Research on Operational Effectiveness Evaluation Model of Shipborne Tracking Radar

Hong-yan SHAN\textsuperscript{1,2,*}, Jun ZHANG\textsuperscript{2} and Xu-wen SUN\textsuperscript{2}

\textsuperscript{1}College of mechanical engineering, Dalian Jiaotong University, Dalian, 116028, China
\textsuperscript{2}Dalian Naval Academy, Dalian, 116018, China

*Corresponding author

Keywords: Tracking radar, WSEIA model, Operational effectiveness evaluation.

Abstract. Based on the operational effectiveness model of shipborne tracking radar, the main impact indices of the system operational effectiveness are analyzed. Through modeling and analysis of system availability vector, dependability matrix and capacity vector, the expression of each factor in system operational effectiveness model is determined, and the calculation formula of the operational effectiveness evaluation of the shipborne tracking radar is obtained.

Introduction

Weapon system operational effectiveness is defined as general comprehensive effectiveness that is achieved by operational people who use weapons system to carry out operational task in accordance with a certain operational action plan under the stated conditions, or results that will be obtained or have been obtained by using weapons system, the same task requires that the results which is obtained or obtained must be in line with the degree of measurement. At present, shipborne tracking radar range test still assesses mainly the tactical performance and tactical performance. From the aspect of efficiency, it’s only a reflection of the signal performance of tracking radar, but not a comprehensive ability study of signal performances under the same conditions. Even the analysis and evaluation of the operational efficiency, also cannot be measured or predicted tracking radar ability when completing a given task. With the development of weapons and equipment, range test ability should be developed from the basic performance evaluation to the high quality effectiveness evaluation.

Operational Effectiveness Evaluation of Shipboard Tracking Radar

The operational effectiveness evaluation of shipboard tracking radar is generally divided into four steps: the establishment of operational effectiveness evaluation model, experiment statistics, effectiveness index calculation and effectiveness evaluation.

Establish System Operational Effectiveness Evaluation Model

Shipborne tracking radar that completes the prescribed combat missions and plays the full role, is mainly related with the following factors: combat service state, tracking capability, anti-interference ability and tactical application. Combat service state is associated with mean time between failures (MTBF) and the mean time of repair failure (MTTR). Tracking capability is associated with operating distance, tracking accuracy, tracking smoothness and anti-interference performance. At present, the most commonly used model is effectiveness model which is established by advisory committee of weapon system efficiency in the United States industry, is also known as model:

\[ E = A \cdot D \cdot C \]  \hfill (1)

In the above formula, \( A \) is availability, that is, the probability of coming into use or regular working in any stochastic time; \( D \) is dependability, that is, the probability of that system is in the
normal state or complete required functions under the given initial conditions; \( C \) is capacity, that is, the probability of completing operational mission under the given mission state.

The efficiency model used in this paper is \( ADC \) model. In this framework, we establish tracking radar Operational effectiveness evaluation model, which is shown as Figure 1.

In this model, we divide the tracking radar index into four levels:

The first level is the basic index, such as photoelectric axis consistency, moving target improvement factor, indemnificatory and other index. Completing the inspection and testing of these indices, we can master the basic technical state and working status of tracking radar, so that we understand that the equipment status is stable and normal or not, it can work properly or not, so as to prepare for the next step.

The second level is the single index, such as the maintainability, reliability, operating distance and other index; these are important performance indices of tracking radar. We can understand that the performance of each index is met the demand or not by experiment and evaluation of these indicators and making objective judgment, so as to provide reliable data for the efficiency indicator calculation of the next step.

The third level is the efficiency attribute index, which is the availability, dependability and tracking ability. Completing calculation of the three performance indices, we can carry out a total operational effectiveness assessment of tracking radar.

The fourth level is the effectiveness, which is comprehensive capability index of tracking radar, generally described by probability of completing a specific mission.

From the above, we can see that indices of the first and second level, which consist of tactical and technical performance indices and tactical use of performance indices, are different sorts of tactical and technical performance indicators and tactical use of performance indicators in the effectiveness model. So the experiment and evaluation of tactical and technical performance and tactical use of performance of tracking radar are the basis of tracking radar system effectiveness evaluation. It should be noted that operational effectiveness evaluation model of tracking radar has not yet established a general standard model, and there may be a large change in the refinement of the capability index. The tracking radar operational effectiveness model in this paper is only a preliminary idea.

**Experiment Statistics**

Experiment statistics is inspection and testing of the first level basic index and experiment and evaluation of the second level single index. The experiment statistics are identical to tactical and technical performance and tactical use of performance of tracking radar, but the purpose of the experiment statistics is to provide reliable data for the next step that is effectiveness index calculation.
Effectiveness Index Calculation

On the basis of the experiment and evaluation of tactical and technical performance and tactical use of performance, the analysis and evaluation of the integrated capability of the shipborne tracking radar can be carried out, that is, the evaluation of the operational effectiveness of the tracking radar is carried out.

The probability of completing the specific task of tracking radar is the most important performance index. For most weapons systems, the system performance generally refers to the probability of completing the specific task of the system, that is, \( E \) is a single value. Its expression is:

\[
E = A \cdot D \cdot C = [a_1, a_2, \cdots, a_n] \cdot \begin{bmatrix}
d_{11} & d_{12} & \cdots & d_{1n} \\
d_{21} & d_{22} & \cdots & d_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
d_{n1} & d_{n2} & \cdots & d_{nn}
\end{bmatrix} \cdot \begin{bmatrix}
c_1 \\
c_2 \\
\vdots \\
c_n
\end{bmatrix}
\]

(2)

(1) Availability \( (A) \)

Availability vector is the line vector \([a_1, a_2, \cdots, a_n]\), \(a_i\) is the probability that the system is in the \(i\)-state when starting to carry out the task. Tracking radar may be in the different states when starting to carry out the task. In this paper, consider two of the most significant states, that is, the normal working state (recorded as 1) and the out-of-order state (recorded as 2) two cases, then

\[
A = [a_1, a_2]
\]

In the above formula, \(a_1\) is the probability that the system is in the normal working state when system begins to carry out the task (that is availability); \(a_2\) is the probability that the system is in the out-of-order state when system begins to carry out the task (that is unavailability).

According to the reliability theory, then

\[
a_1 = \text{MTBF} / (\text{MTBF} + \text{MTTR})
\]

(3)

\[
a_2 = \text{MTTR} / (\text{MTBF} + \text{MTTR})
\]

(4)

In the above formula, \(\text{MTBF}\) is mean time between failures of the system; \(\text{MTTR}\) is the mean time of repair failure of the system.

(2) Dependability \( (D) \)

Dependability matrix is

\[
D = \begin{bmatrix}
d_{11} & d_{12} & \cdots & d_{1n} \\
d_{21} & d_{22} & \cdots & d_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
d_{n1} & d_{n2} & \cdots & d_{nn}
\end{bmatrix}
\]

(5)

In the above formula, \(d_{ij}\) is the probability that the system was in the \(i\)-state when starting to carry out the task and transferred to the \(j\)-state in the process of executing the task. If the system in the process of executing the task is divided into only two cases: normal working state (recorded as 1) and the out-of-order state (recorded as 2), then

\[
D = \begin{bmatrix}
d_{11} & d_{12} \\
d_{21} & d_{22}
\end{bmatrix}
\]

(6)

In the above formula, \(d_{11}\) is the probability that the system was in normal working state when starting to carry out the task and was still in normal working state in the process of executing the task;
\( d_{12} \) is the probability that the system was in normal working state when starting to carry out the task and broke down in the process of executing the task; \( d_{21} \) is the probability that the system was in out-of-order state while was in normal working state in the process of executing the task; \( d_{22} \) is the probability that the system was in out-of-order state when starting to carry out the task and was still in out-of-order state in the process of executing the task.

It is assumed that both the failure and the repairing of the system obey the exponential law. In the process of executing the task, \( \bar{T} \) is the system time, \( \lambda \) is the system failure rate, \( \mu \) is the system failure repair rate, then, the dependability matrix of the radar tracking target is

\[
D_{2} = \begin{bmatrix}
e^{-\lambda T} & 1 - e^{-\lambda T} \\
1 - e^{-\mu T} & e^{-\mu T}
\end{bmatrix}
\]

(7)

(3) Capacity \((C)\)

Capacity vector is a column vector \( C = [c_1, c_2, \ldots, c_n] \), \( c_j \) is the probability that weapon system completes a specific task in the \( J \)-state. If the system in the process of executing the task is divided into only two cases: success (recorded as 1) and failure (recorded as 2), then

\[
C = [c_1, c_2]
\]

(8)

In the above formula, \( c_1 \) is the probability that system completes a specific task in normal working state; \( c_2 \) is the probability that system completes a specific task in out-of-order state.

System capacity vector of tracking target is \( \bar{C} = [c_1, c_2] \). System capacity formula in the normal state is \( c_1 = E_{AJ} \cdot P_T \). In the formula, \( P_T \) is the probability that system accurately tracks the target, \( E_{AJ} \) is anti-jamming effectiveness of system, that is,

\[
E_{AJ} = \frac{\Delta P \Delta G}{\Delta P_j \Delta G_j} \cdot \frac{\Delta R_j}{\Delta R} \cdot \frac{\Delta \Omega}{\Delta B} \cdot K_{AJ}
\]

(9)

In the above formula, \( \Delta P \Delta G \), \( \Delta B \), \( \Delta R \) is the power gain product of the tracking radar, the equivalent bandwidth of the radar receiver and the radar detection distance without interference respectively. \( \Delta P_j \Delta G_j \), \( \Delta \Omega \), \( \Delta R_j \) is the power gain product of anti-jamming system, frequency bands of jammer and the radar detection distance under interfered respectively. \( K_{AJ} \) is anti-jamming effect factor of the system, it is necessary to evaluate and confirm the specific expression according to the different tactical application. Under fault condition, \( c_2 = 0 \).

**System Effectiveness Evaluation**

By the WSEIAC model, it can be known that the operational efficiency of the shipborne tracking radar in the specified working time \( \bar{T} \) is:

\[
E = A \cdot D(2) \cdot C = (a_1, a_2) \cdot \begin{bmatrix}
e^{-\lambda T} & 1 - e^{-\lambda T} \\
1 - e^{-\mu T} & e^{-\mu T}
\end{bmatrix} \cdot \begin{bmatrix}
c_1 \\
c_2
\end{bmatrix}
\]

\[
= [a_1 e^{-\lambda T} + a_2 (1 - e^{-\lambda T})] \cdot C = [a_1 e^{-\lambda T} + a_2 (1 - e^{-\mu T})] \cdot E_{AJ} \cdot P_T
\]

(10)
Concluding Remarks

In this paper, the operational effectiveness evaluation model of the shipborne tracking radar is discussed from the view of experiment evaluation. The parameters of the model not only consider the technical performance of the tracking radar itself, but also contain the tactical performance in the process of tactical application. The parameters can be obtained by repeated experiments, which is beneficial to practical application. But at the beginning of the experiment, we must first set up a typical combat experiment environment. Setting different test environment, operational effectiveness evaluation results will be different. So the parameters obtained by the experiment are the results under a certain operational experiment conditions. According to design different typical operational experiment environment, we can obtain different operational effectiveness evaluation results. The results of comprehensive analysis can be used to evaluate the integrated operational effectiveness of the tested radar.

References


