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Research on Parameter System and Model Construction of Support Effectiveness

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This paper investigates the current status of support effectiveness, the concept connotation of safeguarding effectiveness is proposed through research. Considering the structural characteristics and mission modes of the system, identify the factors affecting assurance effectiveness. A parameter system for support effectiveness is constructed from the aspects of comprehensive parameters, innovatively built a three-level with 22 parameters for support effectiveness parameters system. On the basis of establishing the parameter system, a simulation model of support effectiveness is built from the perspectives of support missions, supported objects and support systems, in light of mission characteristics, system composition, maintenance system, support activities and resource allocation,and carry out the calculation of support effectiveness using the super-efficiency data envelopment analysis method. This paper provides a reference for relevant research on support effectiveness.

Keywords: Effectiveness, Support effectiveness, Parameter system, Simulation model.

1. Introduction

In recent years, the volume of various maintenance and support tasks has been on the rise. Problems such as poor operational readiness, difficulties in operational support, and low efficiency of maintenance support have occurred from time to time, which seriously hinders the full exertion of system effectiveness. An analysis and sorting of the operation, maintenance and support problems of some systems show that the phenomenon of prioritizing tactical and technical performance over supportability design exists to varying degrees in the system development process. The one-sided pursuit of the "operability" of tactical and technical parameters, coupled with insufficient attention to the development of supportability design and support resources related to the formation of support effectiveness, has brought huge support risks to the system after delivery. This paper studies and proposes the concept and connotation of support effectiveness, starts with the influencing factors of support effectiveness to built a three-level with 22 parameters for support effectiveness parameters system, and on this basis, builds a simulation model of support effectiveness from the perspectives of support missions, supported objects and support systems in accordance with mission characteristics, system composition, maintenance system, support activities and resource allocation,,and carry out the calculation of support effectiveness using the super-efficiency data envelopment analysis method.. The research provides a reference for the development of relevant studies on support effectiveness.

2. Research on Concepts and Connotations Related to Support Effectiveness

(i) Capability

Capability refers to the potential to complete a task and execute a series of actions under specified conditions and performance levels.

(ii) Effectiveness

Effectiveness refers to the ability to achieve the specified operational objectives under specified conditions. The "specified conditions" include environmental conditions, time, personnel, operation methods and other factors; the "specified operational objectives" refer to the intended goals to be achieved; and "ability" refers to the quantitative or qualitative degree of achieving the goals.

(iii) Support Capability

Support capability refers to the ability of a support system to complete its tasks, which is a comprehensive reflection of such factors as support personnel, facilities, means, technologies and management levels.

(iv) Support Effectiveness

Guo Qisheng et al. hold that support effectiveness refers to the effective degree to which a support system can achieve the expected goals when performing specific maintenance and support tasks, reflecting the ability of the support system to provide support for the main system.

Li Kang et al. argue that the purpose of support effectiveness evaluation is to assess the actual support capability of a system by studying the support process and resource strength such as facilities, system and spare parts, identify the main factors affecting the exertion of the system's support capability, and improve support effectiveness through measures such as optimizing resource allocation and improving support methods.

Zhang Kun et al. point out that support effectiveness evaluation refers to the quantitative description and evaluation of the system's operational support process, as well as the support mode of its support system, the quality of completing support tasks, and the speed of support response in accordance with relevant standards under certain conditions and within a certain period of time.

To sum up, the connotation of support effectiveness can be considered from the following aspects:

1) Support effectiveness is a dynamic concept related to specific missions and specific environmental conditions, which relies on the existence of support systems and support missions;

2) Defining conditions such as operational environment, missions and economic requirements must be clarified. Support effectiveness evaluation focuses on the coordination, matching and trade-off between "easy to support" and "effective support";

3) It is clear that the ultimate goal of support is to meet the operational readiness and mission sustainability of the main system, so support effectiveness can be reflected in operational readiness and mission sustainability;

4) Support effectiveness is the actual embodiment and measurement of the system's support capability and supportability level. System support capability reflects the capability of the support system, focusing more on inputs such as the types and quantities of support resources, and depicting the inherent capability of the system's support system; in addition to inputs, support effectiveness also focuses on outputs and emphasizes the actual effects in practice.

After research, the definition of support effectiveness is given as follows: it is the measurement of the ability of a support system to ensure that the supported object can economically and effectively meet the requirements of operational readiness and mission sustainability under the expected or specified operational conditions.

3. Research on the Parameter System of Support Effectiveness

To accurately analyze the parameter measurement of support effectiveness, it is necessary to analyze the influencing factors of support effectiveness one by one and identify the key ones, so as to establish a relatively concise and outline parameter system for support effectiveness. Generally, the influencing factors of support effectiveness can be divided into four categories: mission-related, system structure-related, design characteristic-related and support system-related factors.

(i) Mission-related Factors

Mission-related factors refer to the mission modes corresponding to the tasks to be performed by the system. By sorting out the key work links of the system in performing support missions, the key mission-related influencing factors of support effectiveness are extracted. Generally, the main parameters describing the system's mission mode include: mission content, mission duration, and the number of systems performing the mission.

(ii) System Structure-related Factors

System structure-related factors refer to the system composition, which denotes the interrelationships and configuration of each subsystem and component of the system. The key system structure-related influencing factors of support effectiveness can be extracted by analyzing the hierarchical structure of the supported objects and support systems in the system.

(iii) Design Characteristic-related Factors

Design characteristic-related factors mainly refer to reliability, maintainability, testability, support design characteristics and other factors, such as Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR).

(iv) Support System-related Factors

A support system can be described from three perspectives: support organization, support function and support resources. Generally, the characteristics of a support system include timeliness, deployability, economy, universality, availability, survivability and effectiveness. The effect of a support system in providing support for the supported object can be measured by timeliness, deployability and effectiveness.

The exertion of support effectiveness is not only affected by the inherent characteristics of the system, but also largely depends on the support capability of the support system such as spare parts and maintenance. Generally, its effectiveness can be reflected by top-level parameters such as operational readiness capability, mission sustainability capability and economic affordability. The basic parameters determining the above top-level parameters are mainly identified from two aspects: the design characteristic parameters of the system and the system characteristic parameters of the support system. Therefore, innovatively built a three-level with 22 parameters for support effectiveness parameters system, as shown in Figure 1.

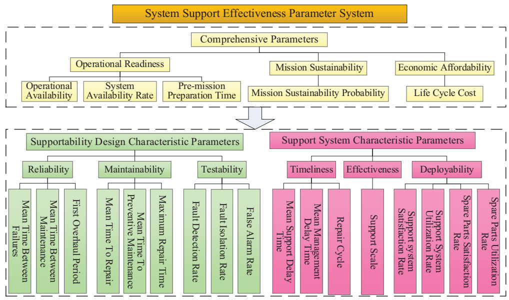

Figure 1 Overall Framework of the Support Effectiveness Parameter System

4. Construction of the Support Effectiveness Model

System support can be divided into two categories: operational support and maintenance support. A better description of the operational and maintenance support processes of the system system can be achieved by studying the interaction between missions, supported objects and support systems. Missions determine the operational intensity and environment of the supported objects and drive their operation; at the same time, missions also put forward support requirements for the support system. The attributes and operational characteristics of the supported objects affect the design of the support system; conversely, the operation of the support system also affects the serviceable status of the supported objects, and thus the completion of missions. The interaction between the three is shown in Figure 2.

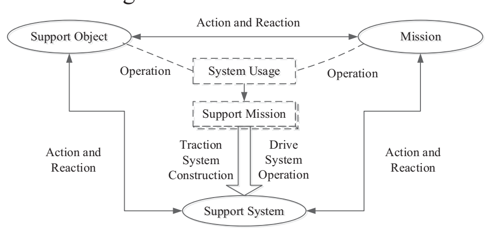

Figure 2 Interaction between Missions, Supported Objects and Support Systems

Based on the research on the interaction between missions, supported objects and support systems, the overall idea of building a support effectiveness simulation model is proposed, as shown in Figure 3. The construction of the simulation static model mainly includes two categories: the modeling of supported objects and the modeling of support systems (organizational elements, resource elements, functional elements); the simulation dynamic model represents the business processes between static models, including mission modeling and support process modeling.

Mission types are divided according to fixed mission mode, regenerative mission mode and continuous mission mode; according to the mission types, the scope of involved supported objects (systems, subsystems, single machines, etc.) is refined, driving the relevant support processes such as pre-mission operational support process, post-mission operational support process, preventive maintenance process, corrective maintenance process, support resource use process and transportation process;

The support system is allocated and called in accordance with the process steps involved in different support processes; under the overall planning of functional elements, the support organizational elements such as maintenance level, support site and support sub-site, as well as resource elements such as human resources, material resources and information resources are

integrated; the support for the application of various individual support processes or the comprehensive application of different support processes is realized from the three aspects of organizational elements, resource elements and functional elements;

The permutation and combination of support processes are extracted according to different missions, and on the basis of the support system's support for the support processes, the support of the support processes for the missions is realized.

4.1 *Supported Objects*

The modeling of supported objects includes two parts: system composition and its attributes. The breakdown structure of supported objects refers to the physical or functional composition structure of supported objects established from the perspective of support analysis, i.e., the hierarchical division of the product's structure or functions. Therefore, the modeling of supported objects should be based on the product tree of the main combat system, and the relevant information for building the model of supported objects should be obtained from the product tree. Generally, the system hierarchy is divided into: system, subsystem, single machine, Line Replaceable Unit (LRU) and Shop Replaceable Unit (SRU).

4.2 *Support System*

4.2.1 *Support Organization*

Support organization refers to the setup of support institutions. Support sites are an important part of support organizations, serving as the places for system deployment, operation and maintenance, and storage of support resources. Maintenance levels are the grades of support sites, divided according to the scope and depth of system maintenance and the sites where maintenance is performed.

Support organizations are divided by maintenance levels; there can be multiple sites at a certain maintenance level, and each site can be further divided into several sub-sites. For example, spare parts warehouses, tool rooms, maintenance workshops and system rooms all

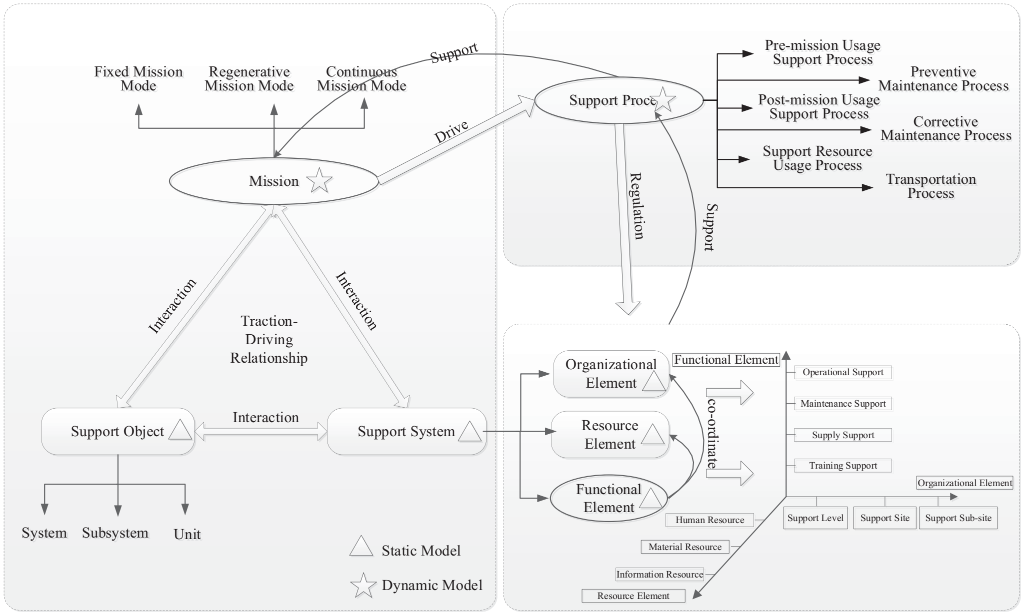

Figure 3 Overall Idea of Constructing the Support Effectiveness Model

belong to the sub-sites included in a specific base-level site. Therefore, the basic elements of the organizational structure of a support system are support sites or sub-sites, as shown in Figure 4. A support organization can be described by the support relationships between support sites and the business relationships between support sub-sites. After refining the sub-site composition of support sites, the operation of the internal support processes of specific sites can be accurately analyzed.

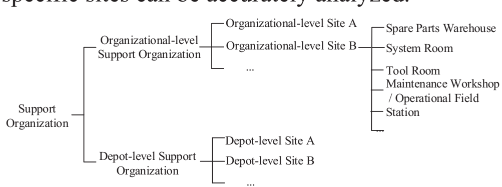

Figure 4 Organizational Structure of the Support System

4.2.2 *Support Resources*

Support resources are the material basis for carrying out operational and maintenance support work, and the most basic elements constituting a support system. Specific support functions can be realized by combining support resources with corresponding operation /maintenance rules; at the same time, specific support organizations are formed by combining support resources with corresponding organizational rules for resource storage and management. The classification and composition of resource elements can be described by four definitions: resource type, resource entity, resource aggregation and resource combination.

1) Resource type: Describes the resources of the support system from the perspective of resource classification, including three categories: human resources (e.g., personnel), material resources (e.g., spare parts/consumables, tools/system and facilities) and information resources (e.g., documents/information). Each type of sub-resource has the attributes of its parent resource.

2) Resource entity: Refers to the bottom-level support resources that cannot be further divided.

3) Resource aggregation: Refers to a collection of resource entities with the same attributes and behaviors, which are organized together to facilitate resource classification, production and management.

4) Resource combination: Refers to a collection of different types of resource entities,

which are organized together to jointly realize support functions.

The resource structure of the support system is shown in Figure 5, and the specific explanation of resource types is as follows.

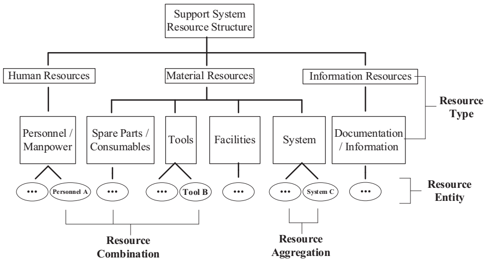

Figure 5 Resource Element Structure of the Support System

4.2.3 *Support Functions*

Support functions are determined by missions and realized by operational and maintenance support work items. Support function types can be divided into three categories: operational support, maintenance support and supply support. Among them, operational support and maintenance support are the core of support functions; supply support is an important component of support functions, which directly affects the quality of the realization of operational and maintenance support functions.

The functions of a support system are determined by its tasks and realized by support work items. The functional types of a support system can be divided into operational support functions, maintenance support functions and supply support functions. Operational support and maintenance support are the core elements of the support system's functions, directly reflecting the level of the support system's support capability; supply support is one of the factors affecting the operational and maintenance support capability, and a secondary element of support functions. The specific composition of different support function classifications is shown in Figure 6.

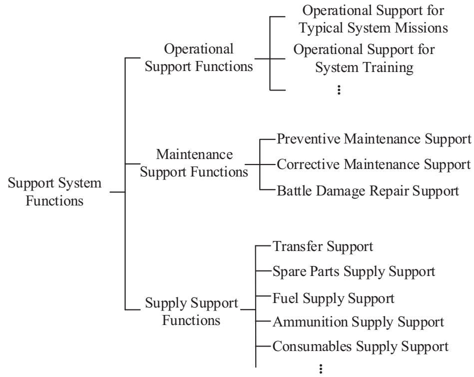

Figure 6 Functional Structure of the Support System

4.3 *Missions and Processes*

A general mission description consists of time description, space description and system description. The assumptions for building the system mission model of basic units in this research are as follows:

1) In terms of time description, it is assumed that the start time of each mission of a basic unit is determined under a certain scenario background, and the impacts of environmental factors, command factors, the opponent's actions, etc., on the mission start time or whether the mission is executed are not considered.

2) In terms of space description, it is assumed that the support organization associated with the basic unit remains unchanged throughout the mission scenario, i.e., the system returns to the initial support organization after each mission execution.

3) In terms of system description, it is assumed that a basic unit consists of a fixed number of system of the same model.

The modeling of support processes includes six categories: pre-mission operational support process, post-mission operational support process, preventive maintenance process, corrective maintenance process, support resource use process and transportation process.

5. Research on the Calculation Method of Support Effectiveness

This paper holds that the level of a system's support effectiveness is comparative, and is an evaluation of the support effect of the support schemes for the system and its support system. Therefore, the super-efficiency data envelopment analysis method can be used to calculate the efficiency values of various support schemes, and the efficiency values can be regarded as the support effectiveness index to evaluate support effectiveness. The higher the operational readiness and mission sustainability, and the fewer personnel, costs and time required, the higher the support effectiveness.

The research idea of the calculation method is to sort out two types of indicators: input indicators that affect the level of support effectiveness, and output indicators that reflect the level of support effectiveness. Then, a support effectiveness evaluation model based on super-efficiency data envelopment analysis is constructed. The indicator data under the support effectiveness parameter system corresponding to different support schemes are taken as model inputs. By solving and calculating the super-efficiency data envelopment analysis model, the efficiency values of different support schemes, namely the support effectiveness index, are obtained. The support effectiveness of each support scheme is ranked according to the support effectiveness index of each scheme.

$$\min \theta$$
$$s.t.\begin{cases} \sum\limits_{\substack{j=1 \\ j\neq j_0}}^{n} X_j\lambda_i + S^- = \theta X_0 \\ \sum\limits_{\substack{j=1 \\ j\neq j_0}}^{n} Y_j\lambda_i + S^+ = Y_0 \\ S^-, S^+, \lambda_j \geq 0 \\ j = 1,2,\ldots,n \end{cases} \tag{1}$$

In the formula, θ is the efficiency value, which is the objective function of the dual model, X_j is the j-th input indicator; Y_j is the j-th output indicator, X_0 is the input column vector of the target decision-making unit; Y_0 is the output column vector of the target decision-making unit, S^- and S^+ are slack variables; λ_i , $(j = 1,2,...,n)$ are the linear combination coefficients of n decision-making units.

The result of the j-th scheme obtained from the above formula is denoted as θ^* 、 S^{*-} and S^{*+} .Based on these, the definitions for judging model effectiveness are as follows:

(1) If $\theta^* = 1, S^{*-} = 0$ and $S^{*+} = 0$, then DMU_j is DEA efficient, indicating that among the n schemes, the input X_j can achieve the maximum output Y_j .

(2) If $\theta^* = 1$ and at least one of $S^{*-} > 0$ or $S^{*+} > 0$ holds, then DMU_j is weakly DEA efficient, meaning that among the n schemes, the scheme can be improved by adjusting inputs or increasing outputs. $S^{*-} > 0$ indicates that an input indicator of scheme DMU_j is not fully utilized; $S^{*+} > 0$ indicates that an output indicator of scheme DMU_j is not optimal, and output can be increased without changing input.

(3) If $\theta^* < 1$, then DMU_j is DEA inefficient,which means the support scheme needs to be improved.Higher support effectiveness can be achieved by reducing inputs of personnel, cost and equipment, or by improving equipment satisfaction rate, etc.

Taking the support effectiveness evaluation of a certain system as an example, the application of the super-efficiency data envelopment analysis method in scheme evaluation is mainly as follows.An evaluation index system is constructed, with maintenance personnel, maintenance equipment, number of spare parts, and cost as input indicators, and operational readiness rate as the output indicator.There are 8 alternative support schemes, and the corresponding data of each scheme are shown in Table 1.

Table 1: Support Effectiveness Data

Scheme	Maintenance Personnel / Person	Maintenance Equipment / Unit	Spare Parts / Piece	Cost / Ten Thousand Yuan	Integrity Rate / %
Scheme 1	1000	800	15000	120	85
Scheme 2	2000	1200	10000	130	90
Scheme 3	2500	1500	10000	140	92
Scheme 4	3000	2000	7000	150	95
Scheme 5	3000	2000	6500	160	96
Scheme 6	3500	2500	5000	180	98
Scheme 7	4000	2800	4500	200	98.5
Scheme 8	4500	3000	4000	220	99.5

Table 2 Calculation Results of Support Effectiveness Indices for Eight Support Schemes

Scheme	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	θ^*	Efficiency Analysis
Scheme 1		0.9444	0	0	0	0	0	0	1.8889	Efficient
Scheme 2	0.0264		0.9539	0	0	0	0	0	1.2099	Efficient
Scheme 3	0	0.8497		0.1634	0	0	0	0	0.9641	Inefficient
Scheme 4	0	0.1977	0		0.8043	0	0	0	1.0292	Efficient
Scheme 5	0	0.3413	0	0		0.6662	0	0	1.0375	Efficient
Scheme 6	0	0	0	0	0.3556		0.6484	0	1.0458	Efficient
Scheme 7	0	0	0	0	0	0.4987		0.4987	0.9975	Inefficient
Scheme 8	0	0	0	0	0	0	1.0102		1.1364	Efficient

Taking the support effectiveness data as input, the super-efficiency data envelopment analysis (DEA) model to be solved and calculated is as follows:

$$\min_{\lambda,\theta} \theta$$
$$s.t.\begin{cases} 20\lambda_2+25\lambda_3+30\lambda_4+30\lambda_5+35\lambda_6+ \\ 40\lambda_7+45\lambda_8 \le 10\theta \\ 12\lambda_2+15\lambda_3+20\lambda_4+20\lambda_5+25\lambda_6+ \\ 28\lambda_7+30\lambda_8 \le 8\theta \\ 100\lambda_2+100\lambda_3+70\lambda_4+65\lambda_5+50\lambda_6+ \\ 45\lambda_7+40\lambda_8 \le 150\theta \\ 130\lambda_2+140\lambda_3+150\lambda_4+160\lambda_5+ \\ 180\lambda_6+200\lambda_7+220\lambda_8 \le 120\theta \\ 90\lambda_2+92\lambda_3+95\lambda_4+96\lambda_5+98\lambda_6+ \\ 98.5\lambda_7+99.5\lambda_8 \ge 85 \\ \lambda_i \ge 0, i=1,2,\ldots,8, \theta \in R \end{cases} \tag{2}$$

By solving the model using software, the optimal solution of the support effectiveness index for Scheme 1 is obtained: $\theta_1^*=1.8889$, $\lambda_2=0.9444$, $\lambda_3=\lambda_4=\lambda_5=\lambda_6=\lambda_7=\lambda_8=0$. Therefore, Scheme 1 is DEA efficient. Similarly, the support effectiveness indices of other schemes can be calculated, and the results for all schemes are shown in Table 2.

According to the efficiency analysis results in Table 2, Schemes 1, 2, 4, 5, 6, and 8 are all DEA efficient, while Schemes 3 and 7 are DEA inefficient. Furthermore, among the 6 DEA-efficient support schemes, the ranking based on the evaluation results of the support effectiveness index is: Scheme 1 > Scheme 2 > Scheme 8 > Scheme 6 > Scheme 5 > Scheme 4. Therefore, it can be concluded that the support scheme with the highest support effectiveness index is Scheme 1.

6 Conclusion

This paper investigates the current status of support effectiveness at home and abroad, and on this basis, studies and proposes the concept and connotation of system support effectiveness, and constructs an system support effectiveness parameter system including comprehensive parameters, supportability design characteristic parameters and support system characteristic parameters. Based on the research on the interaction between missions, supported objects and support systems, a support effectiveness simulation model is built from the perspectives of static models and dynamic models,and carry out the calculation of support effectiveness using the super-efficiency data envelopment analysis method The above research lays a foundation for the comprehensive evaluation of system support effectiveness, and the ideas provided offer a reference for the subsequent development of relevant research.

References

[1] Song T L, Wang Y L, Fang Y, et al. General Theory of the Grand System Support Concept[M]. Beijing: National Defense Industry Press, 2014.
[2] Guo Q S, Zhi Z G, Yang R P, et al. Introduction to System Effectiveness Evaluation[M]. Beijing: National Defense Industry Press, 2005.
[3] Li K, Huang Z J, Wu X J. Research on Mission Issues in Simulation Evaluation of System Support Effectiveness[J]. Computer and Digital Engineering, 2018,46(10):1995-1998.
[4] Zhang K, Jia Y X, Jiao Y. Evaluation Methods for Typical Parameters of Aviation System Support Effectiveness[J]. Fire Control & Command Control, 2020,45(7):110-114.