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Studies on Information States Measurement for Modeling Design

GAN Yi and WANG Junlei

College of Mechanical Engineering, University of Shanghai for Science and Technology, 200093 Shanghai, China

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Abstract: Three kinds of information states in the product information transfer process were introduced, which comes from Top Basic Skeleton to Sub-basic Skeleton or parts layer-by-layer. In the process, the product has three information states, and the structures of the process were series and parallel. In terms of the structures of information transfer and variant design, the information distances among the product information states were measured by calculating transition probability. This method provides a basis of manufacturing informatics for design.

Keywords: information state, information measurement, top basic skeleton, top-down design

1. Introduction

Facing the market with the infinite individual needs and the single enterprise with limited resources and ability, the enterprises must be organic unities which are consisted by a reasonable and orderly flow of information, goods, capital, value and services, and they also can quickly and effectively handle an amount of complex information [1–4]. The design and manufacturing processes contain the information collection, transference, processing and utilization [5], as well as the flow and change of information. The design of the product radically determines their inner qualities and total costs [6].The top-down design model represents the design method which is from macroscopic to microcosmic and from abstract to concrete, and it accords with the product design flow and the cognitive process of engineering designers. The top-down design model also supports product levels of abstraction expression, and it will have a good effect in the development of the new product. [7–9]

Top Basic Skeleton (TBS)[10, 11] of the products is the specific method of the top-down design model. The product assembly models based on TBS can support the processes from the conceptual design to the parametric design and the detailed design. In the transformation processes from the parametric structural model to the specific assembly model, as well as during the adjustment of part size and position, TBS of the product can also effectively keep the engineering constraint and the geometry constraint in assembly model.[10–13] But there are still lack of the manufacturing information [5] during the modeling procedure based on TBS from the perspectives of manufacturing informatics at the present time.

The quantitative expression of the information has been carried out extensive research. Hartley primarily proposed the method of using the pure form to measure product information quantity [14]; Shannon proposed the probability information formula [15]; ZHONG Yi-xin defined the total information, and deduced the measurement methods of syntax information, semantic information as well as pragmatic information [16]; Wang huan-chen proposed the method of quantitative measurement about information and knowledge [17]; ZHANG Bo-peng described on the representation, distribution and operation of the information in the manufacturing engineering [5].On the basis of the above researches, this article analyzes the information state and the information measurement of the product in the top-down design processes based on TBS.

* Corresponding author: e-mail: ganyi@usst.edu.cn

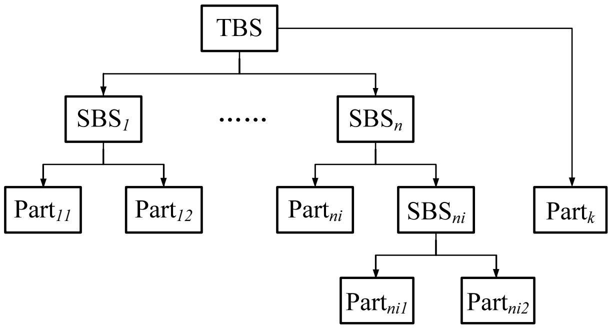

Figure 1 The information transfer structure based on TBS.

2. The modeling design based on TBS and its information states

TBS can indicate the main spatial position and form of the product model, and can basically reflect the topological relationships and its main movement functions among all the sub-modules which constitute the product [10,11]. TBS doesnt contain any geometry of the parts and components or the concrete parts, and in the top-down transfer process, all information related to the product expands gradually. Parts and components replicate the information of design, and the design references of the TBS are inherited, so the sub-basic skeleton (SBS) is established. According to the SBS, the detailed design of the product is carried through. During this process, the production information takes on three states: TBS, SBS and Part.

The product information transfers from TBS to every SBS, then to each part or from TBS to every part directly, which has obvious hierarchical relations. During the modeling procedure based on TBS, parts and components directly replicate the key information from frameworks above them. In order to keep the control of the TBS constraint to the information blow them, parts can't replicate the information through other design routes. It also can avoid the influence of the whole model because of the change of some design routes at the end of the design process. The information transfer process of the modeling procedure based on TBS has the series structure and the parallel structure as shown in Fig.1.

(1) The Series Structure of the Information Transfer Process.

During the modeling procedure based on TBS, the product information is transmitted from the top TBS to the parts at the end by way of the SBS at all levels. Before and after the information transfer process, the product information is interrelated, which reflect the series state. By the layer-by-layer transfers in the series states, the main parameters of the lower parts and components are under control in accordance with the upper skeleton information.

(2) The Parallel Structure of the Information Transfer Process.

For the sub-basic skeleton on the same level, SBS 1 and SBS 2 inherited the upper skeleton information, and have the same design references. At the same time, they transfer the design information to their subordinates. The information transfer process of SBS 1 and SBS 2 are independent, which reflects the parallel state. So they need to be considered at the same time during the design process. Every partial initial state constitutes the total initial state, and every partial final state constitutes the total final state.

3. The information state distance measurement of modeling design based on TBS

The information state transition is the changes among several possible information states of research object. Information state transition distance is called information distance for short, which is the measurement of the obstacles which the research object meets during the process of its states transfer [17]. The farther the information distance is, the more information needs to be acquired during the design process from STB to the part.

Let $X = x_i$ be the state set in the product design process, x_i is the ith information state, and $i = 1,2,\cdots,n$. There are three information states in the modeling procedure based on TBS which are TBS, SBS and Part. The state set X_{TBS} is defined as $X_{TBS} = \{x_1 = TBS, x_2 = SBS, x_3 = Part\}$.

Let p_i be the transition probability of the transfer which is from x_i to x_j, and $DI(x_i,x_j)$ be the information distance of the transfer. $DI(x_i,x_j)$ is that log p_{ij} to the base 2,That is,

$$DI(x_i,x_j) = \log_2(1/p_{ij}) = -\log_2 p_{ij} \quad (1)$$

Where$i,j = 1,2,\cdots,n; \sum_{i,j=1}^{n} p_{ij} = 1$. So it has the same dimension with information entropy[17].

For the transition among more information states, corresponding transition probability matrix P and information distance matrix DI are defined as follows:

$$P = [p_{ij}]_{n\times n} \quad (2)$$

$$DI = -[\log_2(1/p_{ij})]_{n\times n} \quad (3)$$

For the series structure of the information transfer process in the modeling procedure, the total transition probability is the product of every partial transition probability. For the parallel structure of the information transfer process in the modeling procedure, the information transfers processes among every SBS or part on the same level are mutually independent, so they need to be considered at the same time. Every partial initial state constitutes the total initial state, and every partial final state constitutes the total final state.

To the two states above, let the x_{00}th state be the total initial state, and the x_{nj}th state in the end be the final state. Let $P(x_{i1},x_{jM})$ be the total transition probability from the

Table 1 The paraments of the information distance

Parameter Name	Parameter Value
Path node	$a_i(i=1,2,\cdots,n-1)$
State number of each path node	$b_i(i=1,2,\cdots,n-1)$
Information state of node a_i	$x_{i1},\cdots,x_{ib_i}$
Transition probability from state x_{ij} **to state** x_{nj}	$pw_{i1},\cdots,pw_{ib_i}$
State chain	$x_{1j},\cdots,x_{nj}$

state x_{i1} to the state x_{jM}, and $DI(x_{i1},x_{jM})$ be the total information distance. $p(x_{i1},x_{jM})$ and $DI(x_{i1},x_{jM})$ are defined as follows:

$$p(x_{i1},x_{jM}) = \prod_{m=1}^{M} p(x_{im},x_{jm}) \tag{4}$$

$$DI(x_{i1},x_{jM}) = \sum_{m=1}^{M} DI(x_{im},x_{jm}) \tag{5}$$

Generally, the number of the products is more than one. During the information transfer process from the TBS to the parts, the production information will pass through n routes, and it will take on the multi-route structure of the information transfer process. Let $d_i(i=1,2,\cdots,n)$ be the information distance of the nth route, the total information distance is defined as follows:

$$d = \sum_{i=1}^{n} \omega_i d_i \tag{6}$$

Where ω_i is the weight of the ith route.

During the modeling design process based on TBS of one product, let the TBS be the initial state x_{00}, and the part is the finial state x_{nj}, and the node $a_i(i=1,2,\cdots,n-1)$ passed through by the product information has b_i states. And let pw_{ij} be the transition probability from the state $x_{ij}(j=1,2,\cdots,b_i)$ to the state $x_{i+1,j}$ in the information transfer process. The parameters of the information distance are represented in TABLE 1.

The information distance measurement for modeling design based on TBS is defined as follows:

$$\sum_{j=1}^{b_i} pw_{ij} = 1, i=1,2,\cdots,n-1 \tag{7}$$

$$\begin{aligned} p(x_{00},x_{nj}) &= p(x_{00},x_{1j}) \times \prod_{i=1}^{n-1} p[x_{ij},x_{(i+1)j}] \\ &= p(x_{00},x_{1j}) \times \prod_{i=1}^{n-1} pw_{ij} \end{aligned} \tag{8}$$

$$\begin{aligned} DI(x_{00},x_{nj}) &= -\log_2[p(x_{00},x_{1j}) \times \prod_{i=1}^{n-1} pw_{ij}] \\ &= DI(x_{00},x_{1j}) + \sum_{i=1}^{n-1} DI[x_{ij},x_{(i+1)j}]pw_{ij} \end{aligned} \tag{9}$$

Where $p(x_{00},x_{nj})$ is the total transition probability from the initial state x_{00} of the TBS to the final state x_{nj} of the part, and $DI(x_{00},x_{nj})$ is the total information distance.

In the condition of the multi-route information transfer, suppose there are m routes, and $dr_i(i=1,2,\cdots,m)$ is the distance of the ith route. Where ω_i is the weight of the ith route, and $\sum_{i=1}^{n}\omega_i = 1$. The total information distance measurement dr is defined as follows:

$$dr = \sum_{i=1}^{m} \omega_i dr_i \tag{10}$$

The design method based on TBS supports that multiple design workgroup can refer to the same reference information when they are designing the subassemblies and the parts. When the features of the TBS are changed, the parts will change accordingly because of having inherited the association relationships of the TBS, and then the variant design will be realized, so the efficiency and accuracy of the design will be greatly improved. The product can realize various functions by the variant designs. In this case, suppose some product has m functions corresponding to its m variants, the total information distance measurement is defined as follow:

$$df = \sum_{i=1}^{m} \lambda_i df_i \tag{11}$$

Where $df_i(i=1,2,\cdots,m)$ is the information distance of every variant; λ_i is the weight of the ith variant, and $\sum_{i=1}^{m}\lambda_i = 1$.

There is not only one design route based on TBS for the same product. The corresponding optimal solution will be determined by the functional requirements of the product and combining the factors of the information state distance measurement in the product design process, the association and dependency relationship of every part and component, processing technology, material, the relationships between the product and environment and so on.

4. Applications

In the emergency rescue and disaster relief, there are more requirements for stretchers. For example, the wounded need urgent fluids infusion, but all the existing medical stretchers are not with a transfusion shelf attached. In addition, it may need simple ladders to rescue the wounded in the disaster relief, but the existing stretcher cant be used as a ladder in general conditions. At the present time, the most common modeling process of the simple rescue stretcher based on TBS is shown in Fig.2.

There are two kinds of nodes in the modeling process, they are two information states: STB and Part. And the information distance parameters are shown in TABLE 2. Due to the design and function requirements, the lathe bed TBS can only has one possible state. When designing the bedstead Part 1, its transverse section has three optional

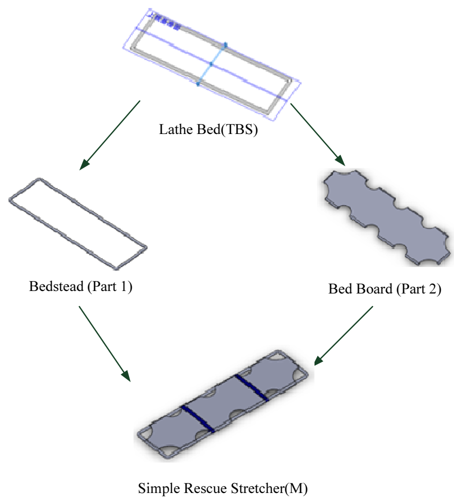

Figure 2 Modeling process of the simple rescue stretcher based on TBS.

Table 2 The information distance parameters of the simple rescue stretcher.

Path node	**State number of each path node**	**State**	**State transition probability**
STB	1		1
Part 1	3	Square	0.3
		Circle	0.5
		I-shape	0.2
Part 2	2	Hard flat plate	0.6
		Soft flat plate	0.4
STB	1		1

shapes (square, circle and I-shape) which correspond to three product information states. We choose round bar steel in the concrete design. When designing the bed board Part 2, we can choose the hard flat board or the soft flat board. We choose the hard flat plate in the concrete design.By the formula (10), we can get the information distance in the simple stretcher design process:

$$DI = 0 + \log_2(1/0.5) + \log_2(1/0.6) + 0 \approx 1.737$$

According to the method of modeling design based on TBS, the article designs a small multifunctional rescue stretcher-ladder which contains a height adjustable and foldable stretcher, a climbing ladder. Infusion bottles can be hung on the rescue stretcher-ladder. According to the function requirements the product can be break up into two function blocks: the stretcher and the suspender which is used for hanging infusion bottles. The height adjustment of the stretcher can be realized by adjusting the distance between the ends of the handrail and the ground, while the climbing ladder can use its support crossbars. According to the data of the ergonomics, the dimensional constraints and physical constraints of the two blocks are determined in TBS. The design process of the small multifunctional rescue stretcher-ladder based on TBS is shown in Fig.3.

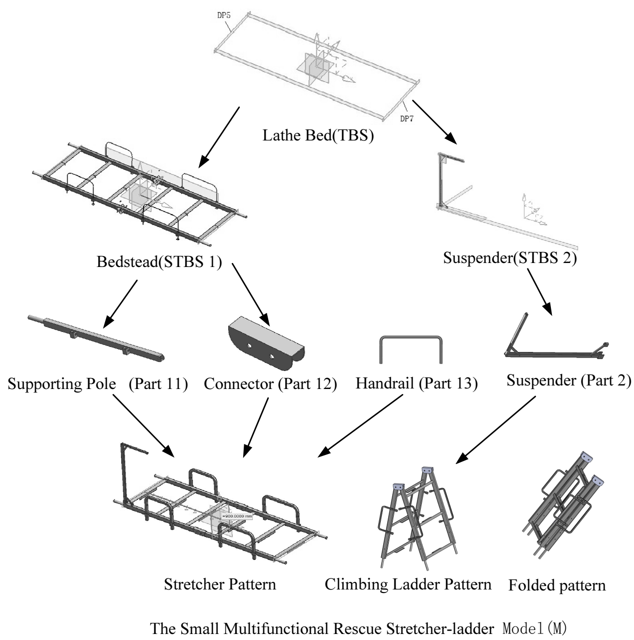

Figure 3 The design modeling process based on TBS of the small multifunctional rescue stretcher-ladder.

The nodes in the design process of the small multifunctional rescue stretcher-ladder have three kinds of information states: TBS, SBS and Part. The number of their possible information states is different. The parameters of the information states about the rescue stretcher-ladder are represented in TABLE 3. Due to the limits of functions and design requirements, TBS only has one possible state. When designing the bedstead SBS 1, there are two folding patterns. They are along the longitudinal axis and along the lateral axis respectively. Taking its function of the climbing ladder into account, we choose the pattern of folding along the lateral axis. When designing the supporting pole Part 11, its transverse section has three optional shapes which are square, circle and I-shape. In order to make the assembly process between the supporting pole and the handrail easy, we choose the square tubular. For SBS 2, Part 12, Part 13 and Part 21, we choose inclined support, non-standard parts, two big and two small, circular steel tube.

By the formula (10), we can get the information distance:

$$\begin{aligned} DI &= 0 + \log_2(1/0.6) + \log_2(1/0.5) + \log_2(1/0.5) \\ &\quad + \log_2(1/0.6) + \log_2(1/0.5) + \log_2(1/0.5) + 0 \\ &\approx 5.474 \end{aligned}$$

Table 3 The parameters of the information states of the small multifunctional rescue stretcher-ladder.

Path node	State number of each path node	State	State transition probability
STB	1		1
SBS 1	2	Longitudinal folding	0.4
		Lateral folding	0.6
SBS 2	2	Has inclined brace	0.5
		Hasnt inclined brace	0.5
Part 11	3	Square	0.5
		Circle	0.3
		I-shape	0.2
Part 12	2	Non-standard parts	0.4
		Standard parts	0.6
Part 13	2	Two big handrail	0.5
		Two small handrail	0.5
Part 11	3	Square	0.5
		Circle	0.3
		I-shape	0.2
M	1		1

Taking the variant design of SBS 1 into consideration, that is changing the folding pattern of SBS 1 from the lateral axis to the longitudinal axis, and their information distances are DI_h and DI_z. They have the same weight. By the formula (11), we can get the information distance in the small multifunctional rescue stretcher-ladder variant design process:

$$df = 0.5 \times DI_h + 0.5 \times DI_z \approx 5.767$$

The functional requirements of a small multifunctional rescue stretcher-ladder are more than a simple stretcher, which means that it has more complex structures, and needs more external manufacturing information and more design information of its internal structure. In the process of variant design, the information state transitions need more information. So it quantitatively shows that different design ideas have different requirements for information quantity from manufacturing informatics. The product design is a process where subjective initiative shall be given full play. There is not only one design route based on TBS for the same product. The information distance measurement can help designers combine factors of sizes, materials, processing technologies, the associations and dependency relationships among every part and component, the relationships between products and environment and so on, so designers can determine the corresponding optimal solution easily from the perspective of quantitatively calculating manufacturing information.

5. Conclusion

The product design intention transfers to every subsystem from up to down by TBS, which has obvious hierarchical relations. During the modeling procedure based on TBS, parts and components directly replicate the key information from frameworks above them, and it reflects the series structure and the parallel structure of the information transfer. During this process, production information takes on three states: TBS, SBS and Part. By calculating the information distances among different information states, we can quantitatively determine the information quantity during the information state transfer process from TBS to Part. And it is also benefit for determining the optimal solution of the design process.

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GAN Yi received the PhD degree from Tongji University. He is currently an associate professor in College of Mechanical Engineering,University of Shanghai for Science and Technology. And he also is a member of Committee member of China Mechanical Engineering Institute of Machinery Industry Automation Branch. His research interests are Modern Design Theories and Methods, and he has published over 30 research articles.

WANG Jun-lei is a graduate in University of Shanghai for Science and Technology.