Research on Evaluation Index System for Software Defined Radar (SDR)

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Abstract:
Software defined radar (SDR) is an important phase and an inexorable trend during the development of radar system technology. The reasonable and pertinent assessment for SDR is worth of profound research in both theoretical methodologies and practical applications. However, studies on the evaluation index system for SDR are rarely reported in literatures so far. In this paper, the technology connotation, typical characteristics and system architecture of SDR are firstly described. Then, the overall architecture of evaluation index system is constructed from four aspects: technological level, combat effectiveness, tactical and technical indicators as well as product quality. Moreover, each of the evaluation indexes is discussed in detail according to the present situation and future trends. This study can not only supply a reference to commanders for decision making in demonstration, development, usage and optimization of radar equipment, but also provide helpful suggestions for industry peers in further associated research work.

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***Abstract*—Software defined radar (SDR) is an important phase and an inexorable trend during the development of radar system technology. The reasonable and pertinent assessment for SDR is worth of profound research in both theoretical methodologies and practical applications. However, studies on the evaluation index system for SDR are rarely reported in literatures so far. In this paper, the technology connotation, typical characteristics and system architecture of SDR are firstly described. Then, the overall architecture of evaluation index system is constructed from four aspects: technological level, combat effectiveness, tactical and technical indicators as well as product quality. Moreover, each of the evaluation indexes is discussed in detail according to the present situation and future trends. This study can not only supply a reference to commanders for decision making in demonstration, development, usage and optimization of radar equipment, but also provide helpful suggestions for industry peers in further associated research work.**

Keywords—software defined radar(SDR), evaluation index system

I. INTRODUCTION

The development of radar can roughly fall into five stages: analog customized radar, digital radar, software defined radar (SDR)[1-4], cognitive radar and intelligent radar. At this stage, radar is in transition amid digital radar and SDR.

The concept of SDR describes that the functionalities of the radar system can be defined by software. The nature of software-defined technology is, namely, virtualization of the hardware resources and the programmability of management functionalities[5]. In other words, all hardware resources can be abstracted as virtual resources and programmable, such that the functionalities can be managed and scheduled by system software. Based on the thought of “Platform +”, SDR can maximize the efficiency of software via making use of it wherever possible. Aimed at satisfying multiple practical requirements and better serving applications, the software is generally utilized to flexibly implement the definition of system functionality, resource allocation, mode expanding as well as performance promotion. Relative to analog customized radar and digital radar, the advantages of SDR mainly lie in the convenience and low cost of radar design and function upgrade or extension. With open type architecture, SDR supports the substitution and upgrade of standards-compliant hardware platform, which makes it feasible for the maintenance management of equipment[6]. Furthermore, the decoupling between underlying hardware and upper task software is carried out by middleware technology, which is thereby possible for the transition of upper task software to domestically-produced hardware platforms and operation systems without any modifications. This is of great significance for safeguarding national security and promoting military and civilian integration. Therefore, a reasonable and pertinent assessment for SDR—the core equipment in information war, is an issue that deserves in-depth study.

Evaluation index system is a set of indicators with internal connections and complementary actions, comprehensively reflecting the overall goals and characteristics of all the evaluation objects[7,8]. While the evaluation index system is an important basis link to evaluate the compressive performance of SDR, the evaluation plays a crucial role in many phases associated with SDR, such as designation, development, purchasing, usage and maintenance. Besides, it becomes an indispensable procedure for the equipment demonstration and its performance will have an immediate impact on the deployment as well as retirement. Therefore, constructing a reasonable and pertinent evaluation index system for SDR can not only provide a reference to commanders for decision making in demonstration, development, production, acceptance, usage and optimization of radar equipment, but also has great martial and economic value. Nevertheless, studies on the evaluation index system for SDR are rarely reported in literatures so far.

An outline of the remainder of this paper is as follows. Section II describes the technological connotation and characteristics of SDR, based on which gives an in-depth analysis on SDR technology. Section III establishes the overall architecture of evaluation index system from four aspects—technological level, combat effectiveness, tactical and technical indicators as well as product quality. In addition, each of the evaluation indexes is discussed in detail according to the present situation and future trends of SDR. Finally, Section IV summarizes the conclusions drawn from this study.

II. ANALYSIS ON SDR TECHNOLOGY

This part details the technology connotation, the system architecture and implementation method of SDR at present. Subsequently, we discuss typical characteristics of SDR.

A. Technological Connotation

On the basis of open system architecture, SDR employs application-oriented developing mode and accomplishes system functionality extension via software defined radar technology, becoming a typical representative of the new generation radar. It should be noted that the rate of functionality implemented by software is very high in SDR, which requires the level of radar software be satisfied with the software technology. The nature of SDR is to accurately control the hardware and operational process by software, aiming at the object of controlling the system functionality by the way of software defining. While, SDR technology is a kind of design philosophy, a fundamental platform

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technology rather than application technology. Instead of directly improving the performance of combat effectiveness of radar equipment, however, it can advantageously facilitate wide applications of new technologies and develop a high-availability, easy-upgrading radar which saves time and effort with the help of hardware reconstruction and software refactoring. That is, SDR technology is dedicated to the development of radar equipment, but its objectives are different when it comes to a certain radar with specific missions.

SDR is mainly consisted of antenna, digital beam forming module, signal processing module, data processing module and display terminal, as shown in Fig. 1. Now the digital beam forming module, the signal processing module together with the data processing module can be implemented by software while the antenna and the display terminal cannot.

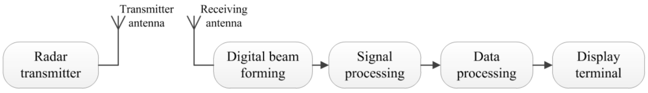

Fig. 1. Basic concept of SDR system

The real challenge for SDR is in the frontend. Specifically, it is very difficult to build a versatile antenna that is suitable for multi-schemes. For example, warning radar has different working mechanisms as well as antennas with diverse shapes and sizes compared to synthetic aperture radar. Nevertheless, the general antenna that satisfies both the two mechanisms cannot be achieved at the present stage. The current solution is to design diverse antenna modules, each of which is corresponding to a certain working mechanism. When some certain antennas are needed, the associated antenna modules can be immediately chosen.

In the signal processing part, specific algorithm programs are usually written into corresponding processing boards, which is tightly coupled with the hardware in the whole process and needs customized boards for unique proposes. By strictly defining the functionality and the form of the interface, people can promote the standardization and modulation of the hardware step by step. For software component, people can determine the standards of information contents and information formats in the data transferring processes among different components. People can also modify the module for component capsulation to fulfill the goals of decoupling and reusing between the software and the hardware in the application layer.

In the data processing part, the middleware, such as operation system, can be employed to accomplish decoupling between the software and the hardware. Actually, existing SDR focuses on promoting the ability of digital backend and its software level is mainly reflected in the software refactoring of the digital backend as well as plug and play for software components with different functions.

Still, there is a hypothesis implied in SDR, i.e., the hardware has sufficient ability to fully implement the instructions from the software. This proposes a very high requirement for the hardware performance and supposes that the influences of the hardware on the software together with the system do not need being paid too much attention in the radar software development. In fact, the bottleneck of SDR is precisely the hardware.

B. System Architecture

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The system architecture of SDR is composed of three parts: hardware platform, radar operation environment and application layer components. According to the hierarchical decoupling idea, the SDR system can be divided into five layers from the bottom to the top—the hardware layer, the system layer, the abstraction layer, the framework layer and the application layer, as illustrated in Fig. 2.

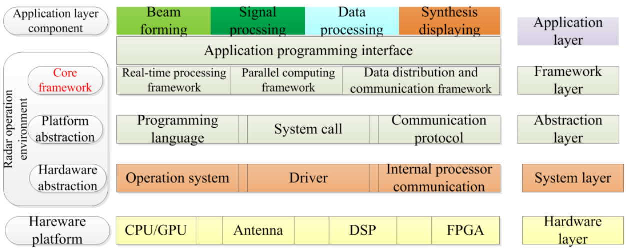

Fig. 2. System architecture of the SDR

The hardware platform mainly contains digital signal processing resources and radar antenna array. The digital signal processing resources, such as CPU/GPU and field programmable gate array (FPGA), can be reconfigured and their computing ability can be extended. Radar antenna array adopts modular design and supports the reconstruction of the antenna aperture.

The radar operation environment is consisted of hardware abstraction, platform abstraction and core framework, ranging from the system layer, the abstraction layer and the framework layer. Thereinto, the hardware abstraction belongs to the system layer and contains operation system, drivers as well as internal modules for communication among processors. It can be used to implement scheduling as well as management of SDR system resources and can provide corresponding radar antenna array and computing resources for diverse applications. Then, the platform abstraction belongs to the abstraction layer, adopts the unified interface specification and defines the interface with the unified software/hardware description language along with the communication protocol. Belonging to the framework layer, the core framework includes real-time processing framework, parallel computing framework, data distribution and communication framework, responsible for communication and providing unified and open APIs for the application components. These three layers are of high independence to each other, in which the abstraction layer and the framework layer are called the middleware. The radar operation environment decouples the software and the hardware by the middleware, such as management and communication modules. Meanwhile, as the key part of SDR technology, the radar operation environment can provide unified interfaces and operation environments for the application components.

The application layer components mainly include beam forming module, signal processing module, data processing module and synthesis displaying module. Different modules are selected to fulfill multi-function and multi-task purposes, like detection, interference, reconnaissance and communication. Besides, the application layer components utilize the modular design and communicate with the framework layer with the help of unified standard interface together with the specification of system calling. It can be upgraded and modified independently, with the addition of the characteristic of plug and play, ensuring the capacity of functional reorganization. During the development of the application layer components, a large number of high-tech enterprises can be absorbed into the research and development. Excellent business achievements can also be embedded to draw on successful experience, promoting the combination within high-tech enterprises and forming a novel supply mode for the application layer components—the integration of the third-part technology, diverse product suppliers and the volume production of the replaceable units.

C. Typical Characteristics

SDR can flexibly extend or reconfigure the capacities via software on the basis of open system architecture[9]—the foundation of SDR. The typical characteristics of SDR can be composed of the following three aspects: 1) open system architecture; 2) decoupling between the software and the hardware; 3) functionality and performance implemented by software.

1) Open system architecture: The open system architecture has the following characteristics，which is listed in the following：（1）Hierarchical and modular architecture is based on the functional decomposition of the radar system, radar working mechanism and open resource for the software and the hardware;（2）The interface specifications that radar sub-systems abide are interacted in a predicable way, making it possible for the single sub-system or component not to affect other parts of the system even when it is replaced;（3）The hardware shows a trend of modularization, standardization and serialization. Meanwhile, the commercial off-the-shell (COTS) should be made full use of;（4）Software generalization means that the application software, independent to the hardware devices, is employed to improve its universality and maintainability;（5）Introducing intelligent mechanism, each radar sub-system can produce their own controlling information and drive themselves so that the controlling and testing for each module can be executed before the integration of the whole system.

2) Decoupling between the software and the hardware: The meaning of decoupling between the software and the hardware includes two aspects:（1）The same set of components can work in various platforms, not relying on some specific platforms, that is to say, the code is transplantable and can be transformed among different operation environments;（2）Oriented by the functionality, functionality upgrade or extension can be achieved by inserting application components with multifunction into the architectural layer. For the application components, standard interface specifications should be defined without considering the radar operation environment, which is consisted of different layers below the application programming interfaces (APIs). The decoupling between the software and the hardware is accomplished by operation environment, general software design rule and logic equipment. Unified and open operation environment provides general and open APIs for the development of the application program in the application layer; based on object-oriented technology and middleware technology, the interfaces are defined by interface definition language and the unified modeling language is utilized to describe the interface; unified universal hardware specifications are determined on the basis of COTS and commercial standards.

3) Functionality and performance implemented by software: Functionality and performance implemented by software means that the functionality extension and performance improvement can be obtained by a software-defined way. Generally speaking, SDR focuses on the functionalities of the applications and the systems from an application perspective, emphasizing to providing better products instead of considering which implementation way is adopted. Furthermore, developers can select high-performance, easy-integrated products through introducing market competition mechanism, which can promote combination of the high-quality software and create the biggest benefit to quickly meet the requirements and to effectively extend the capacities.

III. ARCHITECTURE OF THE EVALUATION INDEX SYSTEM

In foreign countries, SDR has goes through three stages: concept architecture, demonstration and verification, application and promotion. The SDR technology has been successfully applied in synthetic aperture radar. At the moment, the research on SDR is still at an initial stage in China. The signal generation and processing are almost implemented by software, largely improving the functionality extension of radar. However, the universalization of the hardware platform, the university and portability of the software are in the early stage, having not formed the generally accepted standards yet. Therefore, the state-of-the-art and developing trends of SDR in both home and aboard should be given much consideration during the evaluation of SDR. In addition, the evaluation of SDR should be constantly adjusted during the development of the SDR technology. Fig. 3 shows the overall architecture of evaluation index system for SDR from four perspectives—technological level, combat effectiveness, tactical and technical indicators as well as product quality.

A. Technological Level

The evaluation of technological level for SDR can be carried out in five aspects—architecture openness, hardware reconstruction, software refactoring, decoupling extent between the software and the hardware, integration capability.

1) Architecture openness: The scope of the openness for SDR system architecture is restricted to the research and development procedure, rather than the using process. The goal of the open system architecture is to satisfy the diversity of requirements and quickly react to changes. The degree of the openness of SDR system architecture can be measured in the following nine aspects: (1) whether SDR has unified design principles and operating requirements for system architecture or not; (2) whether the software modules and the hardware modules can be upgraded and updated or not; (3)

whether the functionality extension as well as performance improvement can be achieved by updating the software and developing new hardware modules or not; (4) whether new technology in the business field can be widely absorbed or not; (5) whether each sub-systems can be transplanted among different platforms or not; (6) whether components from various layers can interact with each other and share resources or not; (7) whether local technical upgrade has an effect on the architecture of the SDR system; (8) whether each of the components and software environments are easily accessible or not; (9) the use of the open-source software or code.

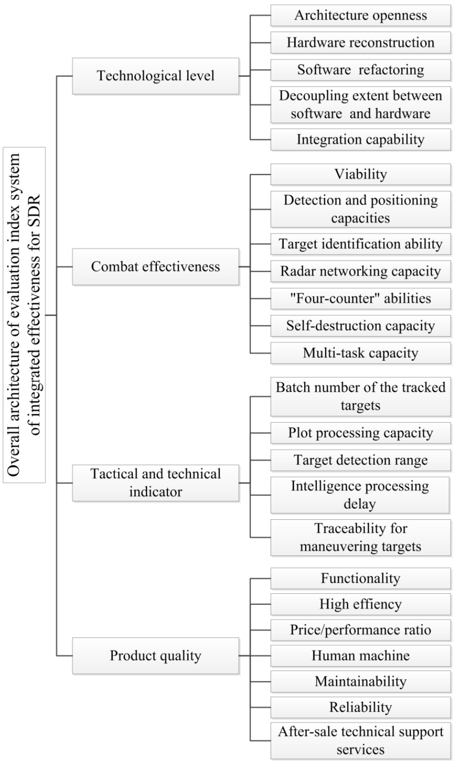

Fig. 3. Overall architecture of evaluation index system for SDR

2) Hardware reconstruction: The ability of hardware reconstruction can be estimated via the following items: (1) the number of the application layer components; (2) the portability of the application layer components; (3) the ratio of the hardware modular design; (4) the number of the reusable hardware component libraries; (5) the usage of the unified general hardware specifications. For the tightly coupled and specially tailored components, the number of the data interfaces complied with the unified standard should also be considered.

3) Software refactoring: The ability of software refactoring can be evaluated by the indicators in the following: (1) the capacity of connectivity and interoperability among different components; (2) the number of the functionalities implemented by software refactoring; (3) the number of novel processing modes accomplished by software; (4) the ratio of software reuse; (5) the kinds of the software components provided by the third-party; (6) the number of the customized tasks fulfilled by flexibly configuring parameters, algorithms and flow paths.

4) Decoupling extent between the software and the hardware: The primary idea of SDR technology is to implement the hierarchical decoupling between the software and the hardware in the radar system, so that the new-type SDR system can utilize the software developing mode, flexibly achieving the system functionality defining, resource configuring, mode extending and performance improvement to satisfy diverse requirements in real applications. The decoupling extent between the software and the hardware can be judged by the following sides: (1) the suitable degree of a set of components which are oriented by functionality and accomplish some certain functions when applied in different platforms; (2) the ability of the code to transform among different operation systems and CPUs; (3) the degree of plug and play for the application layer components; (4) the ratio of the software modules that can update independently; (5) the ratio of the hardware modules that can update independently; (6) the extent of independences of the hardware layer, the system layer, the abstraction layer, the framework layer and the application layer; (7) the uniformity of the interface specifications.

5) Integration capability: In the research and development process of radar equipment, more technical organizations are permitted to take part in so that the optimized and integrated systems can outstrip the original ones in both whole performances and functions. Furthermore, the method of combining high-tech enterprises is adopted to concentrate advantages and strengths and to bring in high-quality products. Hence, the mode, which keeps integration as the central task and attracts high-tech enterprises to participate in, can optimize the functions and the performances of the radar system to the largest extent. The integration ability of SDR can be comprehensively assessed from six perspectives: (1) the horizontal integration ability of each sub-systems; (2) the vertical integration ability of each sub-systems; (3) the price/performance ratio; (4) the general designer's capacity of managing and configuring resources; (5) the number of the suppliers; (6) the technological merit of the suppliers.

It is of paramount importance to note that the ratio of the software in the complete machine can not reflect the nature of SDR, either the percentage of the number of functionalities implemented by the software in the total number of functionalities. Thus, they cannot be regarded as the criteria for judging radar as SDR. The degree of the software in the radar can be weighed by the ability of software refactoring, the decoupling extent between the software and the hardware, the ratio of the COTS used. The hardware of SDR has a tendency of standardlization, modularization and serialization. The COTS are employed to replace the customized components as far as possible, making it a significant feature of radar software that the third-party technology can be widely applied. In addition, the ratio of the mature commercial standards as well as technologies and the degree of diversifications of the suppliers are also the important manifestations of the COTS employed.

B. Combat Effectiveness

Combat effectiveness[10,11] refers to the degree of achieving the expected goal when the weapon equipment system and corresponding troops are utilized to execute specified combat missions under some certain operational environments. Combat effectiveness is a critical indicator of SDR. The indexes of the combat effectiveness include viability, detection and positioning capacities, target

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identification ability, radar networking capacity, "four-counter" abilities, self-destruction capacity and multi-task capacity.

1) Viability: Viability is a measurement of estimating the capacity of SDR to accomplish specific operational tasks under the conditions of specific threat categories. Maneuvering ability, safely destroy-resistant ability, concealing and pretending ability together with sustained combat capacity are indicators of viability. Maneuvering ability refers to the flexible transferring ability of SDR. Due to the use of high-performance digitalized devices, SDR adopts the system architecture of the embedded systems, making SDR much smaller than traditional modulation customized radar both in volume and weight. As a result, the flexibility of SDR is dramatically improved, which has profound significance for promoting the viability of SDR within the modern war environment. Safely destroy-resistant ability indicates that the system can still exert its functions when the enemy deliberately destroys the system in many ways, including anti-electromagnetic pulse attack ability, resisting conventional attack ability. Concealing and pretending ability depicts the capacity of defending the enemy's reconnaissance through pretending ways or setting up false targets, such as electromagnetic interferences, photics and infrared.

2) Detection and positioning capacities: The detection capacity refers to the detecting space that the transmitted signal can cover under some specific conditions, such as prescribed detection probability, false alarm probability and scan cycle. The detection capacity can be measured by the detecting space and data rate. The positioning capacity can be estimated by the measuring accuracy and resolution.

3) Target identification ability: The target identification ability can be quantitatively described by the dimension number of the identified targets. While changes of the task requirements with the missions and environments such as electromagnetic environment, interference patterns and target threatening extent, the identifying features of the targets that meets the requirement of needed accuracy can also be regarded as the indicators of the target identification ability.

4) Radar networking capacity: Modern war tends to be informationized, networked and systematic. The ability of coordinated attack is the development direction of combat system, becoming a critical index of measuring the modernization of defense-related science and technology. Radar networking can dramatically improve the combat effectiveness. The radar networking capacity can be estimated from the following aspects: (1) the information and resources sharing in multi-platforms; (2) reasonable scheduling and precise coordinating of the operational missions; (3) the connectivity, communication as well as interoperability among different radars; (4) the continuity and accuracy for target identification and tracking; (5) netware-based degree; (6) efficiency of command and control.

5) "Four-counter" abilities: The "Four-counter" abilities of SDR are anti-stealth capacity, anti-radiation missile capability, integrated electronic countermeasures and anti-low altitude penetration technique, respectively. The fusions between radar and electronic countermeasure are the developing trend. The "four-counter" abilities are significant signals for evaluating the performances of SDR. The comprehensive evaluation method[12] can be employed to calculate the effectiveness value of "Four-counter" abilities for SDR.

6) Self-destruction capacity: When special conditions like distress landing in the enemy-occupied areas occur in executing tasks, self-destruction program can be launched to immediately destroy the high-grade, precise and advanced systems, avoiding the innovative and advanced technology being acquired by the enemy.

7) Multi-task capacity: Multi-task capacity refers to the ability of SDR to execute multiple tasks at the same time. According to different purposes for SDR like warning radar, height-finding radar, fire control radar, and imaging radar, the corresponding indicators for detection, interference, reconnaissance and communications are presented. For example, the resolution of the 2-D image and the width of the swath are key evaluating measurements in synthetic aperture radar. However, the situation of true and false targets and their number, properties as well as operating range are critical indexes to measure the functionalities and performances for the early-warning radar. Usually, the number of the tasks that can be executed at the same time and the extent that accomplished for each task can be utilized to measure the multi-task capacity.

C. Tactical and Technical Indicators

The main tactical and technical indicators of SDR are the largest batch number of the tracked targets, the maximum processing capacity of the radar plots, the farthest distance of target detection, the tracing ability of the maneuvering targets, intelligence processing delay, and so on.

D. Product Quality

Functionality, high efficiency, price/performance ratio, human interface, maintainability, reliability and after-sale technical support services by provider are critical factors for evaluating product quality.

1) Functionality: The functionality level can be reflected in the following aspects: (1) complete and powerful enough to implement multi-functions; (2) having all functionalities and performances that presented in the product specification; (3) functional expandability to quickly respond to new requirements.

2) High efficiency: The high efficiency of SDR can be comprehensively computed by the following aspects: (1) the time consuming for dealing with a single task; (2) the speed of processing paralleling tasks; (3) the ability to run in good condition at any moment; (4) the ability that adaptively adjusts the signal processing strategy under changing environment; (5) the speed of upgrading and updating; (6) the development cycle.

3) Price/performance ratio: The primary benefits of SDR manifest itself in the low cost and the convenience in radar design and functional expandability. The price/performance ratio can be assessed combined with the four fields: (1) cost, including the purchase cost and maintenance cost during the entire life cycle; (2) performance of the system and its application fields, i.e., multi-function and multi-task; (3) the accessibility of the components, that is, the components can be easily achieved in many ways, not being controlled by some certain sources and liable to integrate excellent COTS;

(4) the sharing, reuse and portability, which means that the functions of the components are independent and can be reused in diverse radar systems.

4) Man-machine friendliness: The man-machine friendliness of SDR can be embodied in the following four aspects: (1) high availability, i.e., easy and powerful to operate and upgrade; (2) beautiful interfacial design, comfort and in good taste; (3) good compatibility, that is, various kinds of application systems can be transplanted in different open-architecture-based systems, moreover, the application systems that operate in a high performance machine can still operate in a low performance machine after being tailored; (4) miniaturization, i.e., SDR is more flexible in maneuvering and more portable.

5) Maintainability: Maintainability can measure the difficulty of repairability and improvement of SDR. The relevant indexes of maintainability for SDR are listed in the following: (1) the time required by fixing a bug; (2) the cycle from finding out a defect to totally solving it; (3) the difficulty level for modifying the function of a system to adjust the external environment or new requirements. Furthermore, the maintainability also involves the self-testing & evaluating ability of the SDR systems. As a part of SDR, the self-testing & evaluating system can be seen as a testing module within SDR and is usually taken into overall consideration and comprehensively weighed. Also, It can be simultaneously designed and produced to optimize and guarantee the radar system.

6) Reliability: Reliability depicts that product's ability of completing expected functions in a given time under given conditions. The reliability of SDR can be measured from mean time between failure (MTBF), mean time to repair (MTTR), the ratio that faults occurred in the radar system within the given time, the stability of the system under execution, the ratio of fault repair, the detection and diagnosis ability of the system itself, the feasibility and durability of the system.

7) After-sale technical support services by provider: It is indispensable to inspect that SDR has all the specific features as the provider claims under given conditions in actual projects. Meanwhile, it is of great significance to inspect the technical support level of the provider, after-sale service ability, the fee of upgrading and updating, which is also necessary for the large-scale applications of SDR in the future.

During real evaluation processes of SDR, the computing method of corresponding indexes and their weighing values should be profoundly considered combined with many factors, such as the development level of the existing SDR technology, specific operational context, operational mission requirements and so on. Moreover, the reasonable evaluation methods are chosen to obtain objective assessment results that complies with integrated effectiveness.

IV. CONCLUSION

Based on an in-depth analysis on SDR, this paper emphasizes to construct a novel evaluation index system for SDR on four fronts—technological level, combat effectiveness, tactical and technical indicators along with product quality. Furthermore, the meaning of each evaluation indexes is discussed in detail, providing helpful reference for further associated research work and practical equipment assessment. Different evaluation methods for SDR will be the research focus of the next step study.

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