision-making, calculated the optimal allocation quantity of the decoy, and simultaneously used the cost-effectiveness ratio model of the decoy for verification and analysis. However, the practicality of its conclusion is questionable.

This paper proposes to replace the commonly used discovery probability with the identification probability [8] based on the Johnson's principle in the electronic focal plane array [9] (In this paper, "identification" refers to the type of target identified by the enemy, that is, identifying whether the target is an armored vehicle or a tank, rather than identifying target or decoy); The cost of each use is calculated by the probability of the decoy being destroyed; On this basis, a cost-effectiveness ratio model is established, which takes the product of the improved survival probability of the true target and the cost of the true target as the benefit, and takes the product of the number of decoys and the cost per use as the cost of the consumed cost [10]. By pursuing the optimization of cost-effectiveness ratio to determine the configuration quantity of decoys, and assuming a certain type of standard decoy for calculation, the configuration quantity of decoys was solved and analyzed according to the model and practical results were obtained, providing theoretical basis and reference for determining the configuration quantity of decoys for display falsity.

2. Research Problem

The configuration quantity of decoys is the main factor in improving the survival probability of targets. There are many factors affecting the configuration quantity of decoys, and the cost-effectiveness ratio is one of the factors that must be considered.

2.1. Situation Scenario

For the convenience of study and practical operation, the assumptions are as follows.

1) The situation studied in this paper is to set a certain number of decoys around

the target according to camouflage requirements to improve the survival ability of the target.

2) According to the newly formulated Johnson Criterion, the reconnaissance level is divided into four levels: discovery, distinction, identification, and confirmation. Once a target is identified, it means it is destroyed in information warfare, that is, the recognition rate of the target is equal to its destruction rate [11].

3) According to the combat technology performance of decoys, the enemy's existing reconnaissance equipment cannot distinguish between our target and decoys [12] [13].

2.2. Problem Analysis

The more decoys are configured, the higher the survival probability of targets and the better camouflage effect. However, the more decoys are required, the more time, manpower, and material resources are needed; The fewer configurations are needed, the fewer decoys are required, and the less time, manpower, and material resources are needed. But, the less the survival probability of the target is improved, the lower the effectiveness of the display falsity. Therefore, we can establish a cost-effectiveness ratio model for determining the configuration quantity of decoys.

3. Methodology

3.1. Basic Concepts and Formulas of Cost-Effectiveness Ratio

The cost-effectiveness ratio is the ratio of output benefits to input costs. Developed countries' armies have long attached great importance to the study and calculation of cost-effectiveness in the military field. During World War I, the British army pioneered the "Lancaster equation" for optimizing the deployment of infantry combat forces. During World War II, the armies of the United States and Britain used military operations research to plan the deployment of air defense forces and maritime transportation. After the war, they applied this method to various aspects, such as selecting national security strategies, developing strategies for weapons and equipment, optimizing the structure of military forces, and reforming policies and systems for military personnel. The calculation of this cost-effectiveness ratio is not just a simple number, it reflects the scientific management concepts of quantitative analysis, cost accounting, detail management, process control, etc. It is an effective method to improve the efficiency of the military field from the accurate management of the whole process of input to output [11].

The cost-effectiveness model can be expressed as follows:

$$\eta = \frac{E}{C}$$

Among them: η represents the cost-effectiveness ratio; E representing the benefits generated; C represents the cost consumed.

3.2 Calculation of Benefits Generated

In the configuration quantity model of decoy based on cost-effectiveness ratio, the product of the increase in the survival probability of the target and the cost of the target is used as the generated benefit. The probability of a disguised target being detected and identified by enemy reconnaissance is P_T, that is, the probability of a target being destroyed by the enemy is P_T, the probability of a decoy that has imperfect camouflage being destroyed by the enemy is $P_F = k * P_T$, the ratio of the probability of a target being destroyed to the probability of a decoy being destroyed is k, the cost of a target is V_T, the configuration quantity of decoy is n, the cost of a decoy is V_F.

When decoys are not configured, the survival probability of targets is P_{TS}:

$$P_{TS} = 1 - P_T$$

After configuring n decoys, the probability of the target being destroyed is P_T':

The situation and corresponding probability of the target being identified and destroyed by enemy reconnaissance are $n+1$ as follows.

The probability of the first reconnaissance target being identified and destroyed by the enemy is:

$$\frac{P_T}{n+1}$$

The destroyed probability that the target is diecovered and identified after the enemy discovers a target and the target is not identified as a decoy is:

$$\frac{n(1-P_F)}{n+1} \times \frac{P_T}{n} = \frac{P_T(1-P_F)}{n+1}$$

The destroyed probability that the target is diecovered and identified after the enemy discovers two targets and the target is not identified as decoy is:

$$\frac{n(1-P_F)}{n+1} \times \frac{(n-1)(1-P_F)}{n} \times \frac{P_T}{n-1} = \frac{P_T(1-P_F)^2}{n+1}$$

$$\cdots$$

The destroyed probability that the target is diecovered and identified after the enemy discovers n targets and the target is not identified as decoy is:

$$\frac{n(1-P_F)}{n+1} \times \frac{(n-1)(1-P_F)}{n} \times \frac{(n-2)(1-P_F)}{n\text{-}1} \times \cdots \times \frac{1-P_F}{2} \times P_T = \frac{P_T(1-P_F)^n}{n+1}$$

The destroyed probability of the target:

$$\begin{aligned} P_T' &= \frac{P_T}{n+1} + \frac{P_T(1-P_F)}{n+1} + \frac{P_T(1-P_F)}{n+1} + \cdots + \frac{P_T(1-P_F)^n}{n+1} \\ &= \frac{P_T}{n+1}\left((1-P_F)^0 + (1-P_F)^1 + (1-P_F)^2 + \cdots + (1-P_F)^n\right) \\ &= \frac{P_T}{n+1} \times \frac{1-(1-P_F)^{n+1}}{P_F} \\ &= \frac{1-(1-kP_T)^{n+1}}{k(n+1)} \end{aligned}$$

The survival probability of the target:

$$P'_{TS}(n) = 1 - \frac{1-(1-k\times P_T)^{n+1}}{k\times(n+1)}$$

The benefits generated by configuring n decoys are:

$$E(n) = \left(P'_{TS}(n) - P_{TS}\right)\times V_T$$

3.3. Calculation of Consumption Costs

The probability that the configured decoy will be destroyed P_F is:

$$P'_F = 1-(1-P_T)\times(1-k\times P_T)^n - P'_T$$

The cost for each decoy V_F is:

$$V_F = V_F \times P'_T$$

3.4. Model Establishment

$$\eta = \frac{E}{C} = \frac{\left(P_T - \frac{1-(1-P_F)^{n+1}}{k\times(n+1)}\right)\times V_T}{n\times V_F\times P'_T}$$

4. Model Solution and Data Validation

4.1. Model Solution

Assuming the probability of a target is identified and destroyed is P_T = 20%, the cost is V_T = 6 million, the ratio of the destroyed probability of decoy to the destroyed probability of target is $k = 1.5$, and the cost is V_F = 200000. The corresponding relationship table and curve graph between the cost-effectiveness ratio η and the configuration quantity of decoy n obtained by substitution calculation are as follows Table 1 and Figure 1.

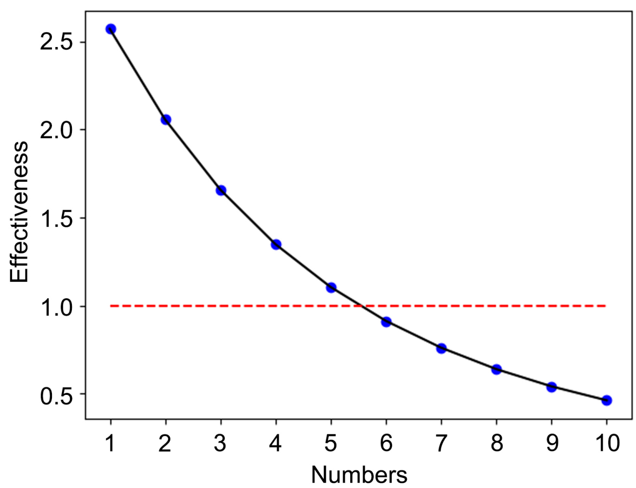

Figure 1. Graph of the relationship between cost-effectiveness ratio η and the configuration quantity of decoys n.

Table 1. The relation between the cost-effectiveness ratio η and the configuration quantity of decoys n

n	η	n	η
1	2.57	6	0.91
2	2.06	7	0.76
3	1.66	8	0.64
4	1.35	9	0.54
5	1.1	10	0.46

4.2. Data Analysis and Verification

According to the calculation results, when the configuration quantity of decoys is 6, the cost-effectiveness ratio is less than 1; that is, the generated benefits are less than the cost of consumption. At this time, we call 5 as the critical value of the configuration quantity of decoys n'. According to the calculation results of the cost-effectiveness ratio, the number of decoys should not be greater than 5, otherwise the gains will outweigh the losses.

For the data in the hypothesis, the probability of target being identified and destroyed is P_T = 20%, V_T = 6 million, the ratio of decoy' destroyed probability to target' destroyed probability is $k = 1.5$, and the cost is V_T = 6 million. Change a certain value one by one, keep other numerical variables unchanged, and analyze its impact on the critical value of the configuration quantity of decoys.

4.2.1. Impact of the Probability of Target Being Identified and Destroyed on the Critical Value of the Number of Decoys

Let P_T change within a reasonable range, V_T = 6 million, $k = 1.5$, V_F = 200000 remain unchanged, the relationship P_T with the critical value of the configuration quantity of decoys n' and its cost-effectiveness ratio η is shown in the Table 2 below.

Table 2. The relationship between P_T and n', η.

P_T	n'	η	P_T	n'	η	P_T	n'	η
12%	3	1.09	22%	5	1.13	32%	5	1.09
14%	4	1.09	24%	5	1.14	34%	5	1.07
16%	5	1.02	26%	5	1.14	36%	5	1.04
18%	5	1.07	28%	5	1.13	38%	5	1.01
20%	5	1.1	30%	5	1.12	40%	4	1.4

4.2.2. Impact of Target Value on the Critical Value of Decoy Allocation

Let V_T change within a reasonable range, P_T = 20%, $k = 1.5$, V_F = 200000 remain unchanged, the relationship V_T with the critical value of the configuration quantity of decoys n' and its cost-effectiveness ratio η is shown in the Table 3 below.

Table 3. The relationship between V_T and n', η.

V_T	n'	η	V_T	n'	η	V_T	n'	η
500	4	1.12	575	5	1.06	650	5	1.2
525	4	1.18	600	5	1.1	675	6	1.03
550	5	1.01	625	5	1.15	700	6	1.06

4.2.3. The Impact of the Ratio of True and Decoy Detection Probability on the Critical Value of the Number of Decoys

Let k change within a reasonable range, P_T = 20%, V_T = 6 million, V_F = 200000 remain unchanged, the relationship k with the critical value of the configuration quantity of decoys n' and its cost-effectiveness ratio η is shown in the Table 4 below.

Table 4. The relationship between k and n', η.

k	n'	η	k	n'	η	k	n'	η
1.2	6	1.09	1.5	5	1.1	1.8	4	1.2
1.3	6	1.03	1.6	5	1.05	1.9	4	1.15
1.4	5	1.16	1.7	4	1.25	2.0	4	1.11

4.2.4. Impact of Decoy Value on the Critical Value of Decoy Allocation Quantity

Let V_F change within a reasonable range, P_T = 20%, V_T = 6 million, $k = 1.5$ remain unchanged, the relationship V_F with the critical value of the configuration quantity of decoys n' and its cost-effectiveness ratio η is shown in the Table 5 below.

Table 5. The relationship between V_F and n', η.

V_F	n'	η	V_F	n'	η	V_F	n'	η
16	6	1.1	19	5	1.15	22	5	1.02
17	6	1.05	20	5	1.1	23	4	1.19
18	5	1.21	21	5	1.06	24	4	1.15

4.2.5. Statistical Analysis

Statistics are made on the appearing number of critical value of the configuration quantity of decoys n' in the data, as shown in the following Table 6.

Table 6. The appearing number of critical value of configuration quantity of decoys n'.

n'	number
3	1
4	10
5	25
6	6

5. Conclusion and Enlightenment

In this paper, by establishing the configuration quantity model of decoys based on cost-effectiveness ratio, mathematical methods and military operations research are used to solve the configuration quantity of decoys, and the data is verified. According to the calculation results, it can be seen that most of the critical value of the configuration quantity of decoys is 5, a few are 3, 4, 6.

According to the calculation results, when configuring decoys, the number should not be greater than 5, otherwise the gain will outweigh the loss. Considering time, manpower and other factors, it is suggested that the number of decoys should be 3 - 5. This calculation method is also applicable to a group of targets, which can be divided into multiple targets or regarded as a whole according to the distance between the targets.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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