A Modeling and Calculating Method for Mission Reliability of Multiple Use Schemes System

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***Abstract*—Considering the difficulty in designing large electromechanical systems and high cost for construction, the system redundancy design often prepares a variety of use schemes in advance, while the cost-benefit ratio of parallel, voting and other redundant methods employed by electronic equipment is not efficient enough. Based on discrete simulation algorithm, this paper proposes a method to model and calculate the mission reliability block diagram for multiple use schemes system, which is easy to understand and applicable, and helpful to get a quick result.**

Keywords-multiple use schemes; mission reliability; discrete simulation algorithm

I. INTRODUCTION

As it's difficult to design large electro- mechanical systems and costly for construction, the system redundancy design often prepares a variety of use schemes in advance. Taking vessel devices as an example, if its propulsion sets include 4 machines and 4 propellers, there will be three use schemes prepared, i.e. propelled simultaneously by 4 machines and 4 propellers, only by external 2 machines and 2 propellers, or only by inner 2 machines and 2 propellers, as shown in Fig. 1. In this circumstance, if 1 machine and 1 propeller fail to work, a backup plan is still available, thus improves the mission reliability of the system.

Traditional mission reliability models like cascade, parallel, vote, joint and etc.[1] have difficulties in describing the mission reliability logic of multiple use schemes. They are hard to get understood by people of non-reliability major, and have a quite complex process of analysis and calculation. Therefore simplified modeling and calculating is adopted at the present projects, however, its calculating results are imprecise.

As multiple use schemes system is quite common in large complex systems, calculating its mission reliability has become a short board.

Large complex systems mostly use discrete simulation algorithm to calculate and analyze mission reliability [2], and it is ordinary to use reliability block diagram or fault tree model to establish the mission reliability logic relationship of the system. Here take reliability block diagram model applied for vessel devices as an example, study the method to model and calculate the mission reliability of multiple use schemes system.

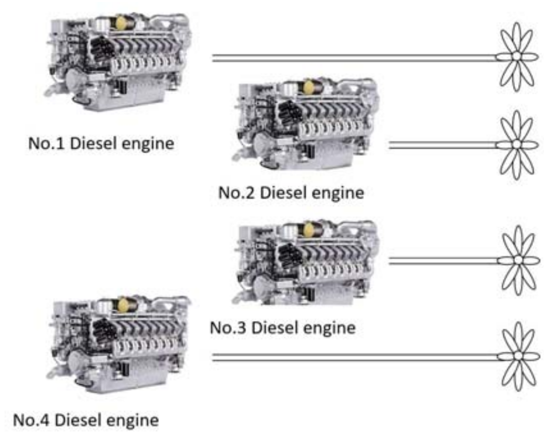

Figure 1. Multiple use schemes example

II. MISSION RELIABILITY LOGIC OF THE SYSTEM

A. *Analysis of Use Schemes*

In multiple use schemes system, the redundancy is usually achieved by a number of applicable combinations of devices within the scope of the system's composition, as shown in Fig. 1. Multiple schemes can be switched and replaced by each other, or connected in series or other different levels of redundancy. The reliability logic in each scheme shown in Fig. 1 is relatively simple, as shown in Fig. 2 to Fig. 4.

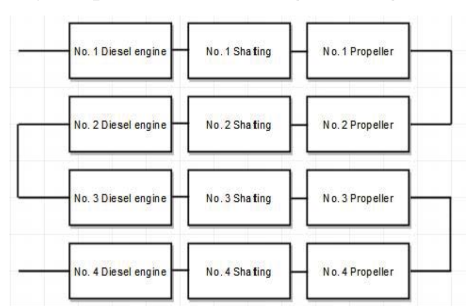

Figure 2. Scheme 1 mission reliability block diagram for 4 machines and 4 propellers

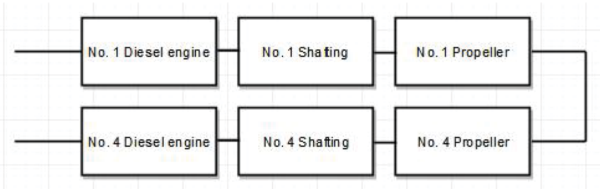

Figure 3. Scheme 2 mission reliability block diagram for external 2 machines and 2 propellers

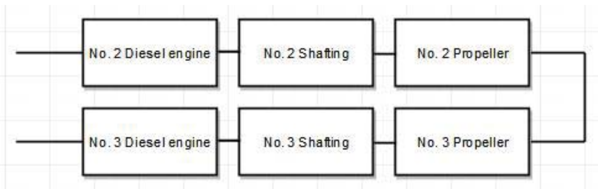

Figure 4. Scheme 3 mission reliability block diagram for inner 2 machines and 2 propellers

Normally, the system adopts the scheme 1 of being propelled simultaneously by 4 machines and 4 propellers. If there's one device failing to work, scheme 2 or 3 will take over until the broken device is repaired. But when there are two or more devices failing at the same time and neither scheme 2 nor 3 is able to process properly, the system will be unable to meet the required capacity and lead to a major failure. A standby model of cold storage could be used to express the traditional mission reliability logic, as shown in Fig. 5.

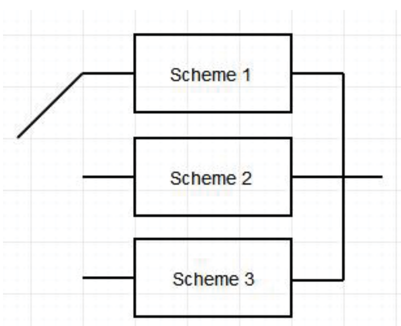

Figure 5. Standby model between schemes

However the model described in Fig. 5 is contrary to the basic assumption of the traditional reliability model in which every unit is independent to each other. As shown in Fig. 6, all devices in scheme 2 and 3 coincide with the devices in scheme 1.

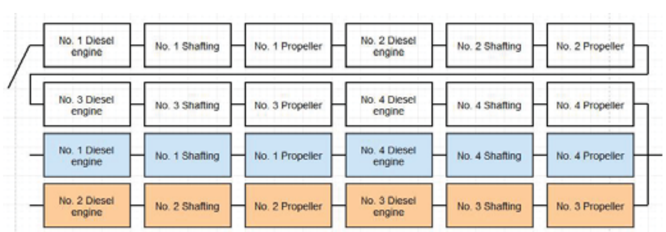

Figure 6. Coincidence between schemes

Reference to the mission reliability modeling method of the shared device [3], it is possible to label the corresponding devices in scheme 2 and 3 as shared devices.

B. *Logic Analysis of Mission Reliability*

In the traditional reliability modeling calculation process, if there's no maintenance, it should be as the following: firstly calculate the mission reliability of scheme1, then the possibility of adopting scheme 2 and its reliability, then the possibility and reliability of scheme 3, and finally the reliability of scheme shown in Fig. 5. However if take maintenance into consideration, it will be very complex to calculate the mission reliability. Therefore discrete simulation algorithm is usually applied.

The standby application between the schemes can be generally divided into two cases:

- The failure branch is shutdown for maintenance and the related branch stops as well, which can adopt the standby relation shown in Fig. 5;
- Neither the failure branch nor related branch is shutdown, which can adopt the parallel relation as is shown in Fig. 7.

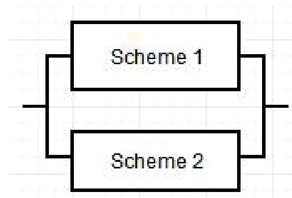

Figure 7. Parallel relation between schemes

Besides, there is also another case which is a blend connection of previous two situations as is shown in Fig. 8.

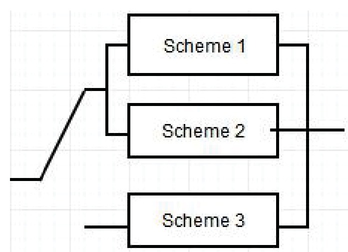

Figure 8. Blend connection

All of these three models could be used to describe the common situation of multiple use schemes.

III. CASE CALCULATING ANALYSIS

A. *Case Set*

The feasibility of the model referred in this paper can be analyzed by a simple case calculation. The system can be set as Fig. 1, while mission reliability block diagram as Fig. 6 and the reliability parameters of devices as Table I.

The devices are unrepairable when the system performs a mission.

Mission period: 200 hours.

TABLE I. THE SIMULATION MODEL PARAMETERS

Device	MTBF（h）	Failure distribution
No.1 Diesel engine	2000	Exponential
No.2 Diesel engine	2000	Exponential
No.3 Diesel engine	2000	Exponential
No.4 Diesel engine	2000	Exponential
No.1 Shifting Propeller	50000	Exponential
No.2 Shifting Propeller	50000	Exponential
No.3 Shifting Propeller	50000	Exponential
No.4 Shifting Propeller	50000	Exponential

B. Analysis Calculation

The system shown in Fig. 6 works by the initial usage scheme 1, described in branch 1. If the device fails in branch 2, it is converted to the scheme 3, described in branch 3; if the device fails in branch 3, it is converted to the scheme 2, described in branch 2. if both branch 2 and branch 3 have device failures, the system will have no available usage scheme, and serious system failure will occur.

The mission reliability calculation method is the probability that branch 1 has not been faulted, plus the probability that branch 3 has been faulted and branch 2 has not been faulted, plus the probability that branch 2 has been faulted and branch 3 has not been faulted, as in (1). Note that this is different from the calculation formula of the bypass model.

$$
\begin{aligned}
R_{system} &= R_{scheme1} + R_{scehme2} - R_{scehme2} \times R_{scheme3} \\
&\quad + R_{scheme3} - R_{scheme2} \times R_{scehme3} \qquad (1) \\
&= 0.66 + 0.8125 - 0.66 + 0.8125 - 0.66 \\
&= 0.965
\end{aligned}
$$

In other words, if any of the schemes 1, 2 and 3 can be reliable, the system mission is reliable, which is equivalent to the traditional mission reliability relationship between the equipment in scheme 2 and the equipment in scheme 3 in parallel, as shown in Fig. 10.

C. Result from the Simulation Method Referred in this Paper

Adopting the discrete simulation algorithm simulates 10^6 times, the result will be 0.964621. According to Monte Carlo simulation theory [4,5], the simulation result should be accurate to10^{-3}, then it’s 0.965.

The simulation main streamwith shared device [3] is shown in Fig. 9. Once the shared device fails, all the subsystems’ working state which contain the shared device need to be judged in parallel from the ground unit to the whole equipment stepwisely.

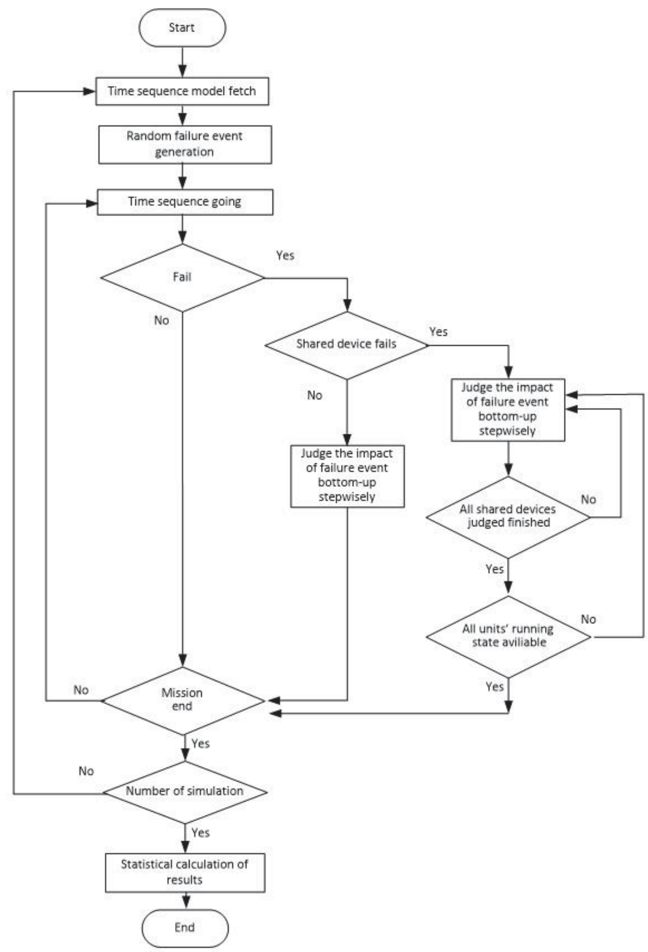

Figure 9. Simulation main stream with shared device in use

D. Result from Traditional Simulation Method

In fact, if there’s no maintenance, the system shown in Fig. 1 is equivalent to parallel connection of the two systems shown in scheme 2 and scheme 3, which can be shown as Fig. 10.

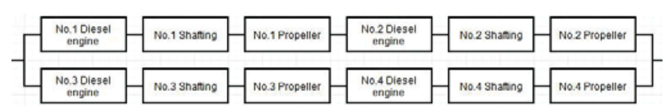

Figure 10. Traditional mission reliability model

Adopting the discrete simulation algorithm simulates 10^6 times for this model, the result will be 0.964968. And when the accuracy comes to 10^{-3}, it will be 0.965.

It is clear that the result from this paper’s method coincides with the discrete simulation result from traditional mission reliability model as well as the analysis calculation. So the modeling and calculating method provided by this paper is effective.

IV. CONCLUSION

This paper aims to solve the problem in modeling and calculating the mission reliability of multiple use schemes system. Based on the traditional reliability method, this paper deeply analyzes the characteristics of the device use and redundancy in multiple use schemes system, and introduces the method for the shared device, thus proposes a solution for multiple use schemes system.

From case study, it's obvious that the traditional modeling method for the mission reliability is incapable neither to describe mission reliability relations in a complex system, nor to set an abstract model for a simple system. Even a model like Fig. 9 is set, it will be difficult to get understood by general engineering designers, and has become a bottleneck in the system design.

The method proposed by this paper is simple and can be applied widely and universally. It is adaptable to the present modeling and calculating method for mission reliability of large complex system, and further completes it. And it also can be applied to set mission reliability model for large electromechanical systems, which extensively adopt multiple use schemes, by using the current system mission reliability block diagram. Meanwhile, as its calculation is worked out by discrete simulation algorithm, it provides a feasible method for the reliability calculation of large electromechanical systems.

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