Research on Mode Selection of Communications Countermeasure Reconnaissance Based on Uncertainty Decision-making

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Abstract. At present, mode selection of communications countermeasure reconnaissance is mainly determined by the method of “attempt to switch, optimize the effect”. In view of the method’s limitation, this dissertation puts forward four mode selections of communications countermeasure reconnaissance, which are abstracted as uncertainty decision-making, based on the mathematical method of decision theory. In various tactical situations, four optimal decision-making schemes are proposed in accordance to four criteria, including equal possibility criterion, max-min criterion, max-max criterion and regret value criterion. The results of calculation examples show that the approach is valid, and provides the optimal decisions under different tactical backgrounds.

1. Introduction
At present, while implementing electronic countermeasure reconnaissance on tactical radio communications, the optimal reconnaissance mode is obtained by constantly switching the optional reconnaissance modes, including CW(continuous wave), MCW(modulated continuous wave), USB, LSB and FM (frequency modulation), according to the effect of signal interception and demodulation. However, tactical radio communications has high transmission rate and timeliness, thereby restricting the application effect of common reconnaissance modes switch-over.

From the perspective of decision theory, mode selection of communications countermeasure reconnaissance is abstracted as uncertainty decision-making. Optimal decision-making schemes are put forward respectively according to equal possibility criterion, max-min criterion, max-max criterion and regret value criterion. The research provides the scientific method for commanders’ optimal decision under different tactical backgrounds.

2. Description of mode selection of communications countermeasure reconnaissance
Assuming that our electronic countermeasure troops need to implement communications countermeasure reconnaissance on tactical forward area, there are three possible types of communications signals: \( \Theta_1, \Theta_2, \Theta_3 \) and four optional reconnaissance modes for reconnaissance station: \( A_1, A_2, A_3, A_4 \). Operational staff figures out the probability of detecting three types of communications signals through four reconnaissance modes, which is shown in Table 1. In order to maximize the probability of signal detection, what decision should the commander make?
Table 1. detecting probability of communications signals through different reconnaissance modes

| signal type | detecting probability |
|-------------|----------------------|
|             | \( \theta_1 \) | \( \theta_2 \) | \( \theta_3 \) |
| \( A_1 \)   | 0.9 | 0.4 | 0.1 |
| \( A_2 \)   | 0.7 | 0.5 | 0.4 |
| \( A_3 \)   | 0.8 | 0.7 | 0.2 |
| \( A_4 \)   | 0.5 | 0.5 | 0.5 |

3. Description of uncertainty decision-making

There is a common problem in the operational command. In the face of different natural states and possibly optional schemes, decision-maker needs to select and implement one optimal scheme. The process of making decision is shown in Table 2.

Table 2. In the face of different natural states and possibly optional schemes

| state benefit and loss scheme | \( \theta_1 \) | \( \theta_2 \) | \( \theta_3 \) | \( \theta_n \) |
|------------------------------|---------------|---------------|---------------|---------------|
| \( A_1 \)                   | a_{11}        | a_{12}        | \( \ldots \)  | a_{1n}        |
| \( A_2 \)                   | a_{21}        | a_{22}        | \( \ldots \)  | a_{2n}        |
| \( \ldots \)                |               |               | \( \ldots \)  |               |
| \( A_m \)                   | a_{m1}        | a_{m2}        | \( \ldots \)  | a_{mn}        |

In the above table, states are the centralized natural states or objective conditions that the decision-maker is faced with, and they are beyond human’s mind as uncontrollable factors. States are represented by \( \theta_1 \), \( \theta_2 \), \( \ldots \), \( \theta_n \), and the probabilities of states’ occurrence are represented by \( P(\theta_1) \), \( P(\theta_2) \), \( \ldots \), \( P(\theta_n) \). Schemes refer to different action plans that the decision-maker possibly adopts, and they are freely chosen by decision-maker as controllable factors. Schemes are represented by \( A_1 \), \( A_2 \), \( \ldots \), \( A_m \). Benefit and loss \( a_{ij} \) is generated as follows. Assuming that the decision-maker selects scheme \( A_i \), when one natural state \( \theta_j \) occurs, some benefit is obtained or some loss is caused, which is measured by \( a_{ij} \).

Decision-maker does not know which type of natural state \( \theta_j \) is inevitable. If the probability \( P(\theta_j) \) of each type of natural state can be estimated in advance, the decision made in this case is called risky decision; while if the probability can not be estimated, the decision is taken as uncertainty decision.

For uncertainty decision-making, there are four models and solutions in accordance to equal possibility criterion, max-min criterion, max-max criterion and regret value criterion.
4. Model and solution based on uncertainty decision-making

4.1 Equal possibility criterion

According to equal possibility criterion, since the occurrence probability of each natural state is uncertain, all natural states’ occurrence probability should be seen as equal. If there are \( n \) states, the occurrence probability of each natural state is \( \frac{1}{n} \). Then decision is made according to the method of expected value or matrix of risky decision.

\[
P(\theta_i) = P(\theta_2) = P(\theta_3) = \frac{1}{3}
\]

\[
E(A_1) = \frac{1}{3}(0.9 + 0.4 + 0.1) = 0.47; \quad E(A_2) = \frac{1}{3}(0.7 + 0.5 + 0.4) = 0.53
\]

\[
E(A_3) = \frac{1}{3}(0.8 + 0.7 + 0.2) = 0.57; \quad E(A_4) = \frac{1}{3}(0.5 + 0.5 + 0.5) = 0.5
\]

Hence, the optimal decision-making based on equal possibility is scheme \( A_3 \). This method applies to the following situations. ① Decision-maker is totally uncertain about the occurrence probability of coming states. ② Decision-maker has unbiased personality.

4.2 Max-min criterion

According to max-min criterion, decision-maker holds a pessimistic and conservative attitude towards objective situation. The optimal scheme is found from the worst situation.

If scheme \( A_1 \) is adopted, detection probability 0.1 is the worst situation.

If scheme \( A_2 \) is adopted, detection probability 0.4 is the worst situation.

If scheme \( A_3 \) is adopted, detection probability 0.2 is the worst situation.

If scheme \( A_4 \) is adopted, detection probability 0.5 is the worst situation.

Hence, the optimal decision-maker based on max-min criterion is scheme \( A_4 \). This method applies to the following situations. ① Decision-maker is unsure about coming states. ② Decision-maker can not undertake the responsibility of the loss that wrong decision brings, since decision-making is a decisive factor of a battle. ③ Decision-maker has conservative and prudent personalities.

4.3 Max-max criterion

According to max-max criterion, decision-maker holds an optimistic attitude towards objective states, believing the optimal natural state will occur. Assuming that the decision objective is to maximize the benefit, the procedure of selecting optimal decision based on max-max criterion is as follows.

① The maximal element of each row in benefit matrix is obtained.

② The maximal value of the above maximal element is obtained.

③ The scheme corresponding to the above maximal value is the optimal decision.

\[
\max_j a_{ij} = 0.9; \quad \max_j a_{2j} = 0.7
\]

\[
\max_j a_{3j} = 0.8; \quad \max_j a_{4j} = 0.5
\]

Hence, the optimal decision-maker based on max-max criterion is scheme \( A_1 \). This method applies to the following situations. ① The objective situations are favorable. ② Decision-maker can undertake the responsibility of the loss that wrong decision brings. ③ Decision-maker has adventurous spirit.
4.4 Regret value criterion

According to regret value criterion, after decision-maker selects one scheme, he must feel regretful if the result is unsatisfactory. When the decision objective is to maximize the benefit, the benefit’s maximal value in each natural state (that is the maximal value of each row in benefit matrix) is taken as the ideal objective of the state. When the decision objective is to minimize the risk, the loss’ minimal value in each natural state (that is the minimal value of each row in risky matrix) is taken as the ideal objective of the state.

The absolute value of the difference between other values and ideal value in each state is called regret value. Then we obtain regret matrix from benefit and loss matrix. The selection of the optimal decision is the process of first obtaining the maximal regret value of each scheme (that is the maximal element of each row in regret matrix) and then obtaining the scheme which minimizes the maximal regret value, as the optimal decision. In a word, decision-making based on regret value criterion means selecting the scheme that makes decision-maker regret least.

The procedure of the optimal decision based on regret value criterion is as follows:

1. Regret matrix is obtained. \( R = [r_{ij}]_{m \times n} \)

   When the decision objective is to maximize the benefit,
   \( r_{ij} = \max_k a_{ij} - a_{ij} \)

   When the decision objective is to minimize the risk,
   \( r_{ij} = a_{ij} - \max_k a_{ij} \)

2. The maximal element of each row of \( R \) is obtained.
3. The minimal value of the above \( m \) maximal elements is obtained.
4. The scheme corresponding to the above minimal value is the optimal decision.

| Benefit Matrix | Regret Value Matrix |
|----------------|---------------------|
| \[ \begin{array}{ccc}
0.9 & 0.4 & 0.1 \\
0.7 & 0.5 & 0.4 \\
0.8 & 0.7 & 0.2 \\
0.5 & 0.5 & 0.5 \\
\end{array} \] | \[ \begin{array}{ccc}
0.3 & 0.4 & \\
0.2 & 0.2 & 0.1 \\
0.1 & 0.3 & \\
0.4 & 0.2 & 0 \\
\end{array} \] |

In scheme \( A_1 \), the maximal value regret value is 0.4;
In scheme \( A_2 \), the maximal value regret value is 0.2;
In scheme \( A_3 \), the maximal value regret value is 0.3;
In scheme \( A_4 \), the maximal value regret value is 0.4;

Hence, the optimal decision-maker based on regret value criterion is scheme \( A_2 \). This method applies to the situation that decision-maker does not want to regret too much for the result.

5. Conclusion

This paper puts forward four optimal decision-making schemes in accordance to equal possibility, max-min criterion, max-max criterion and regret value criterion. Which is the best optimal decision-making scheme? It depends on decision-maker’s choice based on battlefield situations and decision-maker’s personality and preference. In a word, operational command is both a science and an art.
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