THE TECHNIQUE AND MODELLING FOR EQUIPMENT MAINTAINABILITY QUANTIFICATION IN 3D DIGITAL AIRCRAFT DESIGN CONDITION

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Abstract

To solve the problem of maintainability quantitive theory and calculative method that based on aircraft 3D digital design model, this paper puts the expression of design parameter and maintainability parameter, the definition of the attribute, and the technique of integration using for maintainability data on study.Based on the graph theory, this paper puts forward the modelling technique for the equipment and the maintenance process in the 3D digital design condition. The unified Node-Drawing model has been defined to represent the repair process essential factor, these factors which are equipment, line pipe, cable, covers, and so on. And the Network-Node model in maintenance process has been formed, which express the relation of dismantle and fix process, and the relation of manpower and tools and support resource and so on. This paper puts forward the calculation method for static maintenance time expressed by Node-Drawing, and for maintenance time which based on Node-Drawing network and its planning technology. With calculation of maintenance time for an airborne-equipment as example, this method is proved practicable.

1 Maintainability Quantification Technique Process

It is challenge to traditional maintainability that how to build and integrate the maintainability design model, and how to quantify maintainability parameter in 3D digital model.With the digital design condition, the process of design, adjustment and optimization of aircraft is the process based on the 3D sample model. We are confronted with prominence problem for maintainability quantification design.How can we solve the old problem to fit the new need? That is, to bring forward the method accordingly to transform the traditional quantitative index (such as MTTR) to demands of the aircraft design parameter.The core problem is that the maintainability parameter should be transformed to physics parameter which can be designed and controlled, in order to realize the index in phase.

By analyzing the design process of maintainability in digital condition, we propose the new technology process.First, transform the hierarchical modeling design parameters which is adapt to new design condition, and the maintainability parameters into available parameter [1], and integrate the models and parameters into aircraft design digital environment.Then, analyze all elements related to the equipment maintenance, and define the Node-Drawing-Model (NDM) through graph theory to represent the repair process essential factors, these factors include equipment, pipeline, cable, covers, and so on.And then, establish a network-topology-model (NTM) for equipment maintenance process to description the mutual relation of dismantle and fixing process, and the mutual relation of manpower and tools and logistic resource.With the database, we use NDM and NTM to generate dismantlement sequence for equipment repair, that is used to quantify maintainability.Finally, the result of calculation will be verified and the model will be optimized.

The process of quantifying maintainability based on 3D digital model is shown in Fig.1.

2 Parameter Characterization and Information Integration

2.1 Parameter and Information Description

The parameters of airborne equipment can be divided into static parameters and dynamic parameters.The static parameters mean parameters related to the characteristic of product itself, including weight, size, installation mode, physics connection, functional port, cabin size, and so on.The dynamic parameters mean process parameters when maintain the product, including object numbers, obstruction relationship of the equipments, maintenance path, maintenance crews, tools, and so on.

To descript the parameters and the information of airborne equipment maintainability, we standardize and form it by maintainability information model (MIM), and integrate it into product node in different levels.In this paper, the MIM is a set of models that can descript maintainability characteristic of product relative completely, which can express logistical structure, level structure and information classification [1].The MIM can be divided into cabin MIM and system MIM. We can form and utilize the maintainability data from cabin-dimension and system-dimension respectively.

After defining information model, all data can be formed and utilized from product category and level. Here, category means cover, cable, airborn equipment, pipeline, structure, and so on； Level means parts, equipment, system, cabin, and aircraft. A series of MIM compose information model set, the set supply the maintenance data of all equipment of aircraft.

2.2 Definition of Node and Node Attribute

In this paper, the products of aircraft are called nodes. Here, product means generalized product, including equipment, cover, cable, pipeline, and connection. Nodes can be classified into target node, one-step obstruct node, multiple-step node, and so on.

The maintenance characteristic information of equipment in aircraft desgin should be analyzed, traversed, standardized.The reduesed information of the equipment is called node attribute. The attribute can be divided into inherent properties and variable properties. Inherent property indicates the property is not influenced by overall desgin, such as weight, plug number, plug shape, connection number, fastener number, while variable property means opposite, such as cabin segmentation, equipment obstruction, interrelationship between these equipments.

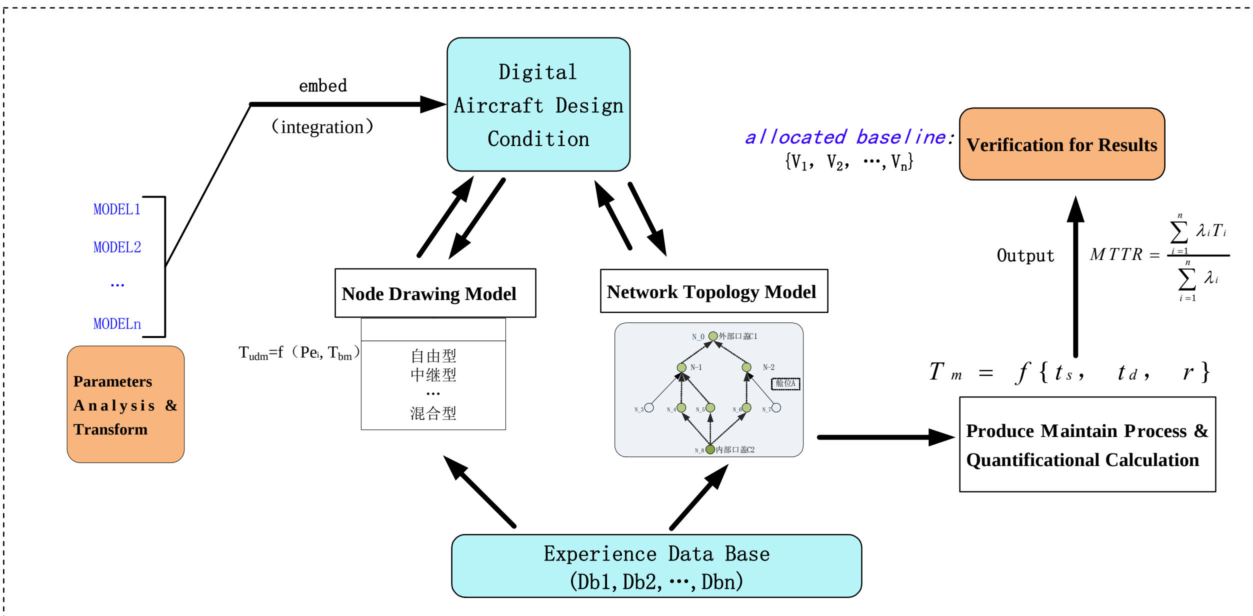


Fig. 1 The Technique of the Maintainability Quantification Calculation Based on Aircraft Digital Design Model

Tab.1 The classification of On-vehicle Equipment (Nodes) Attribute and Characteristic Model

Attribute sort	Subspace	Model	Examples
inherent	● basic information	static model	list names,system,equipment sort,weight,and so on
	● design information	static model	Fixing manner, fastness, restriction, connection,function interfac, disassembly tool/ facility， human-factor,and so on
	● index information	static model	MTBF,MTTR(needed),MTTR(calculational), and so on
	● knowledge information	static model	Maintainability design ruie, design cases,outfield matter history, and so on
	…, …	static model	…, …
dynamic	● layout and fixing information	dynamic model	Layout fixing position, block off node,block off node in succession，approachability,visibility,maintain channel, and so on
	…, …	dynamic model	…, …

The attribute and characteristics of the equipment being considered are shown as Tab1.

2.3 Maintainability Data Integration and Utilization

After establishing MIM, defining the nodes and their properties, it needs integrate the desgin parameters and the propertie data into product digital desgin condition to support maintainability design and maintainability evaluation.By all sorts of MIMs combined an entirety according to rules and logic, the data is integrated into the digital design environment. Instantiated product information model stores and forms data on basis of the PBS, and the entity node is the basic unit of information store. The combinations of multiple information models express the maintainability of product in aircraft design.

By the quantified maintainability technology raised in this paper, the maintainability desgin data is stored and managed by node level and its property, and is formed by the MIM.Using this method, part of the maintainability design information is integrated into the node property.Such as product name, serial number, design ID, weight, cabin, one-step obstruct node, fasten type and its numbers, connection type and its numbers.The other maintainability information is integrated into the data base of the design environment. Such as cabin information, MTBF/failure rate, MTTR (demanded), MTTR (estimated), disassemble tool and equipment, design document, experiential data.

The maintainability calculation system gains the data timely from the digital aircraft design environment, and evaluates the maintainability of the equipment.

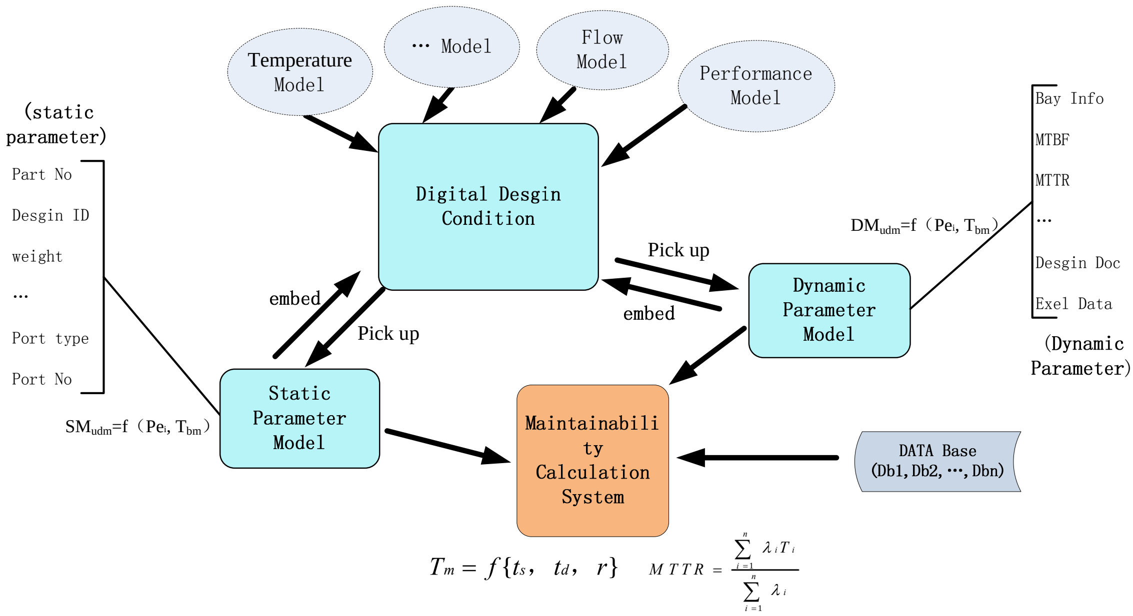
The means of the information integration and the data acquisition is shown as Fig.2.

3 Modelling of Equipment and Maintenance Process

3.1 Node Drawing and Node Network Drawing

After abstracting the priority relationship of product of dismantling and fixing between object dismantling equipment and other equipment, we build the relationship model using the graph theory to express the maintainability design status of the aircraft and airborne product. These models are called node-drawing (ND) and node network-drawing (NND) respectively.

According to the graph theory, we classify nodes of the maintainability-quantification-



$$T_m = f\{t_s,\ t_d,\ r\} \qquad MTTR = \frac{\sum_{i=1}^{n} \lambda_i T_i}{\sum_{i=1}^{n} \lambda_i}$$

Fig. 2 The Parameter Models and the Data Integration in the Aircraft Digital Design Condition

models into six types: target-node, free-node, solitary-node, tail-node, one-step obstruct-node and multiple-step obstruct-node, which are shown as Fig.3.

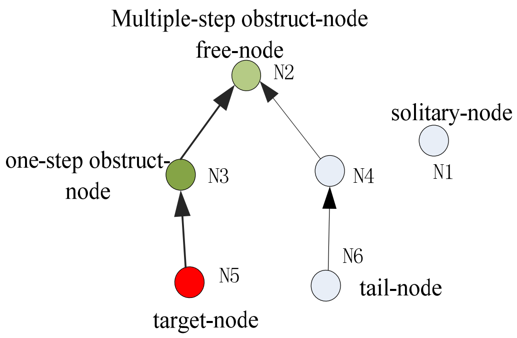


Fig.3 The Node-drawing Term Definition

We traverse the obstruction relationship between the equipments fixed in the cabin of aircraft to graph through the graph theory. After traversing, the equipment is simplified to node, the obstruction relationship to directed edge, which constitute into NND (shown in Fig 4). NND is description of obstruction relationship of the equipments fixed in aircraft, consisting of node and directed edge. Node represents the equipment, while the directed edge represents obstruction relationship.

In this paper, elements related to maintainability, such as equipment, cover, cable, pipeline and connections, are defined to ND model. And the relationship of disassembling and assembling between the airborne equipments, logistical resource, labor, tool, are defined to NND model.

3.2 Single Node Time Model

The airborne Equipment maintenance time consists of diagnosing time, dismantling time, installing time, adjustment time, and examination time.Generally, the time for diagnosis and adjustment and examination, is short and can be ignore.So, the main time is to dismantle and install.In other words, it is mainly composed of the target equipment dismantle-install time and the obstruction dismantle-install time in maintenance path.

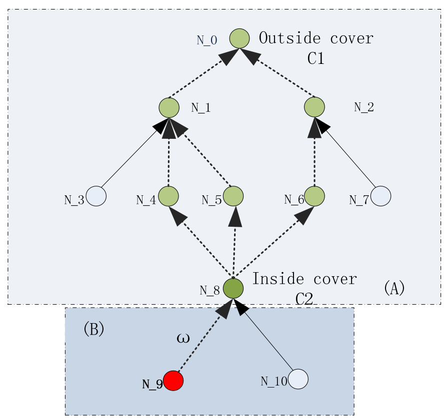


Fig.4 The Node Network-Drawing Term (general view)

We decompose the target-equipment (node) dismantling process to several process time-units.So, the node maintenance time is function of the time-units, and the node time model is as follows:

$$T_{nd} = f\{t_{fa},\ t_{fu},\ t_{el},\ t_{re}\} \qquad (1)$$

Here , t_{fa} represents fastener time unit, t_{fu} represents function-connection time unit, t_{el} represents electric connection time unit, t_{re} represents equipment exchange time unit.Consider environment factor as P_e:

$$T_{nd} = f\{P_e, t_{fa}, t_{fu}, t_{el}, t_{re}\} \qquad (2)$$

Assume there are k types of fastener for the quipment, the fastener time unit is:

$$t_{fa} = \sum_{i=1}^{k} n_i \cdot (l_{ri} \cdot t_{ri} + l_{fi} \cdot t_{fi}) \qquad (3)$$

$$P_e = (p_{efa},\ p_{efu},\ p_{eel},\ p_{ere})^T \qquad (4)$$

Here , n_i stands for numbers of the type i fasteners, t_{ri} stands for standard dismantling time unit, t_{fi} stands for standard fixing time unit , l_{ri} and l_{fi} are influence coefficient of logistic(tools and labor) p_{efa} , p_{efu} , p_{eel} , p_{ere} are time unit influence coefficient of environment to fastener, function connection, electric connection, equipment exchange. And their values are the number between 1 and 100. The high value means good maintenance condition.

So, the single node time model is:

$$T_{nd} = (t_{fa},\ t_{fu},\ t_{el},\ t_{re}) \cdot (p_{efa},\ p_{efu},\ p_{eel},\ p_{ere})^T \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

3.3 Maintenance Process Time Model

According to the definition of chapter 3.1, we can model equipment maintenance time based on the NND.Using process time unit t_i to represent the time for dismantalling single node (the generalized equipment), which determined by the model in chapter 3.2. And we assume t_1 and t_k is the process time unit to open and close the cover respectively.

When it has the only way to dismantle and it is simple series, the maintenance time of target equipment is:

$$T_{mo} = \sum_{i=1}^{k} t_i \qquad (6)$$

If there are parallel parts, assume these are the lst to mth unit, then the time of parallel parts:

$$T_{lm} = \max\{\ t_l,\ t_{l+1},\ t_{l+2}, \ldots,\ t_m\} \qquad \ldots\ldots\ldots\ldots\ (7)$$

$$T_{mo} = t_1 + t_2 + \ldots + \max\{\ t_l,\ t_{l+1},\ t_{l+2}, \ldots,\ t_m\} + \ldots + t_k \qquad \ldots\ldots\ldots\ldots\ (8)$$

For most airborne equipment, subjected to labor, tool, and room interference, the maintenance node network is complex network.For any target maintenance node N_{mo} with ω constraint,the disassembling path witch compose of the order node group can be got using the path searching method.Using s_{ij} to represent the number j node in ith path, then the disassembling path matrix is:

$S = (s_{ij})_{pxk}$, p represents for number of critical path, k is the number of disassembling node.

Assume the first to mth unit parallel in series s_{i1} , s_{i2} , ...,s_{ik}, set:

$$T_{lm} = \max\{\ tt_l,\ tt_{l+1},\ tt_{l+2}, \ldots,\ tt_m\} \qquad \ldots\ldots\ldots\ldots\ (9)$$

$$F_{lm} = \max\{\ tf_l,\ tf_{l+1},\ tf_{l+2}, \ldots,\ tf_m\} \qquad \ldots\ldots\ldots\ldots\ (10)$$

Then, the maintenance time for path i:

$$T_i = \sum_{n=1}^{k+l-m-1} tt_n + \sum_{n=1}^{k+l-m-1} tf_n + T_{lm} + F_{lm} \qquad \ldots\ldots\ldots\ldots\ldots\ (11)$$

Here, tt_n and tf_n represents dismantling and fixing time for node n respectively. So target equipment maintenance time is:

$$T_{mo} = \min\{\ T_1,\ T_2, \ldots,\ T_P\} \qquad (12)$$

4 Preliminary Application

The cabin selected has six equipments, three of which are fastened using screws and collars, others are fastened using standard mounting rack.All of them have the cable connection.And also there is one outside cover (class B).

In 3D digital condition, we set up the information model, the node network model, the single node model and the maintenance process model for our example using the method suggested this paper.The NND is shown in fig.5.

We assume N_7 is the target node, so the dismantling critical path are $s_1(N_7N_4N_2N_1)$, $s_2(N_7N_5N_2N_1)$, $s_3(N_7N_6N_3N_1)$, and fixing path is the reverse path of the S_1, S_2, and S_3.Through taking the data integrated in the corresponding node in aircraft digital design condition, referring standard time unit data （tt_1, tt_2, tt_3, tt_4, tt_5, tt_6, tt_7, tf_1, tf_2, tf_3, tf_4, tf_5, tf_6, tf_7）in accorde with the node involved in the maintenance process, we can get T_{mo} the time of N_7 is 15 minutes. This example verifies the practicability of quantifying model technology proposed this paper.

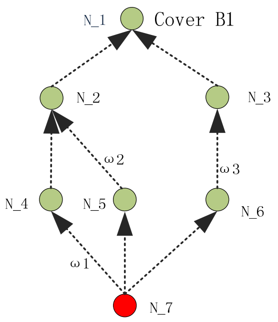


Fig.5 Node Network Model of the Example

5 Conclusion

With rapid development of 3D digital design technology, the traditional maintainability theory and method have more and more limitation. To adapt the new requirement for maintainability desgin of airborn equipment in 3D digital desgin environment, this paper explores a maintainability technology, and propounds parameter description, node property definition, node network drawing definition, time model definition, and the modeling method of them. Using maintainability quantitative computation of airborn equipment as an example, the practicability of the method has been verified.

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