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A survey on C⁴ISR system architecture technique

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Abstract

With the rapid development of information technique, the warfare modes changes continuously, converting from “Platform Centric Warfare” to “Network Centric Warfare” gradually. C⁴ISR system becomes networking, service oriented and intelligent. C⁴ISR systems are required to possess higher capability of situation awareness and coordination decision-making due to the integrative joint operations. In this paper, C⁴ISR systems are studied comprehensively. The development and main technique of C⁴ISR are outlined, and the current research states of its architecture are reviewed in detail. Finally, the major problems confronting in the research are summarized

Keywords: C⁴ISR; Architecture; Command and control system

1. Introduction

Driven by the new military reform with information technology as the core, the combat style of modern warfare has undergone profound changes, and integrated joint operations have become the main operational patterns of future operations [1]. This combat style requires multi-military and military joint operations, emphasizing the confrontation between system and system, and winning the information advantage has become an important prerequisite for winning the victory of war. C⁴ISR system is the central nervous system of modern war. It is the key to seize the advantage of information. Therefore, the construction of C⁴ISR system is of great significance for our army to accelerate the process of informatization and realize the leapfrogging development from mechanization to informatization.

C⁴ISR system, called command information system, is a man-machine information system with complex structure and large scale. The early C⁴ISR systems of the US military were independently built by all kinds of services and services, and the systems could not be connected with each other. During the Gulf War, the US military was deeply troubled by the chimneys C⁴ISR system during the Gulf War [2], and the efficiency of operational command was low. Information can not be shared can only transmit information in the original manual way. After the Gulf War, the US military gradually realized that the connectivity, interworking and interoperation of C⁴ISR systems were the key factors to win the war[3]. After research, the US military put forward the concept of C⁴ISR system architecture, and defined it as the structure of each component of the system, the relationship between them and the principles and guidelines that restrict their design and evolution over time [4], which is to ensure the integration of C⁴ISR systems. The key to interoperation. Dr. Coz (R. J. Curts) points out that the development architecture of all systems is the only way to interconnect, interwork, and interoperate between C⁴ISR systems [5-6]. C⁴ISR architecture provides a logic. A structured approach to defining military combat patterns, related information flows, and The relationship between system capabilities and technical standards. Therefore, this paper makes a comprehensive study of C⁴ISR system, on the basis of introducing the related concepts, main technologies and development stages of C⁴ISR system in detail, sums up and summarizes the existing technology of its structure system, and points out the problems faced in the current research.

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2. C⁴ISR system overview

C⁴ISR (Command, Control, Communication, Computer, Intelligence, Surveillance, Reconnaissance) system [7-8] is a comprehensive use of modern electronic information technology and equipment under the guidance of modern combat theory, and is closely integrated with operational command personnel. The man-machine system for the command of troops and weapons, which integrates command, control, communication, intelligence, reconnaissance, detection, early warning and comprehensive support, is the infrastructure of military command automation, and it is also the reality of the commander. The concrete technical means of giving command. With the development of military change and information technology, the traditional C / S architecture and component-based pyramid command and control system solutions can no longer meet the needs of joint operations, mainly for the following reasons [9]:

First, the client is directly connected to the server, and the server consumes some resources to deal with the connection with the client, which can not meet the real-time requirements of the command and control system. Second, in this master-slave structure, if the line connected to the master server or the master server stops working for some reason, the whole system will be paralyzed. Third, the distribution of client components is extremely tedious, the business logic of the command and control system is compiled in the client, resulting in abnormal bloated client; Fourth, the component-based solution is realized by distributing the corresponding business components to different seats. The functions of the components obtained by the seats are relatively fixed and missing. Lack of task-oriented flexibility. Because pyramid command and control system can not meet the needs of information war, it is bound to develop to flat, networked, service and intelligent C⁴ISR command and control system.

The new service-oriented command and control system, which is developing, takes the command and control of joint operations under the network environment as the background of military demand, and connects the reconnaissance and detection system, command and control system and weapon system. The platform in which each system is located forms a network system in which combatants at all levels make use of the network system to understand the battlefield situation in a timely manner, exchange operational information, direct and implement operational operations [10]. Network centric Warfare [11] is developed on the basis of platform centric Warfare compared with platform centric Warfare. It is to network all the sensor systems, communication systems, command and control systems and weapon systems of the army. To become an information network system, combatants at all levels use the network system to understand the battlefield situation in a timely manner and exchange combat information, so that the various systems and platforms of the network can be greatly shared in information and resources. Each part forms an organic whole, carrying out coordinated and joint operations. By using the existing network interconnection standards for reference and using the existing network interconnection standards, the service-oriented architecture constructs a general, platform-independent and language-independent technical layer specification on the basis of various heterogeneous platforms. Through this technical layer specification, the interconnection and interoperation should be realized on different software and hardware platforms [12].

3. Research status at home and abroad

In this paper, the research status of C⁴ISR architecture technology at home and abroad is described from three main aspects, including architecture modeling technology, design method and development process, evaluation measurement and verification method, its structure is shown in figure 1.

Figure 1 Main research contents of C4ISR architecture technology

3.1. C⁴ISR system modeling method

The main contents are as follows:

3.1.1. Traditional C4ISR system modeling method

The traditional C⁴ISR architecture modeling methods are mainly structured modeling methods IDEF, Petri net modeling method, UML modeling method, SysML modeling method, modeling method based on Lanchester equation, and modeling method based on impact diagram.

In reference [16-18], the structured analysis method is used, mainly using the entity-relational model (E-R) to establish the architecture model, and the typical method is the IDEF (Integration Definition for Function Modeling) method cluster. In reference [34], the related research results of the core architecture data model of C⁴ISR system in US military are studied, and the application of CDMA of IDEF_{IX} in the core of C⁴ISR system is put forward. This kind of method mainly focuses on the functional structure and information flow of the system, and can be more intuitive. It reflects the understanding of military personnel to the process of combat tasks and the basic needs of completing combat tasks, so as to achieve the purpose of communication between military and technical personnel. However, the dynamic characteristics of the system can not be expressed, such as step, concurrency and conflict between activities.

In reference [35-36], the object-oriented method is used to model the architecture, and the main method is to use the unified modeling language (UML) to model the architecture. The modeling method mainly uses the model of UML (class diagram, state diagram, sequence diagram, etc.) to model the architecture product, and puts forward the basic principle of constraint. In reference [37], UML and IDEF are combined to describe and verify the model of C⁴ISR system. In order to overcome the difficulty of model verification of UML, the extension mechanism of UML (by stereotyping, tag value and constraint) is proposed in reference [38-41]. The L model is extended to form metamodel and metatypes that use the architecture).

IDEF and UML modeling methods define the architecture through static picture, icon and text description, and can not fully express the logic, behavior and performance characteristics of the architecture. In view of the problems existing in the above methods, reference [43-45] uses Petri net to transform the models established by structured analysis method and object-oriented modeling method based on UML into Petri net model through certain transformation rules. The modeling of C⁴ISR architecture is realized. In reference [27], the Petri net modeling method of command and control

organization is discussed, and a variable structure command and control structure model is proposed. Literature [46] the decision organization system model of an anti-tank missile command and control system is established by using Petri net. In reference [47], a typical information processing capacity model of command and control system is established by using Petri net. In reference [48], the Petri net-Agent model of command and control system is established by combining the description ability of Petri net to the system and the intelligent characteristics of Agent. The time characteristics of the information processing process of the command and control system are analyzed.

The researchers of National Defense University of Science and Technology first put forward the introduction of object-oriented technology into Petri net theory, and established the object-oriented Petri net [49] (Object Petri Net, OPN) theory. The limitation of Petri net in describing command and control system with complex hierarchy is solved, and the concepts of time, action and predicate are introduced, and the types and attributes of token (Token) are set. The modeling process of command and control system based on OPN theory is described in reference [9]. The C⁴ISR system based on OPN is discussed in reference [50]. The subnet partition and modeling process of the system. In order to make up for the shortcomings of the general Petri net theory that there is no data concept, the colored Petri net theory (Color Petri Net, CPN) [51-53] has been proposed. CPN can do so without affecting the original Petri net. The data structure and hierarchical decomposition are well combined.

3.1.2. Modern C⁴ISR system modeling method

With the requirements of integrated joint operations and the trend of networking and service, the traditional modeling methods can not fully meet the requirements of new C⁴ISR system architecture modeling. With the development of artificial intelligence theory and complexity theory, scholars have proposed new C⁴ISR system modeling methods, including modeling methods based on artificial intelligence, modeling methods based on MAS theory, modeling methods based on complex network theory. Modeling method based on SNA theory.

Artificial intelligence technology has been gradually introduced into command and control modeling. For example, the US military ModSAF (Modular Semi-Automated Forces) system uses finite state machine modeling technology to model individual soldiers and platoons, company combat units, tanks, aircraft, armored vehicles and other weapon systems, and realizes travel, shooting, perception, communication. Major behaviors such as situation assessment. The CCTTSF (Closed Combat Tactical Trainer SAF) system adopts the rule-based representation method to realize the implementation of the rule-based representation method. The intelligent behavior of combat entities. In reference [58], the decision model in command and control is constructed by using Bayesian network. In reference [59], the target recognition model in air defense missile command and control system is realized by using BP neural network.

Compared with the traditional command and control system, the command and control system [60-62] in the information age has changed from the traditional central structure (Centralized) to the non-central (Decentralized) structure. As a result, the command power of the command and control system and the decision-making power of battlefield operations are given more combat units, that is, the so-called principle of marginalization of power (Power To the Edge). The command and control system with this nature tends to be more flexible in organizational form, and more flexible in information flow, situational awareness, command and decision making and so on. At this time, the command and control system has all the characteristics of the complex system [61]. In order to model and simulate it, it will encounter unprecedented challenges. The modeling method based on MAS (Multi-Agent Simulation) theory is described in reference [62-67]. In reference [68], a simulation environment based on Agent technology is established, which is combined with discrete event simulation method (Distributed Events Simulation, DES) to verify the effectiveness of military planning. In reference [69], The agent technology was utilized into the Future Combat System(FCS)of the United States. The paper[70]evaluates the influence of the adoption of new technologies in the command and control system on the command and control system by using simulation methods based on agent modeling.

Social network analysis method (Social Network Analysis) is essentially a method based on complex network. This method mainly describes and analyzes the relationship between people in society, as well as the various tangible or invisible relationships that flow through these relationships. Such as information, resources, etc. It is a recent research direction to apply the social network analysis method to the command and control system for the analysis and design of the command and control system organization[79-87]. PLA University of Technology and National Defense University of Science and Technology are at the forefront of research in this field[86-87].

3.2. C⁴ISR system design and development method

Architecture design method and development process is one of the important problems in the research of C⁴ISR architecture technology. It provides a supporting design method and development process for architecture development. The essence is a strategy to order the essentially disordered architecture development activities. At present, there are three kinds of architecture design and development methods: structured design and development method, object-oriented design and development method, activity-based method and so on.

References [3], [7], [22] propose a general six-step development process for the development of C⁴ISR system architecture. With the support of the general development process, Alexander H. Levis and Lee W. Wagenhals of the C3I Center of George Mason University in the United States have put forward the theories and methods based on system engineering and software engineering. The architecture development of information system, especially C3I system, and how to generate the products specified in C⁴ISR architecture framework are deeply studied [20-22].

In reference [16-19], the object-oriented C⁴ISR architecture design method is studied, which provides the development process based on object-oriented design method for framework product development. The development process of C⁴ISR system evolution is studied by combining UML with Petri net. The process of cyclic iteration and refinement in four main task areas, such as requirement collection, architecture design, establishment of enforceable model and architecture evaluation, is studied. The main activities of each task area in the process of evolution and development are determined and discussed[44-46]. Multiple references to the C⁴ISR architecture described in reference [61] The model is transformed into an enforceable model. The activity-based design method ABM, mainly aims at the development and analysis of integrated DoD architecture, and provides a strict and standardized design method [88].

Among them, the advantages of structured analysis method are that the theory is mature, the application is extensive, and there are many supporting products and tools. The shortcomings of structured analysis method are that the function-centered analysis system destroys the original boundaries of the system and is easy to cause the deviation of people's understanding of the system, and the other is that it is very difficult for software implementation, system maintenance and component reuse. Compared with the structured analysis method, the object-oriented method has obvious advantages: one is that the object-oriented method naturally divides the problem space, which is closer to the human way of thinking, the other is that it supports the reuse of components. Third, it is easy to upgrade and maintain the system. Of course, because of the fact that The development time is relatively short, and there are some problems in the object-oriented method. It is a platform-limited technology, only pays attention to the development of a single system, and the portability is not strong. Only solve the system design and development problems, but not solve the system deployment and system plug and play problems; the design process is too dependent on experience.

3.3. C⁴ISR system Verification and Evaluation method

System performance is a measure of the extent to which a system is expected to meet a specific set of tasks. It is the reflection of the comprehensive performance of the system and the overall attribute of the system. For C⁴ISR system, its effectiveness can be divided into its own efficiency and use efficiency. Its own effectiveness reflects the completeness of the C⁴ISR system itself, and it reflects the static characteristics of the system. The efficiency of C⁴ISR system can be divided into two cases: flat and war. Peacetime effectiveness refers to the favorable role of C⁴ISR system in combat preparedness training, military exercises, enemy surveillance, emergency handling, and the management of military and weapon systems. Operational effectiveness refers to The degree to which C⁴ISR system plays a favorable role in the process and outcome of war through the high integration and automation of command, control, communication and information support in a specific combat environment. The use efficiency reflects the dynamic characteristics of C⁴ISR system.

Because C⁴ISR system is a complex system formed by command and control system, sensor system, communication system, combat platform and so on, its comprehensive effectiveness is not only related to each subsystem. It is also closely related to the organic whole composed of each subsystem. It is necessary not only to examine its performance in physical domain, but also to pay attention to its effectiveness in information domain and cognitive domain, not only to have static analysis, but also to observe the factors that affect its performance dynamically.

At present, it is generally accepted that the evaluation index system proposed by the C⁴ISR EWMOE working group of the (Military Operation Research Society, MORS) of the military Operations Research Institute. Later, NATOCOBP expanded on this basis and gave a hierarchical effectiveness index system. With the emergence of new operational concepts, platform-centric warfare has changed into network-centric warfare, and the focus of military personnel is on their ability to support integrated joint operations. Mainly reflected in the implementation of integrated joint operations, the troops and entities participating in the war have a total of battlefield information. The core competencies of the degree of enjoyment and consistent understanding, the degree of collaborative decision-making, the degree of

synchronization of combat operations and entities are situational awareness and collaborative decision-making capabilities, as shown in figure 4 [89].

Figure 4 Effectiveness Evaluation Index system of C4ISR system in Network Center Environment

At present, the evaluation framework of C4ISR system at home and abroad is mainly modular command and control evaluation structure (Modular Command and Control Evaluation Structure, MCES), cost-combat effectiveness analysis (Cost and Operational Effectiveness Analysis, COEA) evaluation framework, mission-oriented method (Mission Oriented Approach, MOA). Command post effectiveness analysis tool (Head quarters Effectiveness Analysis Tool, HEAT), evolutionary upgrade path (Evolutionary Upgrade Paths, EUP) method and NATO COBP (Code of Best Practice for C2 Assessment).

The existing C4ISR system effectiveness evaluation methods are exponential method, SEA method, ATAM method, method based on influence diagram, verification method based on StateChart diagram, analytic hierarchy process (AHP), Lanchester equation method, comprehensive effectiveness evaluation method and so on. These methods put forward the operation process of system effectiveness evaluation from different angles. The index method of system effectiveness evaluation [90], [91] has the advantages of strong comprehensive ability and intuitionistic method, but its analysis process is greatly affected by artificial subjective factors (such as the determination of "weight", etc.), and the meaning of the results of effectiveness analysis is not clear enough.

The system effectiveness Analysis (System Effectiveness Analysis,SEA) method [59] was from the late 1970s to the mid-1980s. A.H.Levis et al. Of (LIDS) of (MIT) Information and decision Systems Laboratory of MIT put forward an evaluation and measurement method. EA method integrates the parameters or performance indexes of the system into the combat dynamic equation. By comparing the system capability and mission requirements in the same common attribute space, some parameters of effectiveness evaluation are obtained, and these parameters are properly combined according to the system. The degree of matching with the mission can know the possibility of the system accomplishing the predetermined task, that is, the effectiveness of the system.

A method proposed by Carnegie Mellon to evaluate the architecture of information systems ATAM (Architecture trade off analysis method) [92]. Atam is a method of evaluating architecture design. Through the analysis of various non-functional indicators of architecture (such as performance, modifiability, reliability, safety, etc., also known as quality attributes), it determines the compromise point in architecture design, so as to reduce the risk of design. Reference [93] using ATAM method to determine the operational environment and logistics environment To evaluate the C4ISR architecture. Reference [94] describes the architecture of C4ISR system from system architecture view, combat architecture view and management view, and uses StateChart to formalize and verify the system architecture.

Analytic hierarchy process (Analytic Hierarchy Process,AHP) is based on the following considerations: the elements of the system are closely related to the final performance of the system, and the contribution of each element to the effectiveness of the system is often different. Thus, the system efficiency is obtained by analyzing the significance of each element's ability / contribution to the system efficiency. In practical operation, according to the relationship between the system elements, the elements are divided into several levels, which are generally subordinate or dominant. Reference [95] unfolds the idea of QFD based on quality function, and introduces the user requirements into the key of C4ISR system. In the process of capability analysis, the weight of capacity development is determined, the performance index system of each key capability is established, and the contribution of different development schemes to key capability is calculated by analytic hierarchy process (AHP). The ideal solution TOPSIS method is used to

comprehensively evaluate different development schemes and select the optimal development scheme of C⁴ISR key capabilities.

With the development of the times, intelligent information processing technology, as a kind of technology which can deal with uncertain, incomplete, inaccurate, unreliable and other information, its theory and method have become the research trend of weapon system effectiveness evaluation. Because of considering the comprehensive influence of system effectiveness index on the evaluation results, fuzzy comprehensive evaluation method has become the most commonly used combat system operational effectiveness evaluation method [101-102]. Neural network has become another important method to study the operational effectiveness of weapon system because it can establish a nonlinear mapping between multi-index and evaluation results [103-104]. Reference [105] Grey by Analytic hierarchy process Combined with decision theory, the effectiveness evaluation of weapon systems such as unmanned reconnaissance aircraft is realized more reasonably. In reference [106], an expert system for effectiveness evaluation of individual weapon equipment system is established by combining fuzzy reasoning with neural network. In reference [107], The effectiveness of C⁴ISR communication subsystem is evaluated statically by using fuzzy comprehensive evaluation method and qualitative and quantitative analysis.

4. The main problems of current works

From the research status of C⁴ISR architecture technology at home and abroad, at present, there are the following problems in C⁴ISR architecture:

- i. Lack of effective description of system capability. With the transformation from platform center war to network center warfare, the system design pattern changes from threat / demand to capability. The C⁴ISR architecture framework based on threat / requirement analysis is an analysis of a single plot, which leads to some limitations in the system description, such as system description and planning as a whole, and some uncertainties in the system. Risk management and decision making, etc. The combat architecture view reflects some system capabilities, but the description is too limited to clearly and accurately describe the impact of the system capability on the combat architecture view and the system architecture view. It is difficult for system designers to grasp the overall performance and index of the system from the top level and overall level of the system.
- ii. The architecture framework emphasizes "product" as the center, does not describe the data elements in the product, and can not meet the "data-centered capability-oriented" system requirements. Although the core architecture data model based on structured analysis method is described in the framework, the data relational model based on UML is not provided, which leads to the disunity of architecture data terminology and the difficulty of data reuse.
- iii. At present, based on the object-oriented description method, some products in UML are mapped to the product template in the architecture framework, that is, the architecture products are described by UML. But it is a complex system modeling for C⁴ISR, which does not provide elements and relationships in the specific domain of C⁴ISR Type, that is, no UML-based architectural metamodel is provided.
- iv. The existing architecture design methods do not support architecture design reuse and information reuse. Especially when the C⁴ISR architecture is transformed into "service-oriented", what kind of design method is adopted to provide a reasonable development process to realize the large granularity reuse of C⁴ISR architecture data.
- v. Lack of architecture verification and measurement methods. The architecture verification and measurement is the guarantee of the design quality of the C⁴ISR system. At present, the United States DoDAF framework has just begun to deal with architectural evaluation and metrics.

In addition, the development of our army's command and control system is also undergoing the transition from a pyramidal command system to a flat command system for network-centric warfare. At present, our army's command and control system still has the following shortcomings:

- a. Lack of top-level design and low degree of integration. The command and control system of our army is basically built independently in accordance with the types of services and services. Due to the lack of top-level design, the communication and coordination between various services and various business departments is not enough, resulting in disunity of equipment system and information standards. As a result, the ability of "three mutual" between the command and control system is poor, and the degree of integration is low.
- b. The command and control functions are less and the ability to support joint operations is weak. Due to the lack of appropriate system for reference in the construction of our army's command and control system, the operational requirements of the system development are not clear, which leads to the system demand analysis is not in-depth, the purpose is not strong, which makes the built system information processing ability weak. The

auxiliary decision-making level is low, and some command and control functions are not automated. The integration of the existing command and control systems of our army is low, there is no public platform, and the information sharing ability among different systems is poor. In addition, at present, our army has only "regional power" to develop joint operations in war zones that can support joint operations at the battle level of all arms and services. The command and control capability of joint operations at other levels, especially at the tactical level, is generally lacking, so that existing systems cannot effectively support joint operations.

- c. The adaptability of actual combat is poor and cannot meet the actual operational needs. At present, the current command and control system of our army is basically a scientific research system. The scientific research features of the system are prominent, and the system is not strong in anti-destruction, anti-interference and long-range attack, which leads to poor adaptability of the system and cannot meet the actual operational needs.
- d. The crosslink between the weapon system and the weapon system is poor. In the construction and development of our army's weapons and equipment, the construction of the command and control system has not been put at the core, and the coordination between the command and control system and the construction of other weapons and equipment is not enough, and the command and control system is out of touch with the construction of the weapon system. This makes the information degree of weapons and equipment not high, and there is no real combination of general data chain and special data link, multi-frequency band, multi-platform, compatible technical system and unified information format. The crosslink between command and control system and weapon system is poor, so it cannot give full play to the operational effectiveness of command and control system and weapon system.

5. Conclusion

With the development of science and technology, the mode of modern warfare has changed from traditional mechanized warfare to information warfare and network warfare, which puts forward more requirements for C⁴ISR command and control system and the transmission of information. Sharing capability and cooperative combat capability have a great influence on the process and result of war. C⁴ISR architecture technology contains the key technologies of its whole life cycle. This paper first introduces the concept, development and main technologies of C⁴ISR; secondly, summarizes the research status of C⁴ISR architecture technology in foreign countries, including C⁴ISR architecture framework, modeling method, design and development method, and Verification and evaluation methods; Finally, the paper analyzes the main problems facing at present.

Compliance with ethical standards

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