The Verification Method of Maintainability Indexes of Equipment Based on UML

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Abstract: Aiming at the problem that traditional methods can not deal with intercurrent activity and dynamic action,a algorithm of complex equipment’s maintainability index validation based on CPN and UML was put forward.At first,we demarcated the color class of warehouse and order-brand,held in flux and arc with happen condition,and found CPN model of complex equipment.Then,we transformed CPN model to UML model based on the mapping rule from CPN to UML.At last,we programmed to implement it.This method could deal with intercurrent activity and dynamic action of system beautifully,could implement the conversion from the model to procedure structure corking, and had good mutual ability.At last, the author validated MTTR of certain equipment. The result indicated that the apply bound is wide and the maneuverability is fine.

1. Introduction
Maintainability is an inherent attribute of equipment, which is endowed by design. It is the ability of equipment to maintain or restore its specified state when it is maintained according to the specified procedures and methods under the specified conditions and within the specified time. For complex equipment, maintainability verification is to fully understand whether its maintainability is good, so as to ensure that equipment can be repaired quickly in the actual maintenance process, so as to restore the combat effectiveness, and then complete the task. Before the maintainability verification, it is necessary to establish maintainability indexes and reasonable maintainability verification models. The theory of Petri net [3,4] can deal with the concurrent activities and dynamic behaviors in the system well, and the colored Petri net (CPN) can distinguish the Token by coloring, which can make the complex coding required for the modeling of a particular operation easy to realize. In addition, UML [1,2] has the characteristics of good interaction and easy programming. After comparing the advantages and disadvantages of traditional maintainability index verification models, a maintainability index verification method of complex equipment based on colored PN and UML is proposed.

2. CPN Theory and UML Theory

2.1 CPN Theory
Petri net can be expressed as a five tuple \( N = (P,T,F,W,M_0) \), in which \( P = \{P_1,P_2,\cdots, P_m\} \) is the set of finite places; \( T = \{t_1,t_2,\cdots,t_n\} \) is the set of finite transition; \( F \subseteq (P\times T) \cup (P\times T) \) is the set of arcs connecting the place and transition; \( W : F \rightarrow \{1,2,3,\cdots\} \) is the weight function of directed arcs; \( M_0 : P \rightarrow \{0,1,2,\cdots\} \) is the initial marking of the place.
Petri net (PN) is a tool used to describe and analyze the system model to be developed, rather than a simulation tool under computer implementation. Its structure and software structure are different in nature and form. Therefore, it is necessary to establish a proper relationship between Petri net and program structure, so as to realize the transformation from Petri net to program structure. The colored Petri net distinguishes the token by coloring, which makes it easy to implement the complex coding needed in the modeling of a particular operation.

2.2 Basic Theory of UML
With the improvement of the complexity of software system, the need for a good modeling language becomes more and more urgent, so an object-oriented modeling language is proposed. In object-oriented modeling language, UML unifies modeling language by integrating multiple object-oriented modeling methods and multiple software engineering methods. UML is based on static modeling mechanism, including classes, interfaces, properties and relationships. Its dynamic model emphasizes the behavior of objects in the system, including their methods, interactions, collaborations and state changes. Generally speaking, UML is a general visual modeling language, which integrates many object-oriented modeling languages, has good programmability, and can complete the transformation from Petri net to program structure[5].

3. Maintainability Indexes of Complex Equipment
The maintainability index of equipment reflects the use demand of equipment and the goal of maintenance work, that is to improve the equipment integrity and mission success, and reduce the consumption of maintenance manpower and other resources. At the same time, these indexes should be clearly defined and can be tracked and verified in the development. For different types of complex equipment, the appropriate maintainability parameters and indexes are not the same[6]. Here are some commonly used indexes:

1) Mean time to repair: the average value of the repair time required to eliminate a fault. The measurement method is the ratio of the total time of corrective maintenance to the total number of failures of repaired products at any specified maintenance level under specified conditions and within specified time.

2) Average preventive repair time: the average value of one preventive maintenance time for each product or a certain maintenance level.

3) Maintenance downtime rate: the average downtime required per unit working time of a product.

4) Maintenance man hour rate: the average maintenance man hour required per unit working time of a product. The measurement method is the ratio of the total number of direct maintenance man hours to the life unit of the product under the specified conditions and within specified time.

5) Average system recovery time: the ratio of the total system restorative maintenance time (excluding the maintenance time leaving the system and the removed parts repair time) caused by the non working event to the total number of non working events under the specified conditions and within the specified time.

6) Task time for functional recovery: the ratio of the total repair time of a product’s fatal failure to the total number of fatal failures within a specified mission time section.

4. Maintainability Index Verification of Complex Equipment Based on CPN and UML

4.1 The Verification Model of Maintainability Indexes for Complex Equipment
There are always some similarities between different equipment, so some useful maintenance information for new complex equipment can be obtained from the design features, use and maintenance of existing equipment, which is conducive to the maintainability design, allocation, prediction and verification of new complex equipment. Therefore, a case-based maintainability index verification model can be established. The case here mainly refers to the existing equipment which is
similar to the new complex equipment in the structural characteristics and use environment and the prototype of new complex equipment. Once the maintainability verification model based on case is established, the maintainability of system, subsystem, equipment and replaceable unit of new complex equipment can be estimated, so as to evaluate and verify the maintainability of new complex equipment[7]. The following is a comparison of the advantages and disadvantages of several existing maintainability verification models, as shown in Table 1.

| Method name                                    | Main characteristics                                      | Shortcomings                                                                 | Application range                  |
|------------------------------------------------|-----------------------------------------------------------|------------------------------------------------------------------------------|-----------------------------------|
| The traditional maintainability prediction model | Artificial method                                         | Maintenance experience and maintainability information processing of similar equipment is complicated | Similar equipment can be used for reference |
| The maintainability verification model based on fault trees | Starting from the structural relationship between the system and the fault causes, the maintenance process is analyzed by fault trees | It must be based on fault tree analysis                                        | Detailed FMEA analysis data is required |
| The maintainability verification model based on stochastic network | Each step of maintenance work is regarded as a process, and the maintenance network diagram is established | It is necessary to know the distribution law and distribution parameters of the operation and maintenance time in advance, and combine with the maintenance function flow chart and system function level diagram | The distribution of operation and maintenance time is known |
| The maintainability verification model based on black box system | Regarding the maintenance system as a black box, the input and output of the system are studied | Unable to understand the internal structural characteristics of the system | It is suitable for the situation that the detailed structure of the system is not very clear and the existing similar equipment systems exist |

These verification models have certain requirements for the system, and can not deal with the concurrent activities and dynamic behaviors in the system. Therefore, this paper proposes a maintainability index verification model and method based on colored PN and UML. The verification process is shown in Fig.1.
4.2 The Maintainability Index Verification Method of Complex Equipment Based on Colored PN and UML

The method based on colored PN and UML proposed in this paper combines the advantages of both. It has no special requirements for the system to be estimated and verified, can evaluate and verify any system, and can deal with the dynamic behavior and concurrent activities in the system. The established model is also easy to be programmed and verified. The main idea of this method is to first establish the colored Petri net model of the system, and then use the characteristics of UML unified modeling language to verify the maintainability indexes after converting the colored Petri net model into UML model[8].

Main steps:
1. Establish the CPN model of the system.
   As a high-level Petri net model, colored Petri net greatly enhances the modeling function by calibrating the color type of the place and token, and constraining the transition and arc occurrence conditions. Compared with ordinary Petri nets, the system model established with colored Petri nets can not only shield some trivial details in the system, so that the modelers can grasp the essential behavior characteristics of the system more easily, but also make the scale and structure of the whole model more concise and compact.
2. Transform the colored Petri net model into UML model
   1) Get objects from CPN
   2) Convert CPN to state machine graph
   3) Convert CPN to sequence diagram and collaboration diagram

   Table 2  Mapping rules from CPN to UML state machine

   | Steps | CPN       | UML        |
   |-------|-----------|------------|
   | 1     | Place     | State      |
   | 2     | Transition| Trigger event |
   | 3     | Arc       | Transformation |

3. Use UML model to program and verify

5. Simulation Results

Assuming that the maintainability indexes of a piece of complex equipment are to be verified, the average repair time in maintainability indexes is selected as the verification index, the spare part fill rate is required to be 90%, the maintenance activities of each maintainer are independent, and the average repair time is less than 6 hours.

(1) The CPN model of maintainability verification is established.
Figure 2. The colored Petri net model diagram and the state machine diagram of the secondary maintenance subsystem of a piece of equipment

Table 3 The place set of colored Petri nets for the secondary maintenance subsystem of a piece of equipment

| Place  | State                                                                 |
|-------|----------------------------------------------------------------------|
| P1    | Various types of battle-damaged equipment are waiting for transportation |
| P2    | Battle-damaged equipment waiting for repair                          |
| P3    | Prepare to detect battle-damaged equipment and identify faults        |
| P4    | Battle-damaged equipment waiting to be replaced by spare parts        |
| P5    | Ready to retransport good equipment to the battlefield                |
| P6    | Army vehicles status                                                 |
| P7    | Maintainer status of the secondary maintenance subsystem              |
| P8    | Secondary maintenance system information and testing tool status      |
| P9    | Spare parts warehouse status of secondary maintenance subsystem       |

Table 4 The transition table of the colored Petri net for the secondary maintenance subsystem of a piece of equipment

| Transition | Events                                                                 |
|------------|------------------------------------------------------------------------|
| T1         | Charge and transport battle-damaged equipment to the system            |
| T2         | Assign repair personnel according to battle-damaged equipment type     |
| T3         | Collect the corresponding preparation information tools according to the type and degree of damaged equipment |
| T4         | Replace the damaged equipment with spare parts according to the fault diagnosis |
| T5         | Release persons, objects, information, etc that are involved in the repair of equipment |

(2) Convert CPN model to UML model
1) Get objects
From the above places, there are four objects in the system: Maintainer, Equipment, Spare Parts and Vehicle.
2) State machine diagram
The place is grouped according to the described objects, and the result is shown in Fig.2.
3) Sequence diagram and collaboration diagram
Figure 3. Sequence diagram and collaboration diagram of maintenance personnel repairing equipment

(3) UML model is used for coding and simulation verification

The impact of spare part resources on preventive maintenance time $T$ can be described by the spare part fill rate $P$: $T = P \cdot T_{41} + (1-P) \times T_{42}$, where $T_{41}$ represents the time (hours) required to get spare parts from the warehouse (hours) when the spare parts are sufficient, $T_{41} \sim N(0.28, 0.03)$; $T_{42}$ refers to the time (hours) required for vehicle transportation of spare parts when the spare parts are insufficient, $T_{42} \sim N(0.62, 0.15)$.

The maintenance time of each maintainer obeys $N(4.1, 0.35)$. Assuming that there are $n$ maintainers, the maintenance time is $T_{51} \sim N(4.2/n, 0.35/n)$. Other parameters are defined as follows:

$T_1 \sim N(1, 0.4)$, $T_2 \sim N(0.6, 0.25)$, $T_3 \sim N(0.55, 0.2)$, $T_4 \sim N(0.7, 0.3)$, $T_5 \sim N(0.65, 0.15)$

Through the simulation experiment, when the spare part fill rate is 90%, the average repair time is 5.83 hours, so the index has been verified to meet the requirements.

6. Conclusions

Firstly, the basic theory of CPN and UML is briefly introduced, and then the maintainability indexes of complex equipment are introduced. On this basis, a maintainability index verification method based on CPN and UML is proposed. This method can deal with the concurrent activities and dynamic behaviors in the system, and can realize the transformation from the built model to the program structure well, with better interaction ability. Taking the average repair time of the secondary maintenance subsystem of a piece of equipment as an example, the stimulation calculation is carried out and the index is verified. The verification process shows that the method has a wide range of application and good operability.

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