# Research on Product Structural Tree for Product Lifecycle

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***Abstract*-Based on analyzing the connotation of product structure model, the concept of the product lifecycle structural tree and the method of modeling is put forward, the nodes and their relationship of the product lifecycle structural subtree are analyzed, the methods of operation about the node and it's attribute are given. By using the extended IDEF5 schematic language, the six basic operations is described, including the "Copy Node", the "Add Node", the "Delete Node" operation and the "Set attribute", the "Add attribute", the "Delete attribute" operation. Finally, the modeling process is illustrated from the product requirement structural subtree to the product full lifecycle structural tree by the instance.**

## 1. INTRODUCTION

Manufacturing industry today faces challenges. In order to meet the competition in the market, the information technology has become one of the significant factors. Recently the product model is being used to depict product in some of enterprise throughout the product lifecycle. It is pointed out that the product structural tree is the key of product model by SUN [1]. A method was developed to construct the global product information model in PDM (Product Data Management) systems, the enterprise-oriented global product structure model (EOGPSM). The product model is expressed as dendritic structure about data objects and the relation objects and described with the form of matrix. The operation matrix between product model and its view is deduced by YANG [2]. Zhang[3] proposed an ontology - based modeling approach on product configuration and built the meta - model of product configuration and put forward the general modeling process based on configuration ontology. Oh et al. [4] described the product structure mapping between CAD and the PDM with UML. Eynard et al. [5] analyzed the inherent relation about the product structure, personnel and process. They used the object-oriented approach and the used UML diagrams to detail the modelling and integration of product, process, and resource data.

The research mentioned above was taken into account the design and manufacture of product, and the construction and expression of product model existed the limitation from product full lifecycle. Based on analyzing the connotation of product structural tree, the concept of the product lifecycle structural tree and it's modeling method is put forward, the subtree node operations and attribute operations method are defined and the construction method of the product full lifecycle model is given out. Thus the product information sharing of full lifecycle is realized.

The product full lifecycle structural tree mentioned in this paper has these merits as followed: ①supporting the product full life period action. Because this model has structural subtree in each lifecycle stage, the structural subtree can support lifecycle action in each corresponding stage. ② in the product full lifecycle structural tree, the consistency of coherent node attribute in each corresponding stage is kept. ③the product full lifecycle structural tree supports integration of global database and application of the systems such as CRM, PDM and ERP etc. IDEF5 graph language is ontology language, which is built for American air force by Perakath C. Benjamin et al. Its merit is very direct and easy to use. Based on IDEF5 graph language, this paper suitably expanded it and used the expanded IDEF5 graph language to describe the construction process of product full lifecycle structural tree.

## 2. THE PRODUCT FULL LIFECYCLE SRTUCTURAL TREE MODEL

Here, the product full lifecycle structural tree is the set of the product lifecycle structural subtree in each stage. According to the product lifecycle stage, the product full lifecycle structural tree includes seven product structural subtrees, which are the product requirement structural subtree, the product concept structural subtree, the product design structural subtree, the product machining subtree, the product assembly structural subtree, the product use structural subtree and the product fix structural subtree. Each the product structural subtree in each stage formed the integrated product full lifecycle structural tree jointly. The structural subtree mentioned above is composed of the product, assembly and component nodes. It is shown as fig.1 in IDEF5 graph language. Then the expanded IDEF5 graph

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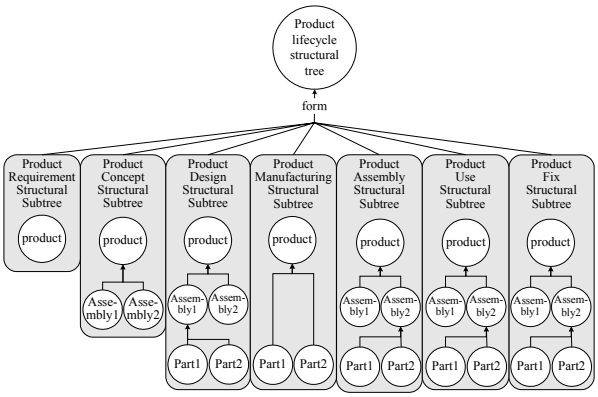
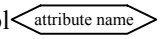



Fig 1.Product lifecycle structural tree

in IDEF5 graph language. Then the expanded IDEF5 graph language is adopted to describe the product full lifecycle structural subtree relation, node attribute, construction model process and some operation examples.

Among them the expanded symbol  indicate the node attribute,  is the relationship of the node and the attribute, the arrow points to the node, the end of arrow connect with the attribute, Φ is null node or null attribute.



The associations among the product structural subtrees are show as Fig.2. The formation of the product full lifecycle structure begins from the product requirement structural subtree, the product concept design structural subtree is generated in the product concept design action, then the product design structural subtree is generated in the product design structural subtree which is the key subtree to the product full lifecycle structure and the it's follow-up structural subtree can be all derived from it.

The product design structural subtree can generate the product machining structural subtree through the product machining

action and can generate the product assembly structural subtree through the product assembly action. The product assembly structural subtree can generate the product use structural subtree through the product use action and can generate the product fix structural subtree through the product fix action. The relationship of the structural subtree in each stage can be expressed in a series of product lifecycle activities mentioned above.

## 3. The Structural Subtree Node

Shown as Fig.1, the node is expressed as the node name. The nodes include product node, assembly node and component node. The component nodes are the leaf nodes of the product structural subtree. The component nodes can form assembly nodes and the product nodes. The assembly nodes can form the product nodes.

The product nodes: the product is the artifact that can satisfy the people's needs. It has some special function and performance

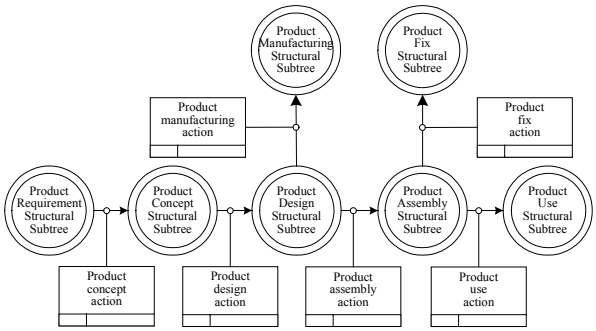



Fig 2.The association among the product structure subtrees

as a integrated product. It is the root node of the product structural subtree.

The assembly nodes: the assembly includes the aggregate of hardware, software as well as both, which satisfies certain the product function needs. A assembly always contains in a product, and it can be decomposed again. The assembly can form the product directly.

The components nodes: the components are basic elements that form the product, which are in a leaf nodes of the product structural subtree and can not be decomposed again. Here not being again decomposed is inside the enterprise. If a component is purchased outside, no matter how it is complicated, it is regarded as a component, which can't be decomposed. The component has the only ID in the system, which is used the identification of system. The component can directly form product and assembly.

Any structural subtree node has the attribute structure shown as Fig.3, and these attributes are divided into two kinds: 1) the foundational attribute; 2) the attaching attribute. The foundational attribute refer to the attribute that has intimate with the product structural tree itself, which contains these attribute, such as the node ID, the father node ID, the subnode ID, performance, function, feature et al. The node of the node ID refers to this node. The foundational attribute describes the inherent attribute of the structure relation, function and feature of these nodes. The additive attribute refer to other information added on these nodes, which includes these attribute, such as document attribute, manipulator attribute, version attribute, state

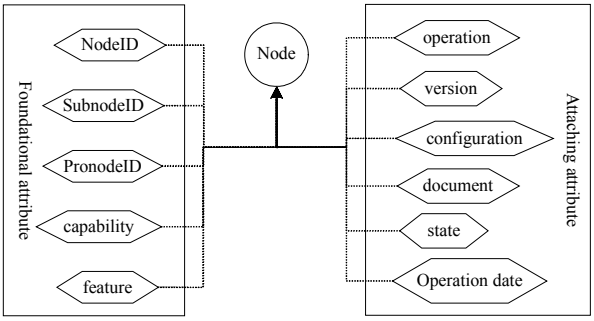



Fig 3.The attribute of subtree node

attribute, configuration attribute et al. The additive attribute describes this information of the state and operation of the node. In order to ensure the consistency of the product information, the text make these promise, which the attribute is expressed by the attribute name and it is unique. The different node may have the same attribute, even the same attribute value. In the process of the product full lifecycle structural tree, when in the latter stage the subtree node P' is changed from in the former stage the subtree node P, the attribute value of the node name is the same, but the attribute state value and the attribute node ID value are different, which are called as the different stage state of the same node. The state attribute of node may have seven state value corresponding to the seven product lifecycle stage shown as Fig.1 (R expresses the requirement stage, C expresses the concept stage, D expresses the design stage, A expresses the design stage, M expresses the machining stage, U expresses the use stage, F expresses the repairing stage respectively). All nodes state attribute value of structural subtree in some stage is the same except the null node.

## 4. THE NODE TRANSFORMATION DESCRIPTION

The product full lifecycle structural tree can be acquired the subtree sets through every action operation of the product structural subtree. In the product full lifecycle structural tree action, the operation among the product structural subtree can be classified as two categories: 1) The node operation, ie the operation among the product node, the component node and the part node. 2) Attribute operation, ie all kinds of attribute operation in the product structural subtree.

### *4.1. Node definition and regulation*

Node operation includes three operations, such as "Copy Nodes" operation, "Add Node" operation, "Delete Node" operation, which can ensure if the node exist or not. The three basic operation is shown as the section a, section b and section c of Fig. 4.

Definition 1: "Copy Nodes" operation. In the product structural subtree, "Copy Nodes" operation indicate the operation that the copied node P together with the subnode of node P and all their attribute completely is copied to the new node P' operation. According to the definition, in fact firstly the whole structural subtree is copied when the structural subtree is altered in the lifecycle stage.

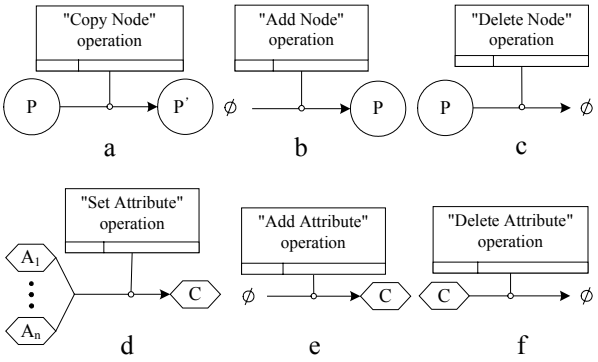



Fig 4.The six basic operations

Definition 2: "Add Node" operation. In the product structural subtree, "Add Node" operation indicates the operation that the new node P is created.

Definition 3: "Delete Node" operation. In the product structural subtree, "Delete Node" operation indicates the operation that a existed node P and all the subnodes of the node P are deleted.

The attribute operation includes three operations, which is "Set Attribute" operation, "Add Attribute" operation, and "Delete Attribute" operation. "Set Attribute" operation confirms the attribute value. The latter two kinds of operation define whether the node exists or not. It is shown as the sections d, e and f of Fig.4.

Definition 4: the attribute correlation. If the value of a certain attribute C of certain node P is obtained by other node attribute Ai (i=1, ...n) through correlation operation (Ai may be the same node also or different node attribute)

This is called that attribute C has correlation with attribute Ai or attribute Ai is correlation attribute of attribute C. Otherwise, the attribute C of node P is not correlated attribute.

Definition 5: "Set Attribute" operation. It expresses the operation that certain attribute C of the certain node is assigned. The operation has two cases:

① if the node attribute C has correlation with other attribute $A_i$（i＝1…n）, the value of attribute c is calculated according to formula 1 and the result is assigned to the attribute C.

Formula 1： $c = f(a_1, \cdots, a_n)$。

$c$ -The value of structural subtree node attribute C;

$f()$ -Function expression including logic operation and arithmetic operation;

$a_i$ -The value of structural subtree node attribute $A_i$, i＝1…n。

② if the node attribute C is not correlative attribute, namely attribute Ai ( i=1 ..... n ) serve for null attribute, the attribute value needs to be set in the system individually(by automatic method and man-made method).

Definition 6: "Add Attribute" operation. It expresses that attribute C of certain node is added.

Definition 7: "Delete Attribute" operation. It expresses that attribute C of certain node is deleted.

Operation regulation 1: "Add Node" operation and "Delete Node" operation must be operated after the father node of operated node has been "Copy Node" operation in progress.

Operation regulation 2: All attribute operation can be operated on the condition that this node exists.

Operation regulation 3: “Set Attribute” operation is operated on condition that these attributes only exist

When the structural subtree is altered, the node attribute value can be determined by following several cases:

① the attribute value directly inherit the node attribute value at preceding state, which is the most common attribute definition method during the structural subtree node transformation. The attributes of number of teeth, material, precision grade in gear wheel are shown as Tab.1

② the real significance of the node attribute is the same, but the measurement units is different, as shown in Tab1, center distance attribute of gear wheel is according to centimeter in the design stage, but adopts the millimeter in manufacturing stage (the problem often appear when the part is cooperatively machining outside).

When the nodes have the same attribute, but the measuring units are different, the corresponding attribute value will be automatically transformed according to the corresponding formula in the system.

③ the attribute has certain functional operation relation to other attributes. As shown in Tab.1, hobbing cutter precision of gear wheel in the machining stage must be AA grade, which can satisfy 7 grades of requirements in gear wheel precision

④ the attribute value has not correlation with other attribute, such as the operator, the operating date etal shown as Tab.1, which can be set automatically and manually in the system.

*4.2.The construction of the structural subtree*

The requiring structural subtree is the initial subtree of the product full lifecycle structural subtree, which has only the product node, but has not the structural subtree that can be transformed, so it can only determine the product node of the product requiring structural subtree through “Add Node” operation, and append the attribute to the requiring product node through “Add Attribute” operation, thus the product requiring subtree can be constructed.

TABLE 1

THE ATTRIBUTE OF COLUMNED STRAIGHT GEAR PART ON EACH LIFECYCLE PHASE

| Design phase | | Manufacturing phrase | | Assembly phase | | Use phase | | Fix phase | |
|---|---|---|---|---|---|---|---|---|---|
| Attribute | Value | Attribute | Value | Attribute | Value | Attribute | Value | Attribute | Value |
| Number of teeth | 80 | Number of teeth | 80 | Directional assembly | Nose balance | Number of teeth | 80 | Number of teeth | 80 |
| Precision | 7 | Precision | 7 | Cramping fixture | Z879 | Precision | 7 | Precision | 7 |
| Material | A3 | Material | A3 | | | Material | A3 | Material | A3 |
| Center distance | 15.8 | Center distance | 158 | Single mass | 1.5 | Operation date | 050309 | Lubricating liquid | common |
| Unit | cm | Unit | mm | Unit | kg | Operator | Liu li | Operation date | 050310 |
| Pressure angle | 20º | Single mass | 1.5 | Gear running | loading | … | … | Operator | Du gao |
| Module | 2.5 | Unit | kg | Backlash check | By machining | | | … | … |
| Operation date | 050301 | Hob precision | AA | Contact precision | Smear test | | | | |
| Operator | Li mi | Operation date | 050304 | Operation date | 050307 | | | | |
| … | … | Operator | Zhang | Operator | Wang | | | | |
| | | … | … | … | … | | | | |

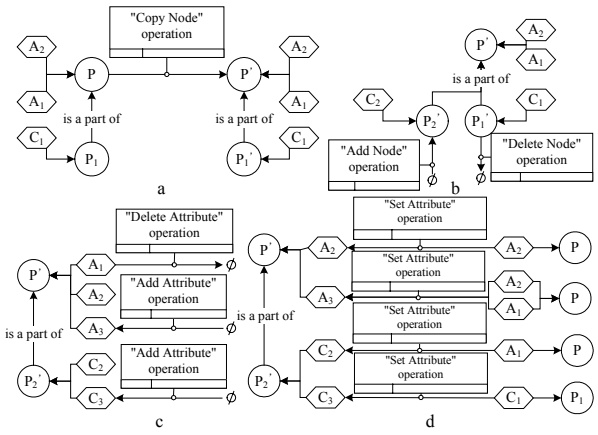



Fig 5.The constitution of the structural subtree

The structural subtree in other stages shown as Fig.1 can follow the former definition and operation regulation and operate according following step:

Step1: According to the relation of the product structural subtree (shown as Fig.2), the product node P can be copied as the product node $P^{'}$ in this stage by adopting “Copy Node” operation. In fact the product node P as well as the structural subtree included in P can be copied, shown as the section a of Fig. 5.

Step 2: According to action in lifecycle corresponding stage, the product structural subtree in the stage can be determined by “Add Node” and “Delete Node” operation of the node copied P. As shown the section d of b Fig. 5, delete the subnode $P_1^{'}$ and add subnode $P_2^{'}$.

Step 3: the attribute of node can be determined by “add attribute” and “Delete Attribute” operation of the node. As shown the section c of Fig. 5, the attribute $A_1$ of the product node $P^{'}$ is deleted and the attribute $A_3$ and the component node $P_2^{'}$ is appended, so the new attribute $C_2$ is appended.

Step4: According to action in lifecycle corresponding stage, the node attribute can be assigned by “Set Attribute” operation. As shown the section d of Fig. 5, the attribute $A_2$ of node $P^{'}$ has only correlation with the attribute $A_2$ of the node P copied, but the attribute $A_3$ of the node P has correlation with the attribute both $A_1$ and $A_2$ of the node P copied. The attribute $C_2$ of the node $P_2^{'}$ has correlation with the attribute $A_1$ of subnode P copied.

Besides the requiring structural subtree, the construction of all product structural tree can follow the four operation steps, and finally comes into being the product full lifecycle structural tree.

## 5. THE PRODUCT FULL LIFECYCLE STRUCTURAL TREE CONSTRUCTION EXAMPLE

By a preparation system of an organic prototype device used the vacuum experiment as the example, the full lifecycle structural tree of the device is constructed. Owing to the limited length, the formation of parts of nodes and attribute of structural subtree in

the organic prototype device preparation system is described. The requiring structural subtree, the concept structural subtree, design structural subtree, assembly structural subtree, machining structural subtree, use structural subtree and repairing structural subtree in the organic prototype system are respectively expressed at section a to g of Fig.6.

According to the technical contract, it can append the node in "preparative system R of organic prototype device" as the product node of requiring subtree, shown as the section a of Fig. 6. It is initial subtree of the product lifecycle structural tree, these attributes, such as the node ID, limited vacuum and state et al, were appended by “Add Attribute ” operation. The attribute

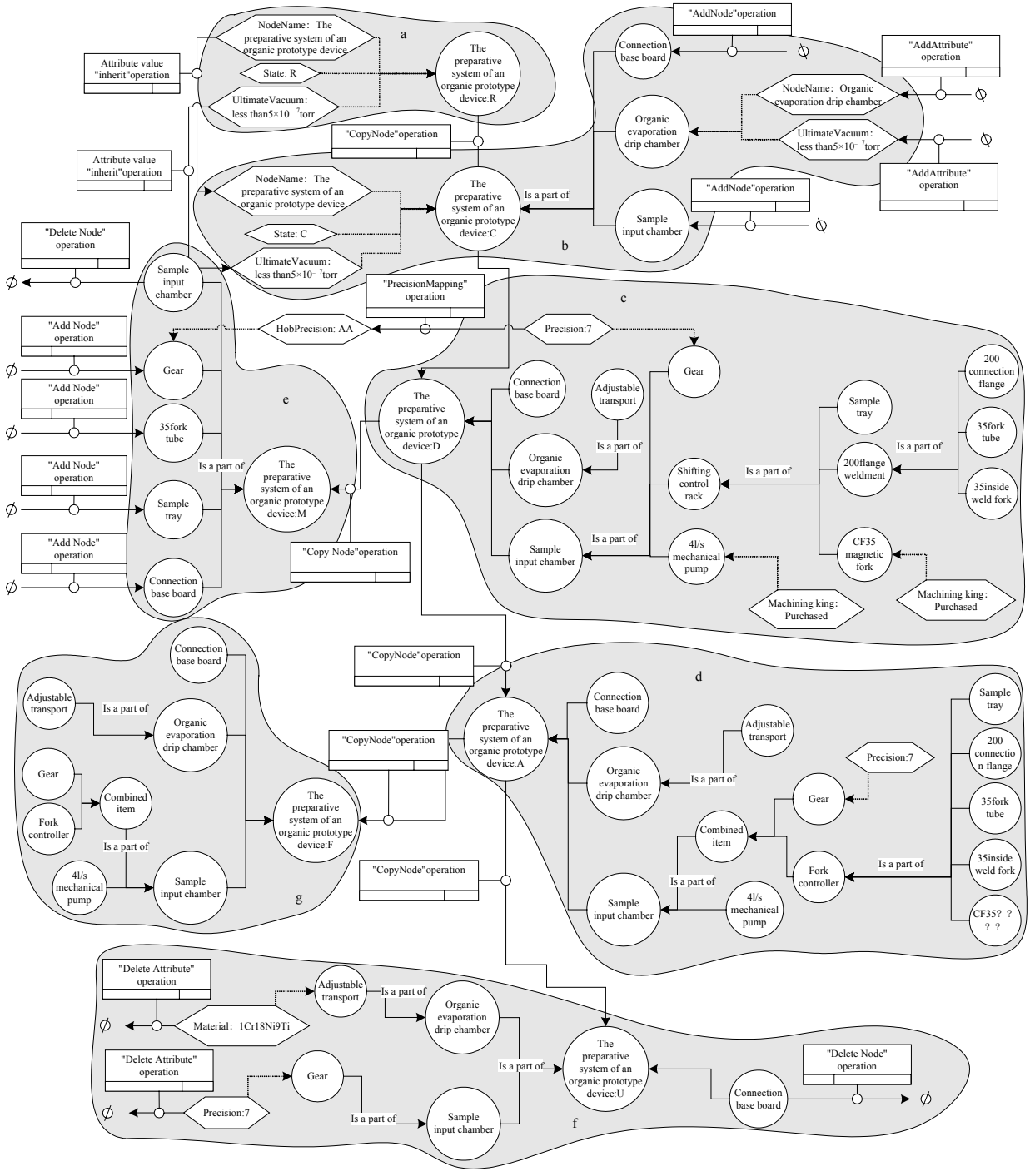



Fig 6.The example of the product lifecycle structural tree

values mentioned above that is made sure by assigning the value for the attribute are respectively “OME.00.00.00”, “less then $5\times10^{-7}$torr” and “R”.

The construction of concept structural subtree: The product node of requiring structural subtree in "preparative system R of organic prototype device" can be copied by “Copy Node” operation, thus the product node of concept structural subtree in "preparative system C of organic prototype device "can be obtained. According to the requirement of product concept design, three subnodes - “Organic evaporation drip chamber”, “Sample input chamber”, “Connection base board ”can be appended under this node by “Add Node” operation, “limited vacuum” can be appended to subnode in “the organic source evaporation and precipitation room” by adopting “Add Attribute” operation, the attribute value that can be made sure by “Set Attribute ”is “prior to $5\times10^{-7}$torr”.

The concept structural subtree in preparative system R of organic prototype device can be constructed by similar operation mentioned above. The construction process of design structural subtree, assembly structural subtree, machining structural subtree, use structural subtree and fix structural subtree in the organic prototype system is the similar to this. Among them, in the transformation action from design structural subtree to assembly structural subtree, because the product design mainly comes from the standpoint of product function realization, but the product assembly comes from the standpoint of assembly technology, so the nodes need to be adjusted when the structure relation of the product structural subtree appears variable, as shown the section c and section d of Fig 6. For example, there are three parts composed of “200 flange weldment” component in the product design stage, but three parts can be directly installed on “shifting control rack” in the assembly stage, the “200 flange weldment” is cancelled. On another case, the “Sample input chamber” is compose of three parts – “4l/s mechanical pump”, “shifting control rack” and “gear” in the design stage, but in the assembly stage, firstly shifting control rack and gear wheel need to be installed to a subassembly, and then the subassembly and 4l/s mechanical pump are installed for the sample introduce room. It is realized by “Add Node” operation and “Delete Node ” operation in two cases.

The product machining structural subtree has only two kinds of node - the product node and the part node， moreover the part node only includes the part that it’s machining category attribute is “home-made part”. The category of “4l/s mechanical pump” and “CF35 magnetic fork” shown as in the section c of Fig 6 are purchased outside, so there are not two parts in the machining structural tree as shown in the section e of Fig 6. The transformation process from the product assembly structural subtree to the product use structural subtree mainly is an information shielding process. The information of the product use structural subtree is less than that of the product assembly structural subtree, no matter what is the number of structural tree node or the attribute of the nodes

As shown in the section f of Fig.6, the “Connection base board” node is deleted from using the use structural subtree by the “Delete Node” operation. The material attributes of the “Adjustable transport” node and “sample input chamber” node are deleted from their nodes respectively by the “Delete Attribute” operation, et al.

Thus, the full lifecycle structural trees in preparative system of organic prototype device are constructed.

## 6. Conclusion

Based on analyzing the connotation of product structural tree， the concept of the product lifecycle structural tree is put forward. The node, node attribute and the their relation of the product lifecycle structural tree are discussed, the principle and method about the operation of the node and the node attribute are researched in this paper. By using the extended IDEF5 Schematic Language, it is defined to the six basic operations, including the “Copy Node” operation, the “Add Node” operation, the “Delete Node” operation, the “Set Attribute” operation, the “Add Attribute” operation, the “Delete Attribute” operation. The operation regulation and operation step are illustrated. Thus it can be seen that the product full lifecycle structural trees in preparative system of organic prototype device are constructed by the example.

The product full lifecycle structural trees express the business model of the product full lifecycle, which supply support for the information analysis and verification of these application system - CRM, ERP and PDM reliably, completely and consistently, which establish the foundational for document formation and the information integration.

## Acknoledgment

Authors gratefully acknowledge the National Basic Research Program, China (Grant No. 2002CB312200) for supporting this research.

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