

Research Article

Index Predigesting Method of ELINT System Based on MIBARK Algorithm

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The effectiveness evaluation of the Electronic Information (ELINT) system, which plays an important role in guiding the theoretical research, equipment development, and practical application, is the key technology of the ELINT system. In practical applications, the effectiveness evaluation of ELINT system is mainly aimed at evaluation methods. However, the establishment of evaluation criteria and the construction of the index system are still two main challenges in this field, especially the optimization of the evaluation index system. In this paper, we aim at establishing the ELINT system index evaluation criteria and optimizing the ELINT system evaluation index system. Based on the principle structure of the ELINT system, we directly construct the original efficiency index system, establish specific evaluation criteria for each index, and quantify the indexes using the criteria. To optimize the proposed index system, we introduce the idea of rough set reduction and develop an index system reduction model based on the mutual information heuristic knowledge reduction (MIBARK) algorithm. Simulation analysis shows that the proposed evaluation criteria quantify each index scientifically, and the established indicator reduction model can eliminate the redundancy of the ELINT efficiency indicator system, making the indicator system more streamlined and reasonable.

1. Introduction

With the increasing complexity of modern electronic warfare, the role of electronic intelligence has become more and more obvious. The ELINT system is an important combat equipment for acquiring electronic intelligence on the battlefield, and the evaluation of its overall combat effectiveness is one of the important issues currently faced [1].

ELINT system effectiveness evaluation is a process of multi-index comprehensive evaluation, which mainly involves the construction of the index system, the establishment of evaluation criteria, and the selection of evaluation algorithms [2–6]. The current algorithm research for multi-index system evaluation is relatively extensive, from basic ADC method [7], analytic hierarchy process [8], SEA method [9], and grey relational analysis method [10] to widely used neural network algorithm [11, 12], which has a relatively mature theoretical system. However, the research and development of the effectiveness evaluation index of ELINT system are very slow. On the one hand, there is a lack

of unified evaluation criteria to analyze, evaluate, and measure indicators. In [13, 14], the authors put forward evaluation criteria for radar jamming effects, but they are not suitable for ELINT systems. On the other hand, the research on the efficiency index system is relatively scarce. The electronic equipment efficiency index system, which is constructed in the traditional method, lacks objectivity and comprehensiveness [15, 16]. It is only constructed based on expert experience, without the reasonable analysis of complexity and redundancy of the index system. In addition, in terms of algorithm optimization, [17–19] proposed an optimal solution based on the ant colony optimization (MSICEAO) algorithm and an improved quantum evolutionary algorithm; these algorithms can find the optimal solution but the computational complexity is relatively high.

Thus, this article establishes the ELINT system evaluation criteria and develops an innovative method to optimize the ELINT system index system. First of all, based on the actual application requirements of the ELINT system, a more comprehensive indicator system is constructed, and the

corresponding evaluation criteria for each indicator are established. Then, the rough set attribute reduction theory is introduced, and a reduction model of ELINT index system based on MIBARK algorithm is constructed. By calculating the mutual information of the indicators, the indicators with greater relevance and redundancy are eliminated, and the optimization of the ELINT system indicator system is realized. The new method makes the ELINT system effectiveness evaluation research more comprehensive and objective.

2. Data and Methods

2.1. Data Sources. In the evaluation, a fixed test condition is set using the battlefield environment, and then combined with the evaluation criteria of each index, the test data corresponding to each index of the 5 systems under test are collected, and the index sample value is obtained after normalization. Experts score the interception performance, parameter measurement performance, signal processing performance, intelligent processing performance, and system performance of the system under test based on the data.

2.2. Rough Set Attribute Reduction Theory

2.2.1. Basic Theory. Rough set attribute reduction theory is a mathematical tool for dealing with fuzzy and uncertain knowledge. It is to obtain systematic classification rules through knowledge reduction under the condition that the system classification ability remains unchanged, and based on mutual information, heuristic knowledge reduction (MIBARK) algorithm is a commonly used attribute reduction algorithm. The theory can dig out decision rules from a large amount of data without any prior information and external information, reveal the relationship between attributes, and delete redundant attributes. All conclusions come from the data itself [20].

Definition 1. Let $K = (U, R)$ be a knowledge base. On the nonempty finite domain U , R is the set of equivalence relations, and the family of all equivalence relations defined in K is denoted as $\text{Ind}(K)$. Let P be a family of equivalence relations, $P \in R$. For $p \in P$, if $\text{Ind}(P) \neq \text{Ind}(P - \{p\})$, then p is necessary in P . If every p is necessary in P , then P is independent. The reduction set composed of necessary relations in P is called the core of P , denoted as $\text{core}(P)$. In addition, if $Q \subseteq P$, if Q is independent, and $\text{Ind}(Q) = \text{Ind}(P)$, then Q is called a reduction of P .

Definition 2. For an information system S , $S = (U, R = C \cup D \cup V, f)$, where $U = \{x_1, x_2, \dots, x_n\}$ represents a nonempty finite set of objects, also known as the universe of discourse; the attribute set is $R = C \cup D$, $C \cap D = \emptyset$. Among them, C is the conditional attribute set, D is the decision attribute set; V is the attribute value range; and $f: U \cdot C \cup D \rightarrow V$ is an information function. Then the information system S is the decision information system, denoted as follows.

Definition 3. Information system $S = (U, R)$; P and Q are equivalent relations in U . The positive domain of P of Q is denoted as $\text{pos}_P(Q)$, that is, all the objects in U that can be accurately classified into the equivalence class of the relationship Q according to the information of the classification U/P . Let $A \subseteq P$, A be the Q reduction of P if and only if A is an independent subfamily of Q of P and $\text{pos}_A(Q) = \text{pos}_P(Q)$; the Q reduction of P is called relative reduction for short. The set of all necessary primitive relations of Q in P is called the core of Q of P , referred to as the relative core, and denoted as $\text{core}_Q(P)$.

Definition 4. The division of conditional attribute set C on U is $X: X = \{X_1, X_2, \dots, X_r\}$; $|X_i|$ and $|U|$ are the cardinality of the set, and its information entropy $H(C)$ is defined as

$$H(C) = - \sum_{i=1}^n \frac{|X_i|}{|U|} \log_2 \frac{|X_i|}{|U|}. \quad (1)$$

Definition 5. The division of decision attribute set D on U is $Y: Y = \{Y_1, Y_2, \dots, Y_r\}$; then a conditional entropy of condition attribute set C relative to decision attribute set D is defined as

$$H\left(\frac{D}{C}\right) = - \sum_{i=1}^n \frac{|X_i|}{|U|} \sum_{j=1}^r \frac{|X_i \cap Y_j|}{|X_i|} \log_2 \frac{|X_i \cap Y_j|}{|X_i|}. \quad (2)$$

Definition 6. The average mutual information of condition attribute set C and decision attribute set D on U is

$$E(X: Y) = H(X) - H\left(\frac{X}{Y}\right). \quad (3)$$

Definition 7. Information system S , $S = (U, R)$, $R \subseteq C$, after adding an attribute $a \in C$ to R , the mutual information increment is

$$\begin{aligned} \text{SGF}(a, R, D) &= E(R \cup \{a\}; D) - E(R; D) \\ &= H\left(\frac{D}{R}\right) - H\left(\frac{D}{R \cup \{a\}}\right). \end{aligned} \quad (4)$$

The larger the increment, the more important the attribute a is to the decision D under the condition that the attribute set R is known.

2.2.2. MIBARK Algorithm Principle. In rough set attribute reduction theory, attribute reduction mainly has two types: algebraic viewpoint and information theory viewpoint. Practice has proved that the reduction under the information viewpoint is more scientific and accurate than the reduction under the algebraic viewpoint [21]. This paper chooses the MIBARK algorithm in the information viewpoint to deal with the problem of conditional attribute redundancy in rough sets. The commonly used reduction

strategy is to find the relative reduction in a bottom-up manner. It starts from the relative core of the decision table. According to the importance of the attribute, the most important attributes are successively selected and added to the relative core until the termination condition is satisfied. The MIBARK algorithm reduction process is shown in Figure 1, and the specific steps are as follows [22]:

Input: a decision-making system S , $S = (U, R = C \cup D, V, f)$, where U is the universe of discourse, and C and D are conditions and decision attribute sets, respectively.

Output: a relative reduction of the decision table.

- (1) Calculate the average mutual information of condition attribute C and decision attribute D in decision table S : $E(C; D)$.
- (2) Calculate the core of C compared to $C_0 = \text{core}_d(C)$, generally $E(C_0; D) < E(C; D)$; sometimes $E(C_0; D) = 0$ the relative core C_0 is an empty set; at this time $E(C_0; D) = 0$.
- (3) Let $B = C_0$; repeat the condition attribute set $C - B$:
 - (1) For each attribute $p \in C - B$, calculate $\text{SGF}(p; C - B; D)$.
 - (2) Choose the attribute $\text{SGF}(p; C - B; D)$ that maximizes the mutual information increment, denoted as p , and $B \leftarrow B \cup \{p\}$.
 - (3) If $E(B; D) = E(C, D)$, terminate; otherwise, go to (1).
 - (4) The final B is a relative reduction of C relative to D .

2.3. The Reduction Method of ELINT System Efficiency Index Based on MIBARK Algorithm. The ELINT system mainly monitors and intercepts the electromagnetic signals of radiation sources in space, then measures, analyzes, and sorts the parameters of the intercepted signals, and finally completes the identification of targets, thereby providing intelligence support for operations [23]. The ELINT system efficiency index is the embodiment of the system's reconnaissance ability in different aspects. The reduction of ELINT system performance indicators based on the MIBARK algorithm mainly involves three aspects: establishing a system performance evaluation indicator system, combining evaluation criteria to quantify indicators, and using an algorithm to reduce the indicator system [24].

2.3.1. Index System. When constructing the ELINT system effectiveness evaluation index system, the selection of the index is generally determined in combination with the actual work of the system. In addition, when constructing the indicator system, in order to achieve systematic scientific evaluation, evaluation indicators must be selected according to the principles of systemicity, completeness, independence, scientificity, and feasibility [25, 26]. The performance of ELINT system is mainly composed of the performance of signal interception, parameter measurement, signal

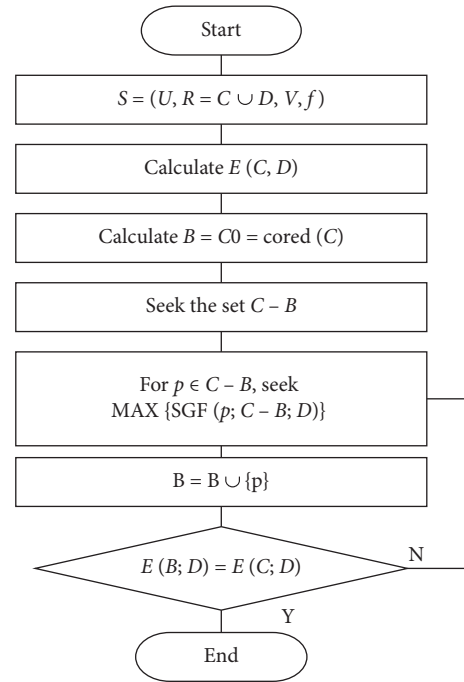


FIGURE 1: MIBARK algorithm reduction process.

processing, and intelligent processing. Therefore, the original performance index system is shown in Figure 2.

2.3.2. Evaluation Criteria. In order to better grasp the system capability in practical applications, the index needs to be quantified to obtain an intuitive system performance value. Evaluation criteria are the basis and methods for quantitative evaluation of indicators, and indicators of different natures are bound by corresponding evaluation criteria [27, 28]. The working principle of the ELINT system is complex, its effectiveness is comprehensively reflected by multiple indicators, and the evaluation criteria involved are also more complex.

(1) Performance Guidelines. For a complex system, its effectiveness is related to the real performance of the system on the one hand and closely related to the working environment on the other hand. Performance indicators are indicators determined by the design, principles, and hardware capabilities of the system and are generally not affected by the working environment. When evaluating the effectiveness of ELINT systems, system performance indicators are a part that must be considered. Therefore, a performance criterion is introduced to quantify the system's azimuth coverage, frequency coverage, dynamic range, instantaneous bandwidth, and system storage capacity according to the real performance value of the system.

(2) Parameter Guidelines. From the perspective of information, the working process of the ELINT system is actually the process of obtaining the signal information of the other party's radiation source. The system extracts and measures the radiation source information through the receiver to

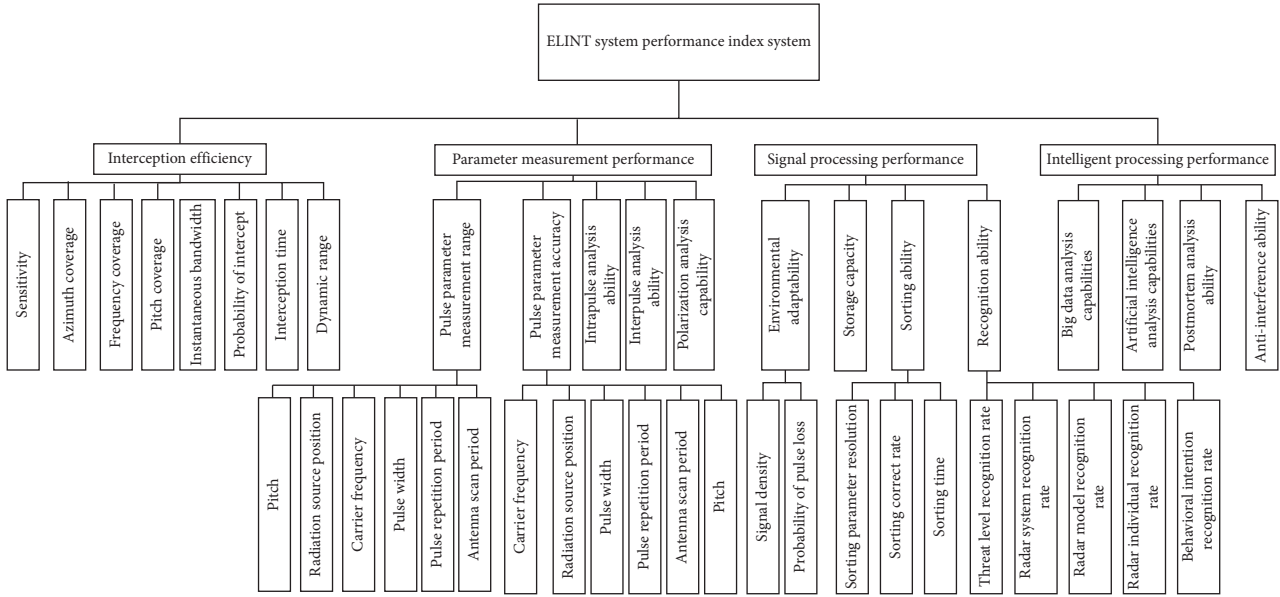


FIGURE 2: ELINT system original performance index system.

obtain various parameter values of the target. Therefore, the accuracy of the ELINT system to measure signal parameters reflects the system's parameter measurement capability [29]. For the ELINT system index system, the pulse parameter measurement accuracy, intrapulse characteristic analysis ability, interpulse characteristic analysis ability, polarization characteristic analysis ability, and resolution can all be quantified by referring to the parameter criterion and can be measured by comparing the ELINT system. The difference between the signal parameter value and the real signal is to determine the indicator value.

(3) *Sensitivity Criterion.* The essence of electronic warfare is a contest in the energy domain. For the ELINT system, sensitivity is an index that measures the efficiency of the system's energy domain. Only when the signal power of the radiation source is higher than the sensitivity of the ELINT system, that is, $P_r = P_t G_t G_r \lambda^2 / (4\pi R)^2 \geq P_{r, \min}$, can the radiation source signal be intercepted by the system [30]. Therefore, the sensitivity criterion is a criterion that must be followed to effectively evaluate the energy domain of the system.

(4) *Efficiency Criterion.* The efficiency criterion is also called the tactical application criterion, or the probability criterion, which refers to the ability of the ELINT system to complete combat tasks under certain conditions to evaluate the effectiveness of the system [31]. For the ELINT system, many of its indicators are measured under certain signal conditions, such as probability of interception, environmental adaptability, sorting ability, and recognition ability.

(5) *Competence Criteria.* With the continuous development of radar systems, traditional ELINT systems have gradually become functionally difficult to adapt to the challenges of complex radar systems. In order to improve the combat

effectiveness of the ELINT system, many emerging technologies have been continuously applied to the ELINT tradition, which has greatly improved the effectiveness of the system. However, because the current effects are difficult to concretize, this paper introduces ability criteria to quantify the indicators. The ability criterion is based on the principle of 0 and 1. It only distinguishes whether or not the ability is available and does not specifically quantify the size of the ability. The intelligent processing efficiency of the ELINT system can be quantified using this criterion, and the capability criterion solves the problem of some emerging indicators that are difficult to quantify and compare to a certain extent.

(6) *Time Criterion.* Under certain conditions, it takes a certain amount of time for each link of the weapon system to complete any task. The ELINT system needs time to intercept signals, parameter measurement, and signal processing. The completion time can intuitively reflect the pros and cons of the system. For the ELINT system, both the interception time and the sorting time can be quantified and analyzed using the time criterion, which is an intuitive and effective evaluation criterion for system capabilities.

2.3.3. *ELINT System Index Reduction Process Based on MIBARK Algorithm.* The ELINT system index system is reduced based on the MIBARK algorithm. First, the indicators that need to be collected are defined according to the established index system; then the indicators to be measured are quantified according to the evaluation criteria of the indicators; finally, the indicator system is optimized with the MIBARK algorithm to remove redundancy and related indicators, keep key indicators, and get an optimized indicator system. The specific process is shown in Figure 3.

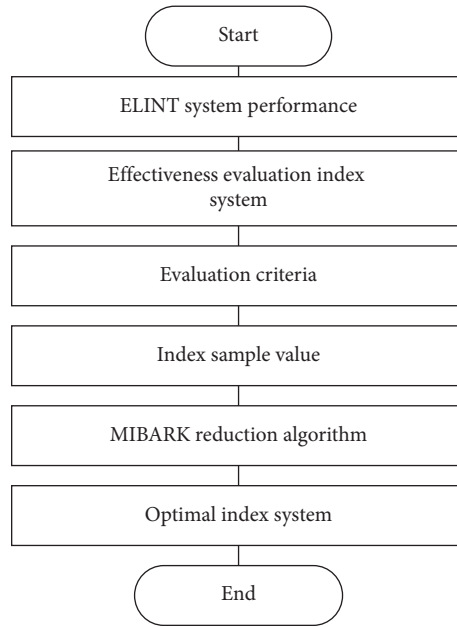


FIGURE 3: Index system reduction process.

3. Results and Discussion

For the ELINT system, the decision information system $S = (U, R = C \cup D, V, f)$, U is the system under test $\{x_1, x_2, \dots, x_n\}$; the attribute set $R = C \cup D$, C is the system under test index set, where $\{c_{11}, c_{12}, \dots, c_{1n}\}$ is the bottom index of interception efficiency, $\{c_{21}, c_{22}, \dots, c_{2n}\}$ is the bottom index of parameter measurement efficiency, and $\{c_{31}, c_{32}, \dots, c_{3n}\}$ is the underlying indicator of signal processing performance, and $\{c_{41}, c_{42}, \dots, c_{4n}\}$ is the underlying indicator of intelligent processing performance. D is the performance decision set, where D_0 is the system performance level, D_1 is the interception performance level, and D_2 is the parameter measurement performance level. D_3 is the signal processing performance level; D_4 is the intelligent processing performance level; V is the performance value set, and the score is three points; the value set is $\{1, 2, 3\}$. The sample values of the system indicators to be tested are shown in Table 1.

3.1. Results. Combining with the principle of MIBARK algorithm, it can be known that ELINT system efficiency index system reduction generally obtains the optimal index system in the order of average mutual information, relative core, increment of each index information, and comparison analysis. Therefore, for the five aspects of interception efficiency, parameter measurement efficiency, signal processing efficiency, intelligent processing efficiency, and system efficiency, the average mutual information, relative core, and information increment of each index of the conditional attribute set to the decision attribute set are, respectively, obtained as shown in Tables 2 and 3; the reduced performance indicators are shown in Figure 4, and the reduced system performance indicator system is shown in Figure 5.

3.2. Discussion. Generally speaking, a decision system with zero conditional entropy $H(D/C)$ is a consistent decision system. The larger the average mutual information of the condition attribute set in the consistent decision-making system, the greater the amount of information provided by the condition attribute set to the decision attribute set, and the more obvious the role it plays in decision-making. It can be seen from Table 2 that the conditional entropy of each part of the efficiency index set relative to the decision attribute set is zero, so the ELINT system is a consistent decision system. Combining the average mutual information of each performance level index, we can know the following: parameter measurement performance = signal processing performance > intelligent processing performance = interception performance. Therefore, for the ELINT system, the parameter measurement performance and signal processing performance indicators have a greater impact on the system performance, and the interception performance and intelligent processing performance have a smaller impact on the system performance.

The greater the information increment of the indicator is, the more important the indicator is in the index set C to the decision attribute set D . By comparing the information increment of each indicator, the importance of each indicator in each efficiency layer and the overall effectiveness of the system can be obtained. It can be seen from Table 3 that for the interception efficiency, the three indicators of system interception probability, dynamic range, and instantaneous bandwidth play a significant role in evaluating interception efficiency. However, the information increment of the two indicators of azimuth coverage and interception time is relatively small, which does not play a significant role in the evaluation of interception effectiveness. Combining with the working principle of the ELINT system, we can see that the data characteristics of the indicator conform to the working

TABLE 1: Sample values of system indicators under test.

		X1	X2	X3	X4	X5	
System indicator set C	Interception performance index set	C11 sensitivity	0.2	0.3	0.3	0.2	0.2
		C12 frequency coverage	0.3	0.6	0.5	0.7	0.3
		C13 azimuth coverage	0.5	0.3	0.3	0.5	0.5
		C14 pitch coverage	0.7	0.1	0.2	0.7	0.7
		C15 dynamic range	0.5	0.5	0.5	0.5	0.5
		C16 instantaneous bandwidth	0.6	0.6	0.6	0.6	0.6
		C17 probability of interception	0.8	0.3	0.3	0.8	0.3
		C18 interception time	0.3	0.6	0.5	0.7	0.3
		C21 azimuth range	1.0	0.3	0.3	0.7	1.0
		C22 carrier frequency range	1.0	0.3	0.3	0.7	1.0
	C23 pitch range	1.0	0.3	0.3	0.7	1.0	
	C24 carrier frequency accuracy	1	0.4	0.4	1	0.4	
	C25 pulse width = range	1.0	0.4	0.4	1.0	1.0	
	C26 antenna scanning period range	0.8	1.0	0.3	0.8	0.8	
	C27 carrier frequency accuracy	0.5	0.3	0.3	0.5	0.5	
	C28 pitch accuracy	1.0	0.3	0.3	0.7	1.0	
	C29 radiation source azimuth accuracy	0.5	0.3	0.3	0.5	0.5	
	C210 pulse width accuracy	0.8	0.3	0.3	0.8	0.8	
	C211 pulse repetition period accuracy	1.0	0.4	0.4	1.0	1.0	
	C212 antenna scanning period accuracy	0.8	1.0	0.3	0.8	0.8	
	C213 intrapulse analysis ability	1.0	0.0	0.0	1.0	1.0	
	C214 interpulse analysis ability	1.0	1.0	1.0	1.0	1.0	
	C215 polarization analysis capability	1.0	1.0	1.0	1.0	1.0	
	C31 signal density	1	1	0.5	1	1	
	C32 pulse loss probability	1.0	0.3	0.2	0.3	1.0	
	C33 storage capacity	1	0.4	0.4	0.4	1	
	C34 sorting parameter resolution	0.8	1	0.3	1	0.8	
	C35 sorting correct rate	0.8	1	0.3	1	0.8	
	C36 sorting time	1	1	0.3	1	0.3	
	C37 threat level recognition rate	0.5	0.3	0.3	0.5	0.3	
	C38 model recognition rate	0.8	0.3	0.2	0.3	1.0	
	C39 system recognition rate	0.8	1	0.3	0.8	1	
	C310 individual recognition rate	1.0	0.3	0.3	0.7	1.0	
	C311 intention recognition rate	1	0	0	1	0	
	C41 intelligent analysis capability	1	0	1	1	1	
	C42 big data analysis capabilities	1	0	0	0	1	
	C43 postmortem analysis ability	1	0	0	1	1	
	C44 anti-interference ability	1	1	1	1	0	
	Effectiveness decision set D	D1 interception performance level	2	2	1	2	2
		D2 parameter measurement performance level	3	1	2	2	3
		D3 signal processing performance level	3	1	1	2	3
		D4 intelligent processing performance level	3	1	2	3	1
		D0 system performance level	3	1	1	2	3

principle of the system, so the result is reasonable; For all other performance levels, the importance of indicators can be analyzed equally. Finally, comparing each index compared to the information increment of each efficiency layer and the information increment of each index compared to the system efficiency, the changes of each index are not obvious, indicating that this method can effectively measure the performance of different indicators in the system effectiveness evaluation process.

By comparing Figures 2–4, it can be seen that the interception time, pitch coverage, pitch measurement accuracy, pulse loss probability, sorting parameter resolution, sorting accuracy, and big data analysis capabilities are completely redundant indicators. Regardless of whether each performance layer is reduced individually or the system performance is reduced, these redundant indicators will be reduced.

In addition, by comparing the index system after reduction of each performance layer and the index system after

TABLE 2: Mutual information and relative check value of each performance index.

	$D1$	$D2$	$D3$	$D4$	$D0$
H (D/C)	0	0	0	0	0
E (C; D)	1.92	2.32	2.32	1.92	2.32
Cored (C)	\emptyset	\emptyset	\emptyset	\emptyset	\emptyset

TABLE 3: Indicator information increment.

	SGF				
	$D1$	$D2$	$D3$	$D4$	$D0$
C11 sensitivity	0.4				0.6
C12 frequency coverage	0.0				0.0
C13 azimuth coverage	0.4				0.6
C14 pitch coverage	0.0				0.6
C15 dynamic range	0.7				1.5
C16 instantaneous bandwidth	0.7				1.5
C17 probability of interception	0.6				1.0
C18 interception time	0.0				0.0
C21 azimuth range		0.4			0.0
C22 carrier frequency range		0.4			0.0
C23 pitch range		0.4			0.0
C24 carrier frequency accuracy		1.4			1.0
C25 pulse width = range		1.0			0.6
C26 antenna scanning period range		0.6			0.6
C27 carrier frequency accuracy		1.0			0.6
C28 pitch accuracy		0.4			0.0
C29 radiation source azimuth accuracy		1.0			0.6
C210 pulse width accuracy		0.6			0.6
C211 pulse repetition period accuracy		1.0			0.6
C212 antenna scanning period accuracy		0.6			0.6
C213 intrapulse analysis ability		1.0			0.6
C214 interpulse analysis ability		1.5			1.5
C215 polarization analysis capability		1.5			1.5
C31 signal density			1.2		1.2
C32 pulse loss probability			0.4		0.4
C33 storage capacity			0.6		0.6
C34 sorting parameter resolution			0.4		0.4
C35 sorting correct rate			0.4		0.4
C36 sorting time			1.4		1.4
C37 threat level recognition rate			1.0		1.0
C38 model recognition rate			0.4		0.4
C39 system recognition rate			0.8		0.8
C310 individual recognition rate			0.0		0.0
C311 intention recognition rate			1.0		1.0
C41 intelligent analysis capability				0.6	1.2
C42 big data analysis capabilities				0.0	0.6
C43 postmortem analysis ability				0.3	0.6
C44 anti-interference ability				0.6	1.2

system performance reduction, it can be seen that the more obvious changes are the parameter measurement performance layer index and the signal processing performance layer index. In terms of system performance, the parameter measurement, there is a certain correlation between

performance level indicators and signal processing performance level indicators and other performance level indicators. Therefore, if only the performance of ELINT system is considered, its index set should be constructed with reference to the index system in Figure 5.

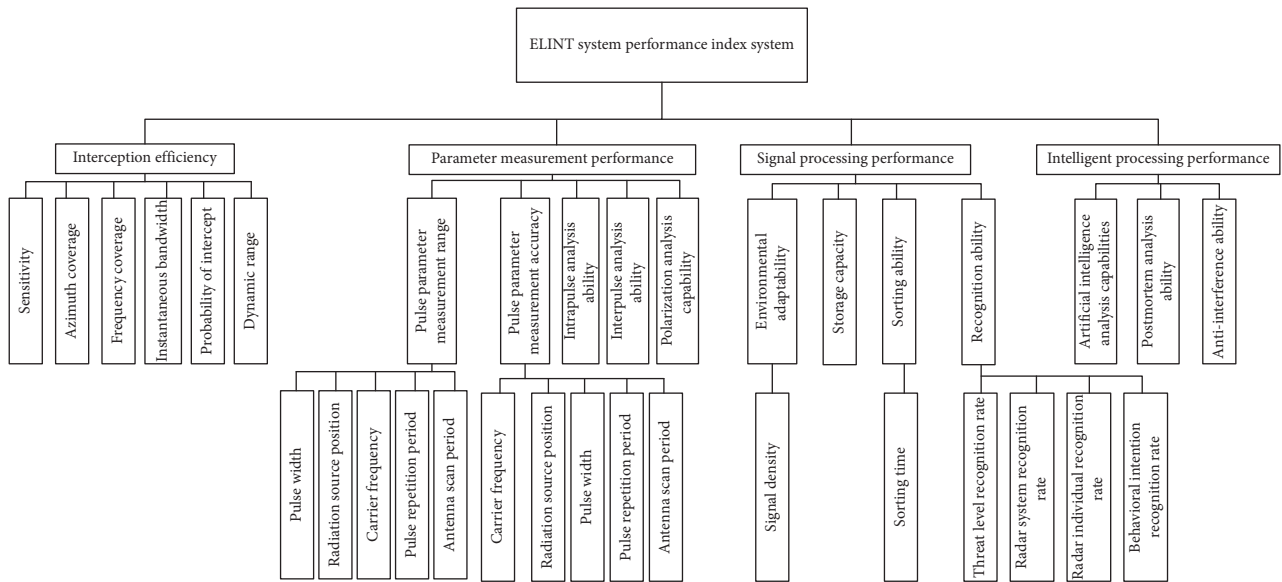


FIGURE 4: Index system of each performance layer after reduction.

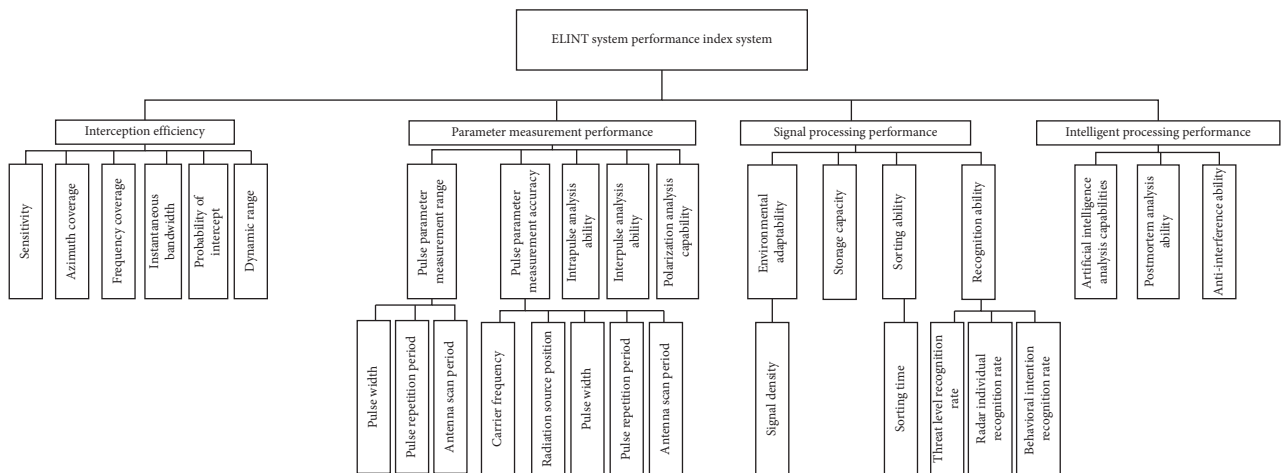


FIGURE 5: Reduced system performance index system.

4. Conclusions

The construction of the ELINT system effectiveness index system is a complicated process. Numerous indicators from different aspects together reflect the ability of the system to complete tasks, forming an organic whole. This article first establishes the evaluation criteria of each indicator based on the working principle of the system, then uses the evaluation criteria to quantify the indicators, and uses the MIBARK algorithm to reduce the quantized ELINT indicator system. Without affecting system performance, the model proposed in this paper minimizes redundant indicators, reduces the complexity of ELINT system evaluation, and improves the objectivity and scientificity of the evaluation conclusion.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of the paper.

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