Research on the construction of supportability index of aviation equipment system of systems

Gang Ding¹,², Li-Jie Cui², Li-Yong Wang³, Rong Hu² and Guang Qian³

¹ School of Air and Missile Defense, Air Force Engineering University, Xi’an, Shaanxi,710051, P.R China.
² School of Equipment Management and Uav Engineering, Air Force Engineering University, Xi’an, Shaanxi,710051, P.R China.
³ Unit 93920, Xi’an, Shaanxi,710061, P.R China.

E-mail:baffulo@sina.com

Abstract. According to the characteristics of the air force operation under the condition of informationization, the concept, connotation and characteristics of the supportability of the AESos (Aviation equipment system of systems) based on task are defined. Based on the supportability logical control relation of the AESos, the capability requirements of the system to different levels are defined, and the requirement of the system support capability is described in particular. Secondly, following the idea of model-capability-index, and on the basis of constructing the supportability index system of AESos, the paper puts forward three system-level indexes to evaluate the supportability of the AESos, which are the intact rate of the AESos, the availability of the AESos and the mission continuity probability of the AESos. Finally, the definition and calculation formula of the three system-level indexes are given, which can lay a foundation for modeling and analyzing the supportability of the AESos. It provides support for the evaluation, control, overall planning and optimization of maintenance support capability of modern AESos.

1. Introduction
In GJB451A, the definition of supportability is as follows: "The ability of the system design characteristics and the planned supportability resources to meet the requirements of wartime readiness and wartime utilization" [1]. From this definition, it can be seen that equipment supportability is the attribute of equipment system, which is of great significance to meet the needs of war preparedness and wartime use. In information warfare, systematic warfare has become the norm, increasingly showing the characteristics of space-sky-earth coordination, man-machine-environment interweaving, software and hardware coupling, and systematic warfare, systematic support and systematic evaluation have become the key technologies in the application of equipment system. The AESos formed by the traction of battle training mission will become the main object of modern air force command, control, support and evaluation. Therefore, the research on supportability evaluation and decision-making method of AESos under typical combat training mission has become the focus and hotspot in the field of equipment support.

As a new research field, system supportability is gradually developed from the supportability of single equipment, and has accumulated in theory and method. Literature [2] puts forward the mathematical analysis method of equipment supportability evaluation based on Grey theory, and
solves the qualitative analysis of qualitative and quantitative indexes in supportability engineering. A supportability evaluation method based on entropy weight multi-objective decision-making is presented in document [3]. The evaluation index and object are oriented to single equipment. A general method for solving the system availability is given and proved in reference [4]. The system is defined as a military aircraft and its subsystems and components. According to the characteristics of multi-phase mission of equipment group, a planning model was established to maximize mission availability. In Document [6], the task success rate simulation model is established by defining the task success rate. Reference [7] establishes the parameter system of maintenance support capability of equipment system, which is helpful to modeling and simulation of maintenance support capability. Claude M and Bolton Jr proposed that support and reliability index is one of the key performance parameters of the Future Combat System [8]. Mohammad et al established a conceptual framework for acquiring the features of supportability, pointing out that availability and life-cycle costs are feasible indicators for quantifying supportability from the perspective of users [9]. Through further research, Mohammad Asjad et al gave the definition of system availability, established a system availability model based on usage and maintenance support, and analyzed the effect of RMS parameters on system availability [10]. Yu-Chang Mo et al analyzed the mission reliability of the fault redundant multi-phase mission system, gave the analytic calculation method, and carried on the case verification [11].

From the above literature, it can be seen that the current supportability research is oriented to single equipment and its components, focusing on influencing the design and manufacturing process of equipment and cost control through supportability analysis modeling. There are relatively few researches on the combat readiness and operational tasks of the equipment system, which highlights that the supportability research is not fully adapted to the characteristics of the combat tasks under modern conditions. On the other hand, it also shows that there are many deficiencies in the construction of supportability index of equipment system. Based on this, this paper establishes the supportability index system of AESos by defining the concept of supportability of AESos and analyzing the logic control mechanism of supportability of AESos, the definition and calculation formula of each supportability index are given, which lays a foundation for the follow-up evaluation and decision-making of system supportability.

2. AESos supportability

2.1. Formatting the title
The equipment system of systems means that under the specific operational command and support conditions, the aim is to complete the operational task, and the direct goal is to form the required operational capability, it is an organic whole composed of a series of equipment systems which depend on each other in function and complement each other in composition [7]. From this, the definition of AESos can be given, that is, the aviation equipment system of systems is a complex system, which is composed of independent and cooperative air platform, airborne weapon system and their support system. Air Platforms include fighter planes, bombers, early warning aircraft, transport aircraft, unmanned aerial vehicles, and on board weapons include air-to-air missile, air to surface missiles, guided bombs, unguided bombs, aircraft guns, etc., a support system includes all support resources and their management activities required to use and maintain the equipment that makes up the system.

According to the difference of function structure and composition type, the aviation equipment system can be divided into five subsystems, namely command and control system, early warning and detection system, information transmission system, combat execution system and combat support system [12]. Each system may be connected by equipment units of different types but with the same functions to exchange resources and information, forming a complex combat network structure. The AESos architecture is as shown in Figure 1.
2.2. AESos Supportability

The basic characteristics of Air Force combat are long mission duration, multi-stage and multi-stage mission advance, multi-support mission equipment and rapid evolution of equipment configuration. The supportability characteristic of AESos is embodied in three aspects: First, the task of support implementation is complex. With the full implementation of the Air Force practical training program, the complexity, diversity and practical characteristics of the equipment support objects become more prominent. Second, it is difficult to ensure command and coordination. Commanders at all levels lack of scientific control methods and index requirements in the process of organizing support activities, and lack of mature modern intelligent system to support the dispatch of support resources. Third, the optimization of security assessment requires high requirements. In order to improve the benefit of aviation maintenance support, it is necessary to improve the ability of comprehensive evaluation and optimization from the aspects of task advance, resource matching, operation organization, etc. This paper focuses on the research of mission-based AESos supportability, therefore, the definition of AESos supportability is given as follows: AESos supportability is system-oriented combat task, the complex system composed of independent and cooperative aviation weapon equipment systems can meet the requirements of peacetime combat readiness and training and wartime use. In order to evaluate the supportability of AESos accurately, we first need to analyze the architecture and put forward the supportability index which can measure the system. Therefore, the supportability index of aviation equipment system should be derived from the logical control relationship among system task, task intensity, equipment system and support system.

3. Construction of supportability index system of AESos

3.1. Supportability Logical Control Model

There is the starting point of the supportability logical control analysis of the AESos is the combat mission. Therefore, the built architecture supportability logic control model takes task process as input source, and then, the mission-related elements such as command organization, battle department, equipment System, task set, equipment unit, support command and so on are placed in the control model. The constructed model is shown in figure 2. The model can be abstracted into two architecture control rings. One is the operational ring (top half of figure 2). When a superior issues a task, the commander implements task decomposition based on a certain process model and decision-making algorithm, and issues the decomposed combat tasks to the combat department, after the combat department receives the subtasks, assign different quantities of aviation equipment and pilots to build

Figure 1. The AESos architecture
the corresponding AESos. During the execution of the mission, the commanding organ will adjust and control the system according to the dynamic changes of the system, especially the operational support of the system. The second is the support ring (lower half of figure 2). In the course of carrying out the mission, the equipment support department shall assign maintenance units to carry out maintenance support for the specific equipment in the system, and provide equipment support such as spare parts for aviation materials, fuel replenishment, environmental conditions, etc. Similarly, the support command department will also implement the support decision and adjustment according to the characteristic of each type of equipment and the situation change of the whole support.

Figure 2. Supportability logical control model of AESos.

3.2. Supportability Analysis
The accomplishment of the task depends on the satisfaction of the task requirement, which is based on the satisfaction of the system capability requirement, and the system capability requirement is ultimately mapped to the function of the equipment system, and the support ability is the support of the system ability realization. Therefore, the aim of supportability analysis is to derive the different supportability requirements of combat commander, support evaluation organization, outfield maintenance organization and equipment unit from "combat loop" and "support loop" in logical control model. For the different levels of the control model, the aviation equipment system has different capability requirements. The command authority is concerned about the impact of the effective organization of the overall support activities on the success of the mission, such as the need for the decision-making bodies to report to their superiors on the completion of the mission under the safeguards constraints; and during the implementation of the mission, the support assessment organization needs to pay close attention to the dynamic changes of the whole equipment system, that is, to evaluate the support ability of the support system to the whole task; The support command and decision-making organs should pay attention not only to the overall system's comprehensive support capability in the field, but also to the reliability, maintainability, testability and support data of different equipment systems themselves, evaluate the dynamic change of all kinds of equipment in support in time. In the aspect of supportability, the whole AESos needs to pay attention to four kinds
of capabilities: one is the ability to complete the task, the other is the ability to support the task, and the third is the comprehensive supportability of the support system. And fourth, the self-support characteristics of specific equipment units.

3.3. Construction of Supportability Index System

The basic starting point of constructing supportability index is that the index should reflect the complete capability requirement of supportability activities in the process of carrying out the task from the superior continuously. Corresponding to different support capability needs, the command and evaluation agency maintains many indicators in an acceptable range through the scientific and effective organization of support activities. According to the capacity requirements, the capacity requirements at different levels can be translated into specific supportability control indicators. Mission success involves many factors, including supportability, which is one of the key factors to support mission success. Therefore, from the perspective of supportability, mission success rate is regarded as the first-level index of mission completion capability. System integrity rate, use availability and task duration probability are the secondary indicators of the ability to support a task in terms of quantity, availability, and minimum configuration requirements. The three-level and four-level indexes are the classical representation of the field integrated support capability and the equipment unit support capability. As figure 3 shows.

![Figure 3. Supportability index of AESos](image)

At present, the research on mission completion capability Index, integrated support capability index and specific equipment unit capability Index is relatively mature, which can be found in references [13-18]. There is still a lack of relevant research on the measurement index of the support capability of the mission of the support system, and the support index of the system level is particularly important under the modern operational conditions, that is, equipment Sos(system of systems) integrity, Sos availability and Sos task persistence probability. Among them, the Sos integrity rate is used to measure the proportion of the equipment that constitutes the system in good condition, and the Sos availability is used to measure whether the equipment system meets the configuration requirements of the tasks in the completion phase at any time, mission persistence probability is used to measure whether the equipment Sos can continuously fulfill the mission capability requirements under the specified conditions and in the specified time. These three secondary indexes can reflect the design characteristics of equipment system and the ability of support organization and resource operation to fulfill the Sos task, which is also the basis of equipment unit maintenance support command and control.

3.4. Construction of Supportability Index System
In order to better analyze and evaluate the supportability of aviation equipment system, this paper gives the definition and calculation method of the second level index.

3.4.1. AESos integrity rate.
The rate of equipment integrity refers to the ratio of the intact quantity of a certain equipment system in a military formed unit to the total number of similar equipment in preparation, expressed as a percentage [19]. In order to consider the equipment integrity of the system under the mission conditions, the concept of the AESos integrity rate is proposed from the point of view of quantity, and the quantity ratio is considered, it is defined as the ratio of the number of AESos intact to the total number of equipment under given mission conditions, and its mathematical expression is.

\[ R_{rrsos} = \frac{N_r}{N_t} \]  

Among them, \( N_r \) for the system intact equipment number, \( N_t \) for the composition of the system number of equipment units. Here intact equipment refers to the mission during the period not due to repair, inspection, failure, to life, spare parts delay or other impact on the implementation of the mission. Among them, does not exceed the given maintenance time scope of the Locomotive Preparation Work Does Not Count in the incomplete scope. The system integrity rate reflects the reliability, maintainability and supportability of the equipment unit, and also reflects the comprehensive supportability of the equipment system.

3.4.2. AESos operational availability.
The operational availability of AESos is a measure of the condition of the equipment system, which refers to the capability of the equipment system to perform the corresponding task in the course of carrying out the task [20-22]. Its concrete expression is decided by the system can carry out the task time and can not carry out the task time. Operational availability of equipment system is a complete measure of system supportability, which measures the degree to which the equipment system can work normally when needed. If the mission requires \( K \) aircraft to carry out combat missions in order to ensure the success of the mission, requires the deployment of \( N (N \geq K) \) aircraft to carry out the mission, once the available aircraft is less than \( K \), the system is considered unusable. Its mathematical expression is.

\[ A_{osos} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} Tava_{ij}}{\sum_{i=1}^{m} \sum_{j=1}^{n} (Tava_{ij} + MT_{unava_{ij}} + LDT_{unava_{ij}})} \]  

The operational availability of the aviation equipment system is recorded as Aosos, \( Tava_{ij} \) is the availability time of the \( j \) equipment system in the \( i \) mission phase, \( MT_{unava_{ij}} \) is the unavailability time of the \( j \) equipment system in the \( i \) mission phase for maintenance reasons, \( LDT_{unava_{ij}} \) is the unavailability time of the \( j \) equipment system in the \( i \) mission phase due to the support delay such as the spare parts delay time, etc..

Based on the operational availability of combat mission, the equipment system is assumed to be operational at the beginning of the mission, that is, the operational preparation of the equipment system can always be completed before the mission is started. When serious system failure occurs, the equipment can not complete the assigned task or exceed the system performance range. Serious failure of a system means that the system can not continue to perform a task under specified conditions (task profile) and specified time (life profile). From the time dimension, Aosos reflects the time proportion of certain task-based AESos, that is, the attitude of different configuration equipment system on the time line.
3.4.3. AESos task persistence probability.
Persistence probability is the probability that the time before the equipment mission is interrupted is not less than the specified duration of the equipment mission [20], which is usually used to measure the capability of the equipment to complete the mission. The supportability index of the AESos mainly measures the readiness of the equipment system and the ability of the mission to complete continuously. A third important indicator to consider is the capability of the equipment system to sustain the required tasks under the required conditions and for the required time period. The task persistence depends on whether the task intensity is achieved, that is, whether the minimum architecture is satisfied in the process of task execution. System task persistence probability (PMC) is a measure of the system's ability to perform tasks continuously, which is divided into two categories: fully mission capable (FMC) and partially capable (PMC). In this paper, the mission persistence probability of FMC which can perform all tasks continuously is considered, and the event occurrence probability is considered from the perspective of mission success. Mission persistence probability is a measure of mission capability of an AESos, which refers to the probability that an aircraft equipment system continues to complete a specified mission under a certain mission intensity. Its mathematical expression is:

\[
R_{mcsos} = P(t \geq T) = P\left(\left(t_1 \geq T_1 \right) \left(t_2 \geq T_2 \right) \cdots \left(t_i \geq T_i \right) \cdots \left(t_n \geq T_n \right)\right) = P\left(\left(t_n \geq T_n \right) \left(t_{n-1} \geq T_{n-1} \right) \cdots \left(t_2 \geq T_2 \right) \left(t_1 \geq T_1 \right)\right) \cdots P\left(\left(t_2 \geq T_2 \right) \left(t_1 \geq T_1 \right)\right) P\left(t_1 \geq T_1 \right)
\]

The AESos task persistence probability is recorded as Rmcsos, \( t \) is the time before the mission interruption, \( T \) is the duration of the mission, and \( t \geq T \) is the mission intensity of the phase \( i \) configuration equipment. For a given mission, the mission intensity of the Phase \( i \) configuration equipment is determined by the phase mission requirements, and the type, quantity and duration of the equipment are determined by the mission requirements. In the same way, the above task persistence probability can be generalized to the partial task state.

Acknowledgments
I gratefully acknowledge the help of my friend Professor Cui Lijie. I do appreciate his patience, encouragement, and professional instructions during my paper writing. Also, I would like to thank Mr Wang Liyong, Mr Qian Guang and Mrs Hu Rong, who kindly gave me a hand during the writing. Last but not the least, my gratitude also extends to my family who have been assisting, supporting and caring for me all of my life.

References
[1] T L Song, B Z Zhang and L P Ding 2005 GJB451A Terms of reliability, maintainability and supportability 2
[2] N Guan 2006 Guarantee-nature-engineering evaluation based on grey systemm theory Journal of Qindao University (Natural Science Edition) 19 7-11
[3] R Jin 2007 An evaluation method of supportability based on entropy weight multi-objective decision making Journal of Air Force Engineering University (Natural Edition) 8 56-59
[4] J L Li, K N Teng, and P Xia 2017 An availability calculation method for complex repairable systems Acta Aeronautica ET Astronautica Sinica 38 145-53
[5] X W Guo, B G Li, and K N Teng 2016 Maintenance decision model of equipments subject to availability of phased mission System Engineering and Electronics 38 582-7
[6] Y Wei, T X Xue and J Y. Gu 2011 Modeling and simulating for mission completion success Probability based on phased mission system Computer Simulation 28 5-10
[7] K Lu, and C L Nie 2016 Study on the Parameter System Study of Maintenance Support Capabilities of the Equipment System Journal of Ordnance Engineering College 28 11-5
[8] Claude M. Bolton Jr. 2005 FCS Supportability Army AL&T
[9] Mohammad Asjad, Makarand S Kulkarni, O.P. Gandhi 2014 A conceptual framework for capturing supportability attributes of a mechanical systems International Journal of Services and Operations Management 17 1071-118
[10] Mohammad Asjad, Makarand S Kulkarni and O P Gandhi 2015 An insight to availability for O&M support of mechanical systems International Journal of Productivity and Quality Management 16 462-72
[11] Yu-chang Mo Daniel Siewiorek, Xiao-zong Yang 2008 Mission reliability analysis of fault-tolerant multiple-phased systems Reliability Engineering & System Safety 93 1036-46
[12] G Tu and J L Guo 2014 Reliability analysis of aviation equipment system based on combat mission Military Operations Research and Systems Engineering 28 53-6
[13] D H Ding 2011 Significance and recommendation on top-level parameter of military equipment Electronic Product Reliability and Environmental Testing 29 1-5.
[14] Y D Su, J Qiu, and P Yang 2011 Missile testability requirement analysis and index determination oriented to mission Journal of National University of Defense Technology 33 125-29
[15] H C Zhang, Q C Tu and G F Fu 1994 GJB1909.1. Equipment reliability maintainability parameter selection and index determination requirements general
[16] L M Mao, Q C Tu and H S. Luo 1994 GJB1909.5. Equipment reliability maintainability parameter selection and index determination requirements, military aircraft.
[17] B F Ran, Y F Zhang and L Zhang 2015 Target decision method of airplane supportability based-on CAIV & effectiveness-cost-risk weighting Command Control & Simulation 37 109-32
[18] J J. Zhang 2009 Research on maintenance support capability evaluation and optimization technology of combat unit National University of Defense Technology
[19] B Chen X D Zhu and Y G Wang 2014 Research on materiel readiness rate and talented person growing law of task allocation model Fire Control & Command Control 39 96-100
[20] R Kang 2014 Reliability maintainability supportability engineering foundations National Defense Industry Press 214-17
[21] Y Xu, S Q Li and X X Li 2015 Test and verification technology of support characteristics for model equipment National Defense Industry Press 24-36
[22] Z W Shan 2008 Equipment Integrated Support Engineering National Defense Industry Press 5-6