Level Assessment Criterion and Method for C⁴ISR Systems Interoperability

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Abstract. In this paper, the concept of C⁴ISR systems interoperability is analyzed and the difference compared with traditional system interoperability is presented. The influencing factors of C⁴ISR system interoperability is analyzed from the overall framework of the US military global information grid. Six attributes including structure, application, facility, security, operation and maintenance, and data are selected. The selection process of evaluation attributes is described. Based on the enhanced interoperability maturity mode, the C⁴ISR system level attribute model is given by combing with the development trend of C⁴ISR system technology system. The grade of maturity and an evaluation index system for C⁴ISR systems interoperability are built and the index level reference model is designed. Combining qualitative assessment with quantitative assessment, an index synthesis criterion based on the mapping model and the corresponding interoperability level evaluation method for C⁴ISR systems are proposed to provide a specific method model for measuring the interoperability level of the C⁴ISR system.

1. Introduction
Command, Control, Communication, Computing, Intelligence, Surveillance, Reconnaissance (C⁴ISR) systems is set the functions including command and control, early warning detection, communication, weapon control, and the other operation information assurance as one of military information system, which can be used to obtain/process/pass the military information and operate decision support, command and control, and battle field management [1][2].

Interoperability is a key factor to evaluate the capacity of systems. The definition of system interoperability has been proposed firstly in 1997 by US DoD [3]. The best known definition says that interoperability is the capacity that two or more than two systems of components to exchange information and use the exchanged information[4].

The systems of systems (SoS) is set of independent systems, which own their functions and can emerge new higher capacity when they are aggregated together. For joint operation, SoS represents the joint systems have the capacity of cooperation and interoperability[5].

The SoS interoperability refers to the ability to coordinate the work through the interaction of information between system elements, thus achieving information advantages. When the system elements complete the task, they coordinate other elements through information exchange to perform corresponding information activities to meet the needs of the task[6]. The concept of SoS interoperability is the extension of the concept of system interoperability. In addition to the information exchange, information understanding and collaborative coordination among the system elements, the impact of factors for system interoperability such as the rationality of the architecture, security of the information exchange environment, efficiency of operation and maintenance...
management are considered from the perspective of the SoS [7].

The major methods for interoperability evaluation include maturity model and level model. Typical interoperability measurement models include levels of information systems interoperability (LISI)[8], organisational interoperability maturity model (OIM), and levels of conceptual interoperability model (LCIM), etc. However, on the one hand, models such as LISI evaluate the interoperability of the system from a qualitative perspective by using the capability characteristics corresponding to each level of each attribute, while lack of quantitative evaluation. On the other hand, research such as LISI is carried out under the component system, while the main features of the current C4ISR system has changed from the past componentization to network and service, and the system adopted by the network information system has developed into a service-oriented global information grid (GIG) and a new system such as “network cloud” that can provide ubiquitous services. The system is gradually moving towards intelligent development, and the system adopted by the C4ISR system will further move to a new theory based on "military cloud brain"[9][10]. When the interoperability assessment of the network information system is carried out, the problems that need to be considered have also changed, and the meaning of the original attributes has also changed. In [11], it considers the impact of new technologies such as Internet of Things and mobile computing on military information systems, and proposes an enhanced interoperability maturity model. On the basis of LISI and other models, the connotation of interoperability is expanded. Based on the six attributes of structure, application, facilities, safety, operation and maintenance, and data, the six characteristics of each attribute are given. However, there is no analysis process and basis for selecting these six attributes has been given in this literature, and an analysis method has not been given also.

In summary, this paper analyzes the concept of C4ISR system interoperability, and analyzes the influencing factors of C4ISR system interoperability from the overall framework of the US military global information grid (GIG), aiming at the development direction of C4ISR system technology system. Based on the enhanced interoperability maturity model, the C4ISR system level attribute model is given, and the qualitative evaluation and quantitative are combined. The C4ISR system interoperability level evaluation criteria and methods based on the mapping model are proposed.

2.1 The concept of C4ISR systems interoperability concept

The C4ISR system is a SoS consisting of multiple systems such as intelligence, command and control, weapon control, operational support, and communication. From a SoS perspective, we propose that C4ISR system interoperability concept contains two respects based on the overall structure of the C4ISR system. On one hand, each system in the C4ISR system exchanges data, information, services and other resources to obtain the sharing of these resources among systems and the circulation in the system, so that the system can obtain mutual cooperation and promote the overall capacity of the C4ISR system. On the other hand, the C4ISR system flexibly configures the business relationship between systems for certain mission through the functional handover between systems, and enhances the ability of the C4ISR system to adapt to tasks and environment changes.

Compared with traditional interoperability, C4ISR systems interoperability has the following differences and extensions:

1) Traditional system interoperability mainly considers the information interaction between systems. The interoperability of C4ISR systems not only considers the interaction of data, information, service and other resources in the system, but also considers the circulation of these resources in the whole system, and the mutual cooperation between systems not only aims at local collaborative tasks, but aims to maximize the overall capabilities of the system.

2) Traditional system interoperability mainly considers the collaboration ability between systems through information interaction. The interoperability of C4ISR systems not only considers the ability of systems to cooperate with each other, but also considers the adaptability of network information system under complex and environmental changes. Each system can be configured to form a functional handover between systems.
3. C⁴ISR systems interoperability maturity level model

3.1. Attribute composition

The origin of the US military global information grid (GIG) theory is to solve the problem of the inconsistency of the technical system for military information systems and poor interoperability. It aims to construct a grid information system with the information transmission capability between any two or more points in the world[12]. Therefore, it is possible to analyze the factors affecting the interoperability of the C⁴ISR systems from the overall framework of GIG, and to extract the evaluation attributes of the C⁴ISR systems interoperability assessment.

In the five layers of GIG overall framework, each layer contains content that affects interoperability. In the base layer, the architecture can standardize the various elements of the system from the top of the system, so that the various elements of the system are developed and constructed based on the same specifications. Whether the system can achieve the overall traction from the top layer to achieve interoperability; in the communication layer, the infrastructure of optical fiber, satellite, basic information system network, the scope of communication coverage, performance and other aspects determine whether the system can. In the computing layer, the completeness and standardization of various types of databases determine whether each system in the system exchanges and shares data based on the same data format; in the global application layer, various tasks. The system determines the interaction performance of the system software in the aspects of the openness and interaction mode of the application software. At the same time, the management measures and security systems that pass through the layers determine the interoperability of the system in sequence, and the physical devices such as communication and software. Security, data, and operational security also determine the boundaries of interoperability.

Therefore, this paper evaluates the interoperability of C⁴ISR systems from the top-level architecture, main infrastructure, applications, data, and operation and maintenance. Each attribute describes the key points that affect the interoperability of the C⁴ISR system from their respective perspectives.

Among them, the structural attribute is the evaluation of the business processing relationship between the components of the information system in the C⁴ISR system; the facility attribute is the evaluation of the network interoperability maturity; the application attribute is the evaluation of the software interoperability maturity; the security attribute is the security The evaluation of confidentiality maturity; the operation and maintenance attribute is the maturity evaluation of the information resource scheduling ability; the data attribute is the evaluation of the data structure modeling maturity.

3.2. Level model

From the perspective of forming the C⁴ISR system information advantage and improving the adaptability of the C⁴ISR system, the C⁴ISR system interoperability level model is constructed. As shown in Table 1, the six attributes corresponding to the six attributes are given in the model. Compared with the enhanced interoperability maturity model, the C⁴ISR system interoperability level model further considers the impact of intelligence on the interoperability of C⁴ISR systems, and defines the iconic features of the six attributes of structure, facility, application, data, security, and operation and maintenance in the fifth level of adaptation as structural self-reconfiguration, software-defined network, functional self-synchronization, knowledge model, system self-protection, intelligent operation and maintenance.

Table 1. The interoperability level model of C⁴ISR systems.

| Level | Name            | Structure             | Facilities                      | Application          | Data          | Security     | Operation and maintenance |
|-------|-----------------|-----------------------|---------------------------------|----------------------|---------------|--------------|--------------------------|
| 5     | Adaptation level| structure self-reconfiguration | software-defined network        | function self-synchronization | knowledge model | self-protection | Intelligence operation and maintenance |
4. Collaboration level
mesh interconnection grid connection servitization cross-domain sharing cross-domain protection integrated operation and maintenance

3 Integration level tree interconnection wide area connection componentization domain model wide area protection wide area operation and maintenance

2 Functional level Local area interconnection Local area connection Program data separation Functional model Local area protection Local area operation and maintenance

1 Entry level single function point-to-point connection isolated program program model endpoint protection end infrastructure operation and maintenance

0 Isolation level no structure independent not applicable private model physical isolation Manual operation and maintenance

4.3 C^4ISR system interoperability index system
In order to quantitatively evaluate the interoperability of C^4ISR system, firstly, based on the C^4ISR system interoperability level model, attribute index trees can be constructed for each of the six attributes. Take the attribute of architecture as an example, the corresponding attribute index trees are given, as shown in Figure 1. Each attribute indicator tree further constitutes the C^4ISR system interoperability evaluation index system

![Figure 1. The architecture attribute index system.](image)

5. C^4ISR systems interoperability level evaluation method
System capacity assessment refers to the process of evaluating the intrinsic ability of a certain aspect of the system by analyzing the factors affecting the inherent potential of the system through pre-set rules and approaches. For the evaluation of interoperability, most of the existing evaluation methods are qualitative evaluation by evaluation model. Combining qualitative evaluation with quantitative evaluation, an interoperability level assessment method for C^4ISR system is given in this paper.

5.1. Index calculation
In order to evaluate the grades of each attribute, it is first necessary to obtain the evaluation results of the three-level indicators in each attribute indicator tree, and then further integrate the three-level index evaluation results, and gradually obtain the second-level indicators and the evaluation results of the respective attributes. The method of evaluating the three-level indicator and the method of comprehensively obtaining the evaluation result of the second-level indicator can be designed according to the characteristics of the indicator itself, and the qualitative evaluation method or the quantitative evaluation method can be adopted.

5.2. Index level reference model
According to the C^4ISR system interoperability evaluation index system, the reference values
corresponding to different levels and the secondary indicators in each attribute index system are analyzed, and an interoperability index mapping model is constructed, as shown in Table 2, where the setting of the target value should be given with the evaluation process of the corresponding index. Taking the indicators of structural attributes and facility attributes as an example, the index values of the two secondary indicators at 0-5 level are respectively given. It can be seen that the mapping model does not require the indicators to correspond to the respective levels. The values are different, because the final level of each attribute and the level of interoperability of the C4ISR system are a comprehensive evaluation result obtained by taking into account the various indicator levels.

Table 2. The level reference model of interoperability evaluation index for networking information-centric system-of-systems

| Attributes | Secondary index | level 0 | level 1 | level 2 | level 3 | level 4 | level 5 |
|------------|-----------------|--------|--------|--------|--------|--------|--------|
| Structure  | Grammatical layer | A0=0   | A0=1   | A0=1   | A0=1   | A0=1   | A0=1   |
|            | Sematic layer    | B0=0   | B0=1   | B0=1   | B0=1   | B0=1   | B0=1   |
|            | Pragmatic layer  | -      |        |        |        |        |        |
|            | Facility robustness | -     | Manageable | Manageable | Manageable | Controllable | Definable |
| Facilities | Agreement suitability | Single point isolation | Single point interconnection | Redundant interconnection | Redundant interconnection | Large scale Interconnection | Large scale Interconnection |
|            | Facility controllability | Local Area | Local Area | Local Area | Wide Area | Wide Area | Wide Area |

5.3. Index mapping model
The results of the three-level index and the second-level index in each attribute indicator tree can be obtained by the index calculation method, and the result of the second-level index is compared with the reference value of each level in the reference model of the C4ISR system inter-operability evaluation index level, and one can be obtained. The index mapping model, for example, assumes that the calculation result of the syntax layer indicator is A0=1, and the evaluation result of the facility controllability index is controllable, and the indicator mapping model is as shown in Table 3.

Table 3. The mapping model of interoperability evaluation index for C4ISR systems.

| Attributes | Secondary index | level 0 | level 1 | level 2 | level 3 | level 4 | level 5 |
|------------|-----------------|--------|--------|--------|--------|--------|--------|
| Structure  | Grammatical layer | A0=1   |        |        |        |        |        |
|            | Sematic layer    | B0=1   |        |        |        |        |        |
|            | Pragmatic layer  |        |        |        |        |        |        |
| Facilities | Facility robustness | -     | Manageable |        |        |        |        |
|            | Agreement suitability |        |        | Large scale Interconnection |        |        |        |
|            | Facility controllability | Local Area |        |        |        |        |        |

5.4. Comprehensive guidelines for indicators
According to the command mapping model, the evaluation results of each secondary indicator are combined to obtain the level corresponding to each attribute. The comprehensive guidelines for indicators are as follows:

The six attributes of structure, application, facility, security, operation and maintenance, and data are numbered from 1 to 6, which are set to the first to sixth attributes, respectively, for the i-th (i=1, 2, 3, 4, 5, 6) The attribute indicator tree corresponding to each attribute is such that the corresponding level set of the jth (j=1, 2, 3) three-level index result in the interoperation contour is Gij. The maximum
values of the three sets $G_{i1}$, $G_{i2}$, and $G_{i3}$ are respectively taken out, and the three sets are sorted according to the size of the three maximum values taken, so that the set with the smallest maximum value is $\{G_{i}\}_{\text{min}}$, and the maximum value is the largest. For $\{G_{i}\}_{\text{max}}$, the set of the maximum value is $\{G_{i}\}_{\text{mid}}$, then the maximum value of $\{G_{i}\}_{\text{min}}$ is the level of the $i$-th attribute.

For example, for structural attributes, the corresponding level sets of the three three-level indicators in the interoperable contour are $G_{i1} = \{1, 2, 3, 4, 5\}$, $G_{i2} = \{1, 2, 3, 4, 5\}$, $G_{i3} = \{3\}$, in the three sets. The maximum values are 5, 5, and 3, respectively, so the minimum value 3 of the three is taken as the level of the application attribute, that is, the structural attribute level is 3 (integration level).

5.5. Determine the interoperability level of the C4ISR system

The C4ISR system interoperability level can be obtained by combining the evaluation results of each attribute level. There are many methods that can be used to comprehensively derive the total evaluation results by using a set of evaluation results. The following two methods are available.

5.5.1. Method 1: User setting method. The weight of each attribute is manually set by the user according to the current focus or current needs, and the weights are normalized, and the obtained level values are used as the interoperability level of the C4ISR system by weighting, summing, and rounding. Assuming the weights of the six attributes $\gamma_i (i = 1, \ldots, 6)$, the normalized weight is $\gamma_i / \sum_{i=1}^{6} \gamma_i (i = 1, \ldots, 6)$.

5.5.2. Method 2: Comprehensive evaluation method

Comprehensive results such as analytic hierarchy process, grey comprehensive evaluation method and fuzzy evaluation method are used to obtain the comprehensive results of the interoperability level of C4ISR system.

6. Conclusion

In this paper, the concept connotation and influencing factors of C4ISR system interoperability is analyzed, the selection process of structure, application, facility, security, operation and maintenance, and data evaluation attributes is described. Combined with the development trend of C4ISR system technology system, it constructs C4ISR system level attribute. The model, based on the six attributes corresponding to the six levels of landmark features, constructed a C4ISR system interoperability index system with six attribute indicator trees, using a combination of qualitative evaluation and quantitative evaluation, and constructed the C4ISR system interoperability index. The level reference model and the mapping model propose the C4ISR system interoperability level evaluation method and criteria, and provide a specific method model for measuring the interoperability level of the C4ISR system.

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