Maintenance Support System Constitution Analysis Based on FNDA

YUWEN FU and JIANPING HAO

ABSTRACT

A main battle equipment is often followed by a large maintenance support system as a support. It becomes a key part of the war to win whether the maintenance of the operation of the system is smooth. This paper introduces the idea of functional dependency network analysis (FDNA). This approach will provide new ideas for the study of maintenance support system constitution and maintenance concepts.

KEYWORDS

Maintenance Support System, Function Dependency Network Analysis, System Components.

INTRODUCTION

In modern warfare, the importance of maintenance support system is becoming more and more obvious. A main battle equipment is often followed by a large maintenance support system as a support. The outcome of the war is no longer decided only by the performance of the equipment itself. It becomes a key part of the war to win whether the maintenance of the operation of the system is smooth. However, unlike the equipment system in the general sense, the maintenance support system has the complex interaction between the various elements within the system due to the influence of many uncertain factors, and its design process is hindered.

For more and more large and increasingly complex maintenance and security system, how to rationally configure it to ensure the continuous operation of equipment support capacity and maximize its function, become an important problem facing our army. In view of this problem, this paper introduces the idea of functional dependency network analysis (FDNA). Functional dependency network analysis is a way to model and measure the dependencies between the various elements within the system [1]. In recent years, FDNA technology has been applied to the maintenance and architecture analysis of aeronautical systems [2], to solve the problem of information transfer in collaborative satellite networks [3], technology development of R & D process modeling [4] and security analysis of satellite navigation systems [5,6] and other areas. This approach will provide new ideas for the study of maintenance support system constitution and maintenance concepts.
INTRODUCTION TO FDNA

Functional Dependency Network Analysis (FDNA) was first proposed by Garvey and Pinto et al. [7] to analyze the impact of a system functional failure on other system performance with dependencies. The technique is based on graph theory, which can express the relationship between elements within the system clearly and provide a way to measure the dependencies between elements.

Basic Theory

First of all, we need to clear the meaning of dependence in FDNA technology. In the FDNA diagram, dependency is a condition that exists between two nodes, where the performance of a node may depend to some extent on the performance of another node. As shown in Figure 1.

Effectiveness as a macro concept, representing a system or subsystem of a state, is the node in a certain condition and the expected expectations of the functional embodiment. The level of performance that a node can achieve can be represented by a measure or "running capacity" [8]. In FDNA, the level of efficacy of the receiver nodes is affected by two dependency characteristics. The first is the intensity of the receiver node dependent on the feeder node. The second is that the dependency between the feeder node and the receiver node is critical to the level at which the receiver node can achieve its performance level. We call them Strength of Dependency (SOD) and Criticality of Dependency (COD).

For example, assume that the receiver node $N_j$ in Figure 1 is the vehicle chassis system and the feeder node $N_i$ is the vehicle control system. If the full performance level of the chassis system is 600 miles per hour, then $P_j(x_j = 600) = 100$. In the absence of any contribution of $N_i$, $N_j$ can only reach 400 miles per hour. If the speed of 400 miles is recorded as the level of performance 60, that is $P_j(x_j = 400) = 60$. This represents the basic level of $N_j$ performance is 60. It is assumed that the control of the feeder node is ideal for the normal operation of the chassis system. If there is no control output, the chassis will run erratically, its components will be depleted, and the performance level of the chassis will be reduced from the basic level 60, and ultimately completely unavailable, that is, the level of performance is 0.

Thus, depending on the level of performance of the feeder node, the level of performance of the receiver node can be represented by a general function

Figure 1. An FDNA Graph Models Dependency Relationships.
\[ P_j = f(\alpha_{ij}, \beta_{ij}, P_i), 0 \leq \alpha_{ij} \leq 1, 0 \leq \beta_{ij} \leq 100, 0 \leq P_i, P_j \leq 100 \] (1)

In the formula: \( P_j \) is the performance level of \( N_j \), \( \alpha_{ij} \) is strength of dependency, \( \beta_{ij} \) is criticality of dependency, \( P_i \) is the level performance of \( N_i \).

**Build the Model**

In general, the function can be determined according to the principle of the barrel

\[ P_j = \text{Min}\left[g(\alpha_{ij}, P_i), h(\beta_{ij}, P_i)\right], 0 \leq P_i, P_j \leq 100 \] (2)

Where:

\[ g(\alpha_{ij}, P_i) = SODP_j = \alpha_{ij}P_i + 100(1-\alpha_{ij}) \] (3)

\[ h(\beta_{ij}, P_i) = CODP_j = P_i + \beta_{ij} \] (4)

More generally, the level of performance of a node \( N_j \) depends on the operational level of \( k \) feeder nodes \( N_1, N_2 \cdots N_k \)

\[ 0 \leq P_j \leq \text{Min}(SODP_j, CODP_j) \leq 100 \] (5)

Where:

\[ SODP_j = \text{Avg}(SODP_{j1}, SODP_{j2} \cdots SODP_{jk}), SODP_{ji} = \alpha_{ij}P_i + 100(1-\alpha_{ij}) \] (6)

\[ CODP_j = \text{Min}(CODP_{j1}, CODP_{j2} \cdots CODP_{jk}), CODP_{ji} = P_i + \beta_{ij} \] (7)

\[ 0 \leq \alpha_{ij} \leq 1, 0 \leq \beta_{ij} \leq 100, 0 \leq P_i, P_j \leq 100, i = 1, 2 \cdots k \]

**DETERMINE \( \alpha_{ij} \) AND \( \beta_{ij} \)**

There are many ways to determine the strength of dependency and criticality of dependency between nodes in a FDNA graph. Here is the general method.

First, \( \alpha_{ij} \) can be determined by the level of performance of the receiver node. Then it is necessary to determine the basic performance level of the receiver node by determining whether there is no contribution from the feeder node. If the level of performance is 0, then \( \alpha_{ij} = 1 \); if it is 50, then \( \alpha_{ij} = 0.5 \); if it is 70, then \( \alpha_{ij} = 0.3 \), and so on. Therefore, \( \alpha_{ij} \) can be obtained from the following formula \( 100(1-\alpha_{ij}) = x \). Where \( x \) is the basic level of performance of the receiver node in the absence of feeder nodes. The greater \( \alpha_{ij} \) is, the stronger the dependence of the receiver nodes on the feeder nodes.
Second, the criticality of dependency represents the performance level of the feeder node have constrain on the performance level of the receiver node. Even if the other feeder nodes reach the maximum performance level, the receiver node may be limited by one feeder node. For a receiver node $N_j$ with $m$ feeder nodes, the performance level cannot exceed any $P_i + \beta_{ij}$ of the nodes, $0 \leq \beta_{ij} \leq 100, i = 1, 2 \cdots m$.

**ANALYSIS OF COMPONENTS OF MAINTENANCE**

The maintenance support elements shall include, but not be limited to, the following 14 items: (1) product support management; (2) design interface; (3) maintain project; (4) supply support; (5) maintenance planning and management; (6) packaging, handling, storage and transportation; (7) technical information management; (8) support and testing equipment; (9) training and training supply; (10) manpower and personnel; (11) support facilities and infrastructure; (12) computer resources and software support; (13) product support budget and funds; (14) Environment, safety and occupational health.

At the same time, it should be noted that in the analysis of the maintenance of the relationship between the elements of the system, we cannot put aside the equipment or system characteristics, because the maintenance of the ultimate goal of the maintenance system is to make the entire equipment system to complete the scheduled task and achieve the required requirements. Therefore, the equipment or system RAM (reliability, availability, maintainability) requirements should also be taken into account, as a maintenance of information sources and drivers, according to which to reach the establishment of a dependency model.

The RAM requirements of the equipment generally include the mean time between failures (MTBF), mean time to repair (MTTR), and so on. Table 1 lists the possible RAM requirements and work items.

When considering the interrelationships between maintenance support elements, the impact of RAM requirements on maintenance support elements should be accurately addressed. For example, the mean time to repair as an average time to take a repair service will affect the downtime of the repair, which will affect maintenance planning and human resources, and the mean time to repair is an important measure of controlling fund and training system

| Table 1. RAM Demands and Work Items. |
|--------------------------------------|
| **RAM Demands and Work Items**       |
| Mean Time Between Failures (MTBF)    |
| Mean Time to Repair (MTTR)           |
| Mean Logistic Delay Time (MLDT)      |
| Operational availability (AO)        |
| Material Availability (Am)           |
| Material Reliability                 |
| System Analyses (FMECA)              |
| ...                                  |
Figure 2. Demonstration of a Maintenance Support System.

By analyzing the influence of RAM requirements on the maintenance support elements and the interaction between them, the function-dependent network model of the maintenance support system can be established according to the analysis process of FDNA technology. Figure 2 shows partial relationships between the elements of maintenance support system.

**EXAMPLE ANALYSIS**

The study of the relationships between the elements of the maintenance system is a complex analysis process, related to maintenance resources, human resources, environmental conditions and other aspects. Here is only a part of the relationships between elements as a research object, with which we make a brief analysis for the reader reference.

**Build the Model**

Combined with the above diagram of the maintenance system elements of the relationship diagram, we establish a maintenance support system dependent network relationship model, as shown in Figure 3.

We transfer the RAM requirements through the relevant theory into reliability, maintainability and other functional parameters, such as $R = e^{\frac{t}{MTBF}}$; $M = 1 - e^{\frac{t}{MTTR}}$, and multiplied by 100 to obtain its performance level. As input conditions of functional dependency network analysis, can we establish FDNA equation? Maintenance planning, supply support, human resources and training, facilities, funds, etc. are calculated according to the following formulas.

Figure 3. Basic Dependent Network Model
\[ p_4 = \min \left( \frac{\alpha_{24} P_2 + \alpha_{43} P_3 + \alpha_{54} P_5 + \alpha_{74} P_7 + \alpha_{84} P_8}{5} + 100 \left( 1 - \frac{\alpha_{24} + \alpha_{34} + \alpha_{54} + \alpha_{74} + \alpha_{84}}{5} \right) \right) \]

\[ p_2 = \beta_{24} P_2 + \beta_{34} P_3 + \beta_{54} P_5 + \beta_{74} P_7 + \beta_{84} \]

\[ p_3 = \min \left( \frac{\alpha_{15} P_1 + \alpha_{35} P_3 + \alpha_{85} P_8}{3} + 100 \left( 1 - \frac{\alpha_{15} + \alpha_{35} + \alpha_{85}}{3} \right) \right) \]

\[ p_6 = \min \left( \frac{\alpha_{16} P_1 + \alpha_{26} P_2 + \alpha_{46} P_4 + \alpha_{86} P_8}{4} + 100 \left( 1 - \frac{\alpha_{16} + \alpha_{26} + \alpha_{46} + \alpha_{86}}{4} \right) \right) \]

Based on the data of the maintenance support system of a certain type of artillery as well as the expert evaluation result, the model is analyzed. Table 2 lists the values of the strength of dependency and criticality of dependency between the various elements of the maintenance support scheme.

The conversion of the three sets of performance data of MTTR, MTBF and MLDT are taken into the calculation, and the results obtained in Table 3.

**TABLE 2. VALUES OF \( \alpha_{ij} \) AND \( \beta_{ij} \).**

| \( i/j \) | \( \alpha_{ij} \) | \( \beta_{ij} \) | \( i/j \) | \( \alpha_{ij} \) | \( \beta_{ij} \) |
|---|---|---|---|---|---|
| 1/5 | 0.45 | 0 | 3/5 | 0.20 | 0 |
| 1/6 | 0.15 | 0 | 4/6 | 0.25 | 35 |
| 1/7 | 0.35 | 0 | 5/4 | 0.30 | 20 |
| 1/8 | 0.20 | 0 | 7/4 | 0.35 | 20 |
| 2/4 | 0.25 | 0 | 8/4 | 0.25 | 25 |
| 2/6 | 0.20 | 0 | 8/5 | 0.20 | 30 |
| 2/8 | 0.20 | 0 | 8/6 | 0.35 | 25 |
| 3/4 | 0.30 | 0 | 8/7 | 0.15 | 35 |
| 3/5 | 0.20 | 0 | |

**TABLE 3. INPUT AND OUTPUT ANALYSIS OF DEPENDENCY MODEL.**

| input       | Group1 | Group2 | Group3 |
|-------------|--------|--------|--------|
| MTBF        | N1     | 95     | 85     | 75     |
| MTTR        | N2     | 85     | 75     | 95     |
| MLDT        | N3     | 75     | 95     | 85     |
| Maintenance planning | N4     | 75     | 75     | 85     |
| Supply support | N5     | 75     | 85     | 75     |
| Manpower and training | N6     | 85     | 75     | 75     |
| Facilities  | N7     | 95     | 85     | 75     |
| Fund        | N8     | 85     | 75     | 75     |
Analysis of Results

The results can be based on positive and negative two different analytical ideas to carry out different conclusions and achieve different purposes.

(1) positive analysis

Seen from Table 3, RAM requirements have a heavy influence on the various elements of the maintenance support system. And the performance level of each factor often depends on the weakest link of the equipment development. For example, MTBF will have an impact on the maintenance frequency of the maintenance plan, so that it can affect the entire maintenance planning stage and activities of the decision-making requirements. As the MTBF time changes, the type and quantity of spare parts will change, and with the changes in reserve costs, it will affect the entire supply support program. At the same time, the required maintenance manpower will also be adjusted for changes in the time interval between failures. MTBF will also require the equipment to be equipped to meet the number of repaired products, which directly affects the space used for repair and storage as well as the power requirements. Finally, all maintenance activities, spare parts facilities, human resources have direct relationships with the funds, which also reflects that MTBF plays a decisive role in funding requirements.

(2) Negative analysis

This idea is mainly used in the maintenance support system configuration design with RAM as the basis, reaching a reasonable optimization of the system structure and related configuration. Take MTTR as an example. It is the average time for the implementation of repairable maintenance, including the detection, positioning, isolation, repairing, verification and other time. Therefore, equipment designers tend to pursue as short as possible MTTR, and achieve a higher level of maintenance. In such a goal, in the design of the maintenance support system, the elements should be integrated to meet the maintenance requirements. Specifically, for maintenance planning, a reasonable and effective maintenance strategy should be developed to minimize the downtime of the repair. At the same time, it should be equipped with the appropriate personnel to meet the system for human needs, and planned to achieve the ability to target the training system. Providing funds at the system development stage to achieve shorter average recovery time can increase system availability to reduce the system's life cycle costs.

SUMMARY

At present, most of the researches on maintenance support system focus on the research of system performance evaluation and index evaluation. The relationship between the constituent elements of the maintenance support system is relatively less, which is not conducive to the design of the maintenance system and the development of the corresponding maintenance concept.

This paper uses FDNA technology, establishing the dependency network model of various elements of the maintenance system and related RAM requirements. Readers can get the interaction between the various elements, as well as the impact of RAM, so that can provide reference and basis for maintenance support system design. When more effective information is obtained, the dependency network model of the
maintenance support system can be further expanded to obtain more accurate factor analysis and functional configuration.

REFERENCES

1. Paul R. Garvey, C Ariel Pinto. Introduction to Functional Dependency Network Analysis[J]. Massachusetts Institute of Technology, Cambridge, Massachusetts, June 15-17, 2009.
2. Guariniello C, De Laurentis D. Communications, information, and cyber security in systems-of-systems: assessing the impact of attacks through interdependency analysis [J]. Procedia Computer Science, 2014, 28: 720-727.
3. Drabble B. Information propagation through a dependency network model[C]/2012 International Conference on Collaboration Technologies and Systems (CTS), Denver, Colombia, IEEE, 2012: 266-272.
4. Sun Ya-dong, Zhang Xu, Ning Ru-xin, Wang Kai. Development process model of dynamic response based on dependency relationship between index parameters[J]. Computer Integrated Manufacturing Systems, 2013, 19(7):1509-1519.
5. Wang Y, Zhang W X, Li Q. Functional dependency network analysis of security of navigation satellite system [J]. Applied Mechanics and Materials, 2014, 522-524: 1192-1196.
6. Zhang W X, Wang Y, Li Q. An improved functional dependency network model for SoS operability analysis [J]. Applied Mechanics and Materials, 2014, 602-605: 3355-3358.
7. Garvey P R, Pinto C A. Advanced risk analysis in engineering enterprise systems [M]. Florida: Chemical Rubber Company Press, 2012.
8. Bernoulli, D., 1738. Exposition of a New Theory on the Measurement of Risk [J]. The Econometric Society, 1954, 22(1): 23-36.