Abstract—System fault behavior modeling is a method of building a model around system malfunction. The system fault behavior model describes the occurring process of system malfunction and the behavior after system in fault, and it also presents the effect of basic unit failure on the whole system. After describing the backgrounds and requirements of system fault behavior modeling, the concept and the connotation of system fault behavior were analyzed in detail. Then the definition of the model was put forward and the framework of the model was built. The structure of the model was defined as three levels, containing object level, behavior level and restriction level on the basis of the definition and framework of the model. The formalized description of the model based on polychromatic sets theory was also represented. Finally, a simple case was analyzed.

Keywords: fault behavior; model; fault modeling; behavior modeling

I. INTRODUCTION

Fault is a core attribute related to product’s non-functionalities such as reliability, maintainability and supportability so on and so forth. The cognition and description of the fault rules provide a basis of system non-functionality design. Since reliability engineering came into being, the people have started to research system fault. With the continuously deep cognition of objective things, and the description of system fault is more and more refinement. At present, it mainly includes two aspects:

(1) Describing system in the fault point of view directly, it depicts the fault effects on system and the relations among these effects, which had by the unit, structure design or environment, such as FMEA, fault tree, failure physics etc.

(2) Describing system in the function point of view, it adopts fault ejection, adding the description of fault factors into system functional model to depict the accomplish circumstance of system function, and do the reliability analysis, such as ADEPT, MFM, functional reliability simulation etc.

Although the two methods have the different point of view of system fault description, they both describe system as a object. They usually analyze the static fault logic relations of system, which are difficult to depict the dynamic process of the occurrence and development of system fault clearly. In order to found the theory of reliability system engineering, we must make further research of engendering and behaving rules of system fault. System fault behavior modeling has that purpose, and it describes the occurring and development process of the system malfunction from the view of behavior.

II. SYSTEM FAULT BEHAVIOR

A. the concept of system fault behavior

Behavior is defined as the system changes as time goes. In behavior, behavior refers to the activity form, phonation, posture and some changes distinguished in appearance of the animal. All the changes make effects to communicate with each other, and could arise an action mode of another animal[1]. Extended to describe the equipment, the behavior is the activity, state changes of each unit composed of the system and the dynamic process as the system in fault. Thus system fault behavior is defined as the change of system status which deviates from the predicted function in this paper. It appears to make changes as time goes. It reflects not only the basic unit fault behavior influenced by intrinsic and extrinsic factors but also the relationship between different basic unit fault behaviors—a fault behavior causes another. System fault behavior is decided by system composing, structure and potential external stimulation. According to system approach, interaction effect and restriction exists between fault behaviors. And system fault behavior is the result of fault behavior propagation rather than simple addition of individual behavior. After analyzed and summarized, system fault behavior was classified as I, II and III in this paper.

- SYSTEM FAULT BEHAVIOR I: It refers that the system fails in function because of the faults of the composed units.
- SYSTEM FAULT BEHAVIOR II: It refers that the system loses its function because of not the fault but the influence in units
- SYSTEM FAULT BEHAVIOR III: It refers that the system could still finish its function although the units are in fault.

System fault behavior includes unit fault behavior and whole fault behavior.

- UNIT FAULT BEHAVIOR: refers to the fault behavior of the unit itself.
• WHOLE FAULT BEHAVIOR: refers to the system whole fault behavior after the unit fell in fault. It is made up of a series of unit fault behavior.

According to the relationship between behaviors, fault behavior could be classified into five: ordinal fault behavior, intercurrent fault behavior, parallel fault behavior, scrambled fault behavior and united fault behavior.

B. the description of system fault behavior

From reference[2] we know that system fault comes into being in the effect of the synthesis of intrinsic factors(material, structure, technics etc.) and extrinsic factors(usage mode, environment, human factors). The exterior behave of system fault takes on determinacy, randomicity and fuzziness. Thus, the description of system fault behavior should reflect all these characters of system malfunction above. So the description of fault behavior is defined as follows.

System fault behavior is defined as a vector of four dimensions, let

\[ \text{Beh} = (P, E, T, S) \]

Thereinto, \( P \) (Property) is the property of system unit, which includes structure, material and technics.

\( E \) (Environment) is the external influence factors sets, which includes usage mode, environment, human factors etc.

\( T \) (Time) includes general time, which describes the moment of a certain fault behavior in the system operational process, and part time, which describes the developing process of a certain fault behavior.

\( S \) (Stimulate) is the stimulus on system unit, which includes stimulant and stimulus intensity.

Every system fault behavior should include all the attributes above. This definition ensures a complete description of intrinsic and extrinsic factors influences, and also reflects the determinacy, randomicity and fuzziness of system fault occurring.

III. SYSTEM FAULT BEHAVIOR MODEL

The behavior model is to describe the dynamic behavior process of system and equipment change and develop as time goes. The fault behavior model is to describe the development and change of system behavior when the units fall in fault or are disturbed by external influence factors. On the basis of the study above, a fault behavior modeling approach which considered multi fault behavior influence factors was proposed, and a theoretical model of system fault behavior (FBM, Fault Behavior Model) was built.

A. the definition of system fault behavior model

Fault behavior model (FBM) is defined as a vector of three dimensions, let

\[ \text{FBM} = (\text{OBJ}, B, E) \]

Thereinto, \( \text{OBJ} \) is system object sets, which includes basic units at product different levels.

\( B \) is fault behavior sets. Different fault behavior belongs to different objects.

\( E \) is external influence factors sets, which includes usage mode, environment, human factors etc.

Object sets reflect inherent attributes of system composing, including system structure, material, technics etc. External influences factors sets reflects external stimulus such as environmental factor, usage factor etc. Fault behavior sets which reflects system behavior changes, is the state transfer of system as time goes. Thus FBM is the composition of system structure, behavior and environmental information.

B. the framework of FBM

On the basis of the definition of FBM, The framework of FBM shown in Fig. 1 is built.

FBM includes three parts: BASIC UNIT FAULT BEHAVIOR MODEL, RESTRICTION RELATIONSHIP MODEL and FAULT BEHAVIOR RELATIONSHIP MODEL. Basic unit fault behavior model is for every unit composed of the system. Restriction relationship model applies to the factors in external influence factors sets. Fault behavior
relationship model is for all kinds of trigger relationships between fault behaviors. Restriction relationship model produces restriction condition on basic unit fault behavior model, all basic unit fault behavior models joint into a whole then through fault behavior relationship model. Thus the system whole fault behavior model could be built.

C. build FBM

FBM is a complex entity with certain function, which comes into being through every level based of the attributes (behavior and environment, that is restriction) of each unit.

FBM building starts with system functional drawing, and acquires the physical connected relationships between system and their units, then abstracts their behaviors and builds their relations according to system structure and environment. FBM has multi levels including system structure level, behavior level and restriction level, and its goal is to realize to describe the occurring and development process of the system malfunction.

Considering both the intrinsic factors and the extrinsic factors which result in system malfunction, this paper builds FBM structure as three levels: structure level, behavior level and restriction level, which is shown in Fig. 2. The model describes the system fault behavior process and the fault information propagation. Structure level reflects the static structure between basic units. Behavior level reflects the dynamic process of fault behavior of system and system units. Restriction level reflects the restriction on system and system units in run. The whole model expresses the system hierarchical relationship, associated relationship etc. adequately. In addition, it describes the trigger-characterized dynamic behavior process.

D. the formalized description of FBM

Since FBM contains various information, such as object, behavior and restriction, which has the characteristics of hiberarchy and information variety, this paper adopts polychromatic sets theory[3] to describe system fault behavior model. It could clearly reflect the relations among behavior status and objects of different gradation in the model. What’s more, polychromatic graphs[4] node expresses the object in FBM which is the product part, that is, structure level; different colors in nodes expresses different attributes of object, including the behavior and restriction of object, that is, behavior level and restriction level; the side of polychromatic graphs expresses the connection relations among objects in FBM; the colors with the side expresses connection types, including inference relation and trigger relation. Thus, the formalized description of FBM could be described as follows.

\[ PG = (A, F(a), F(A), F(a) \times F(A), A \times F(A), F(A) \times F(A), C, F(c), C \times F(c)) \]

Thereinto, \( A = (a_0, a_1, \ldots, a_n) \) expresses object sets in FBM.

\[ F(a) = (F_1(a), F_2(a), \ldots, F_n(a)) \] expresses the sets of individual behavior of object in FBM.

\[ F(A) = (F_1(A), F_2(A), \ldots, F_n(A)) \] expresses the sets of whole behavior of object in FBM.

\[ C = (c_{ij} | 0 \leq i \leq n, 0 \leq j \leq n) \] expresses the sets of connection relations among objects; \( c_{ij} \) expresses whether the connection relation between \( a_i \) and \( a_j \) exists or not.

\[ F(c) = (F_1(c), F_2(c), \ldots, F_k(c)) \] expresses the types of connection relations among objects, here \( k = 2 \).

The product objects are expressed as \( a_i \) and the collection of the attributes of \( a_i \) are expressed as \( F(a_i) \), which contains the behavior of \( a_i \) and all restriction conditions related to it. As a result, the collection of objects \( S_a \) could be expressed.

\[ S_a = \{< a_i, F(a_i) > | i = 1,2,\ldots,n \} \]

The structure of FBM showed in Fig. 2 is expressed in hierarchy which is shown in Fig. 3. From top to bottom merging the restriction node and behavior node in the above levels to the corresponding object node in the lower levels into one and express it as orderly group. After merging, the \( i_k \) node in the \( k \)-level, whose superior node is the \( j_k \) node in the \( k-1 \)-level, is expressed as \( \text{dp}(k,i_k,j_k) \). Thereinto, \( \text{dp}(k,i_k,j_k) \) is object node in the lower level, \( F(dp(k,i_k,j_k)) \) is the corresponding restriction node and behavior node in higher level. Then the structure of FBM could be shown as Fig. 4.

![Figure 2. The structure of FBM.](image)

![Figure 3. The structure of FBM in hierarchy](image)
The recursion of FBM is:

$$\forall k(1 \leq k \leq n), \forall i_k (1 \leq i_k \leq n_k)$$

$$ \langle dp(0,0,0), F(dp(0,0,0)) \rangle = \bigwedge_{i_k=1}^{n_k} \langle dp(1,i_k,0), F(dp(1,i_k,0)) \rangle$$

$$ = \bigwedge_{i_k=1}^{n_k} \langle dp(k,i_k,f_{i_k-1}), F(dp(k,i_k,f_{i_k-1})) \rangle$$

$$= \bigwedge_{i_k=1}^{n_k} \langle dp(k+1,i_{k+1},i_k), F(dp(k+1,i_{k+1},i_k)) \rangle$$

$$n_0 = 1, \quad n_k = \sum_{i_k=1}^{n_k} n(k,i_{k-1})$$

Thereinto, $n(k+1,i_{k+1})$ is the number of the sub-node of the $i_k$ node in the $k$ level; $n_k$ is the number of all nodes in the $k$ level.

If $\forall l(1 \leq l \leq n)$ and $\forall i_l (1 \leq i_l \leq n_l)$ satisfy this condition---

$$\langle dp(l,i_l,f_{i_l-1}), F(dp(l,i_l,f_{i_l-1})) \rangle \in S_0$$

this node is the terminal node. This is the terminal condition of decomposition of the various depth ranges branch in the model.

Polychromatic sets are used to describe system fault behavior model, so that correlativity among different element in FBM could be expressed in matrix. The model transforms into matrix entirely by filling information matrix. We do not need modify model but extend matrix to describe complex model, which is the biggest advantage of the method.

### IV. CASE STUDY

Take the GK0058-1 high speed lock type sewing machine[5] as an example. Select the raise line mechanism and hook line mechanism of it to do a simple analysis and manifests fault behavior which in its work process possibly appears. The computer simulation schematic of the raise line mechanism and hook line mechanism of lock type sewing machine is shown as Fig. 5.
V. SUMMARY

The paper analyzes the system fault from the behavior angle. It regards the system as the main body of the behavior implementation. The fault behavior is the reaction that the system is accepting various external stimulations. After that, it considers the system has the initiative, and has the selection towards the behavior after occurring the fault. So that we can describe the dynamic process of the occurrence, development and disappearance of system more clearly. FBM, which was built based on those, considers multi influence factors causing system fault and describes the changing process of system and units dynamic behavior. Accordingly analyze unit fault development process in system and the influence of factors on system. All study above is to make further effort to depict system fault rules and do some groping work for developing the theory research of reliability systems engineering.

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