Studies on Information States Measurement for Modeling Design

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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-basicSkeleton 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.

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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 \( i \)th 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 \( x_{it} \)th state in the end be the final state. Let \( P(x_{i1}, x_{it}) \) be the total transition probability from the
state $x_{i1}$ to the state $x_{iM}$, and $DI(x_{i1}, x_{iM})$ be the total information distance. $p(x_{i1}, x_{iM})$ and $DI(x_{i1}, x_{iM})$ are defined as follows:

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

(4)

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

(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 $d_i(i = 1, 2, \ldots, n)$ be the information distance of the $i$th route, the total information distance is defined as follows:

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

(6)

Where $\omega_i$ is the weight of the $i$th 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 final state $x_{nj}$, and the node $(i = 1, 2, \ldots, n - 1)$ passed through by the product information has $b_i$ states.

And let $pw_{ij}$ be the transition probability from the state $x_{i1}(j = 1, 2, \ldots, b_i)$ 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:

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

(7)

$$p(x_{00}, x_{nj}) = p(x_{00}, x_{i1}) \times \prod_{i=1}^{n-1} p[x_{ij}, x_{i+1,j}]$$

(8)

$$DI(x_{00}, x_{nj}) = -\log_2[p(x_{00}, x_{i1}) \times \prod_{i=1}^{n-1} pw_{ij}]$$

(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 $dr_i(i = 1, 2, \ldots, m)$ is the distance of the $i$th route. Where $\omega_i$ is the weight of the $i$th route, and $\sum_{i=1}^{m} \omega_i = 1$. The total information distance measurement $dr$ is defined as follows:

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

(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:

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

(11)

Where $df_i(i = 1, 2, \ldots, m)$ is the information distance of every variant, $\lambda_i$ is the weight of the $i$th 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 can't 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
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.

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:

$$DI = 0 + \log_2(1/0.6) + \log_2(1/0.5) + \log_2(1/0.5) + \log_2(1/0.6) + \log_2(1/0.5) + \log_2(1/0.5) + 0 \approx 5.474$$

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

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

<table>
<thead>
<tr>
<th>Path node</th>
<th>State number of each path node</th>
<th>State</th>
<th>State transition probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>STB</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Part 1</td>
<td>3</td>
<td>Square</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Circle</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I-shape</td>
<td>0.2</td>
</tr>
<tr>
<td>Part 2</td>
<td>2</td>
<td>Hard flat plate</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soft flat plate</td>
<td>0.4</td>
</tr>
<tr>
<td>STB</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

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**Figure 3** The design modeling process based on TBS of the small multifunctional rescue stretcher-ladder.
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 $D I_h$ and $D I_z$. 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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### References

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