PRODUCT PARAMETER CALCULATION BASED ON CONFIGURABLE BOM MODEL

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Abstract. In order to meet the customer’s demand for product customization and to solve the problem of complicated BOM configuration and product parameter calculation in manufacturing enterprises, we design a configurable BOM model and realize a dynamic calculation engine of product parameters based on the model. The configurable BOM model abstracts key entities such as product, product attribute, material, material attribute, material brand, and so on. It realizes flexible expansion of customized product and its materials. In order to get the key parameters of the product, such as raw material cost, sale price, etc., the key parameter’s expressions of the product are dynamically configured, the values of product attribute and material attribute are used as input parameters and the real-time dynamic calculation is realized by using the algorithm based on the JavaScript engine-Mozilla Rhino, which makes the parameter calculation logic decoupled from the business logic and achieves the scalability of the product parameter calculation. The validity of the configurable BOM model and the calculating engine of product parameters are illustrated by an example of BOM structure and raw material cost calculation of a flat box in carton manufacturing industry.

1. Introduction
BOM (Bill of Material) is interpreted as a "material list" in a narrow sense. It is interpreted in a broad sense as "standard information related to the product structure and production process centered on material data, and [¹] of historical information derived therefrom". As a management document, BOM involves the sales, planning, production, supply, cost, design, product control, and function of the enterprise, it is an important part of receiving customer orders, selecting assembly, preparing production and purchasing plans, matching materials, tracking logistics, tracing tasks, calculating costs, and changing cost design. In a product produced by an enterprise, a product consists of multiple types of materials. Each type of materials has different specifications, attributes, and brands. Some materials and sub-materials need to be further expanded.

In order to win market competitiveness, in addition to the production of standardized products, production enterprises are more of order production, product-oriented production mode [²], to meet the customer's personalized requirements to provide product customization services. Submit product requirements through the online system, the system can configure the BOM based on customer requirements, automatically calculate the product unit price, and provide a discount based on the customer level. Customized products meet customers' personalized requirements, and the traditional offline price inquiry process can be canceled because of price calculation and recommendation, which
will improve customer interconnection efficiency and bring enterprise benefits.

BOM-based product research has been widely used in manufacturing enterprises. One of the research hotspots is the conversion between multiple types of BOM views, which has been studied a lot \cite{3-5}. In the automobile manufacturing industry, the Shanghai Volkswagen Parts Club system is developed by You Weijian, based on the multi-level maturity BOM and project matrix management mode, which improves the management efficiency of vehicle models projects and supports the development and management of new vehicle parts\cite{6}. For the issue of vehicle BOM generating millions of single vehicle model under the free selection business, Xu Juhong proposed a method \cite{7} to check and verify the integrity of the entire vehicle configuration BOM in free selection mode. In order to improve the level and efficiency of MRO service, Li Ling designed a maintenance and running status data management framework based on composite maintenance material list, and proposed the maintenance and operation state evolution model based on finite state machine \cite{8}. In building materials and equipment manufacturing enterprises, Wang Lei proposed a production scheduling, project progress monitoring and early warning model based on bill of materials, and designed and developed a production progress management and control system \cite{9} in view of the difficulties of data collection, low efficiency of progress feedback, and untimely discovery of abnormalities in the production and processing of large-scale equipment. In the management of intelligent manufacturing engineering, Chenyi Zhou expounded the theory of intelligent manufacturing, introduced the concept and function of material list, proposed an improved material list tracking model, and realized the whole process quality tracking \cite{10}. In the power grid field, for the issue that the existing BOM design and knowledge management are not conducive to sharing data or information with heterogeneous systems, Zongliang Yang proposed a new method of ontology based BOM model design and knowledge management for power grid, which provides a new way for power grid material management \cite{11}. In all above literature, BOM is used for manufacturing enterprises, and the introduction of flexible BOM is expected to improve production efficiency and production capacity.

This paper has done two aspects of work, one is the establishment of BOM model. By abstracting the key entities such as product, product attribute, material type, material attribute and material brand, a flexible BOM model is established, which can store product information and BOM structure, and provide the model basis for meeting the customized needs of customers. On the other hand, the customized products vary greatly. In order to get some parameters of the products, it takes a lot of work to write the corresponding calculation logic. Moreover, some important parameters, such as the calculation of price, are not as simply as the product of material quantity multiply unit price, and then get the sum of them. For example, the cost of a carton involves the area of raw materials, which requires a more complex calculation process. At the same time, in the enterprise production, the optimization of production process often brings material changes at the same time. The hard coding calculation logic cannot adapt to this change. In order to solve this problem, a product parameter calculation engine based on expression configuration is designed and implemented. The product attribute and its material attribute value are taken as input, and the related results are obtained by batch calculation.

2. Configurable BOM model

In order to enable the BOM model to be dynamically configured and expanded on demand, a configurable BOM model is designed, as shown in Figure 1.

2.1 BOM model

The model abstracts key entities such as products, product attributes, materials, material brands, and material attributes. A product entity has common attributes such as the product name, customer information, creation time, and remarks. The product attribute defines the specific attribute of the product, including the attribute name and data type. When a product is created, the product attribute table stores the specific attribute value and is associated with the product attribute definition, the specific attribute value of a product is the input parameter for calculating the product parameter.
The materials of a product are constructed in the BOM tree. The Level-1 material type is split first. The minimum material unit that needs to be purchased in the production is used, and expand the materials that can be expanded. To facilitate management, some abstract parent material types are often defined for materials of the same type. The material type has attributes such as the material name, item code, and parent material. One material type has multiple brands. The brand records the material specifications and production company information. The specific material information, such as color and weight, must be defined in the material attribute, for the materials of a specific brand, the attribute values are stored in the attribute table.

Figure 1. Configurable BOM model

2.2 System Design Based on BOM Model

Based on the BOM model structure of the preceding products and materials, a customer-oriented online product customization system can be designed. Customers can obtain related product parameters and BOM structure by customizing product attributes online, and use the default material type, brand, and attribute value in the recommended BOM structure. If some senior customers have special preferences for the product brand or professional considerations, they will customize the brand and attributes of the materials. The system should be designed to meet the refined product customization requirements through the flexible BOM model.

According to the BOM model, the online product customization system is designed to form the ER diagram in Figure 2.
The following table 1 is a brief description of the seven tables shown in FIG. 2, which can support flexible expansion of a product and its BOM.

| Code Name                           | Full Name                        | Description                                              |
|-------------------------------------|----------------------------------|----------------------------------------------------------|
| Product                             | Product table                    | Stores standard products or customized products.          |
| product_property                    | Product attribute definition table| Product attribute definition, which is associated with the product table. |
| product_property_value              | Product attribute value table     | Stores specific product attribute values.                |
| Material                            | Material table                   | A self-associated material and stores common attributes.  |
| material_brand                      | Material brand table              | Brand attribute of a material.                           |
| material_property                   | Material attribute definition table|                                                          |
| material_property_value             | Material attribute value table    |                                                          |

2.3 Configurability of BOM Model

The preceding table structure design considers product expansion and material expansion. When adding a product, you can define the proprietary attributes of the product and specify a value for the standard product design and customized product customization. In the BOM, the material attributes and brand can be extended to meet the multi-dimensional quantitative description requirements of various material categories.

3. Product parameter calculation engine

To obtain the product parameter values based on configurable BOM, the parameters are represented by a customized calculation expression. The dependent parameters involved in the expression are replaced by their codes, and the calculation result is obtained through the product parameter calculation engine.

3.1 Calculation Expression Configuration

Product calculation expressions include input parameters, intermediate parameters, and output parameters. During calculation, input parameters are transferred by product attribute value and material attribute value. The formula calculation engine parses expressions, calculates the intermediate result and final result, and pushes and displays key parameter values.

The product parameter expression is defined in product_parameter_expression. The following table describes the field description.

| Field      | Name                  | Description                                                                 |
|------------|-----------------------|-----------------------------------------------------------------------------|
| id         |                       | Primary key                                                                 |
| Name       | Name                  |                                                                             |
| Code       | Unique code           | Unique ID of a parameter.                                                   |
| expression | Calculation expression| Parameter calculation expression                                             |
| levelcode  | Level Code            | This parameter is used for sorting. The parameter calculation depends on the sequence. |
| digits     | Reserved decimal places| By default, two decimal places are reserved.                                |
| product_id | Product ID            | Associated Product                                                          |
| deleted    | Logic deletion flag   |                                                                             |

The unique ID code indicates the parameter. Although it can also be represented by the primary
key ID, the code has better readability and is easier to configure on the GUI. The null value of the evaluation expression indicates that it is an input parameter. A non-empty value is an intermediate parameter or an output parameter, which is a parameter that needs to be calculated. The parameter calculation is sequential. The output of a parameter is usually the input of the latter parameter.

3.2 Product parameter calculation engine
The product parameter calculation engine is implemented by the Mozilla Rhino. The Mozilla Rhino is an open-source JavaScript engine that is written in the Java language. It is mainly used to provide script capabilities for end users in Java programs. The algorithm for calculating product parameters based on the engine is as follows:

Algorithm 1: Product parameter algorithm is based on the Mozilla Rhino

| Input: Product Parameter Calculation Expression |
|-----------------------------------------------|
| Output: Product parameter calculation result   |

1. Expression obtaining and sorting: Obtain all parameter expressions and configurations of the product in the expression configuration. The parameters are sorted by levelcode. Go to step (2).
2. Expression verification: Check whether the calculation variables in each expression are defined and whether the brackets match. If the verification fails, an exception is thrown. Otherwise, go to step (3).
3. Check the input parameters. Check whether all parameters whose expression is set to null are transferred through the input parameter. If no value is transferred, an exception is thrown. Otherwise, go to step (4).
4. Replace the calculation expression value. Replace the values of the variables such as $\{\text{code}\}$ in the parameter expression with the corresponding values. Then, go to (5).
5. Rhino engine calculation: The value replacement expression is sent to the Rhino for calculation and result obtaining. If an exception occurs, an exception is thrown. Otherwise, the calculation result is transferred to the next expression to be calculated as the input parameter value and transferred to the (4). After all expressions are calculated, the process exits.

After the preceding algorithm is used, the parameter values of the product can be obtained.

4. Example: Calculation of Raw Material Cost of a Carton
This section takes the cost calculation of raw materials in carton manufacturing industry as an example to illustrate the validity of the configurable product parameter calculation engine in this paper.

4.1 BOM model of the carton
According to the foregoing configurable BOM model, a structure of a carton may be simply represented as shown in FIG. 3.
For the sake of simplification, the BOM structure of the carton does not list the brand information of the materials. The product attributes of the carton include the length, width, and height. Further, the carton can be divided into the inner diameter, width, height, and outer diameter. In addition to the basic attributes, the carton contains the processing fee and printing fee. The carton BOM consists of three or five layers of paper, three layers of paper includes inside paper, surface paper and corrugated paper. Five layers of paper includes inside paper, surface paper, two layers of corrugated paper, and corrugated paper, different products have different materials, such as self-adhesive carton materials and rubber strips.

4.2 Calculation of Raw Material Cost of Flat Box

To define the price of the carton more precisely, the cost of the carton needs to be clarified. The cost of a carton includes raw material cost, processing cost, auxiliary material cost, version cost, freight cost (delivered by the manufacturer to the customer), and packaging cost, the sum of its cost plus profit is the market price of the carton. In the above cost, the cost calculation of raw materials is the most complicated. The following describes the working principle of the product parameter calculation engine by calculating the raw material cost of a carton.

1) Constraints

In order to simplify the process, select a flat box as a carton, its raw material paper is 3 layers, input parameters including length, width and height, are the inner diameter size.

2) Raw material cost formula

Total cost of raw materials = cardboard square meter unit price * carton area * (1 + increase rate).

3) Cardboard square meter unit price formula

Unit price of 3 layers cardboard square meter = paper price per ton /1000000* paper weight + tile paper price per ton /1000000* tile paper weight * rate +inside paper price per ton /1000000*inside paper weight.

4) Formula for calculating the area of a carton

Manufacturing length = inner diameter length + cardboard thickness; Manufacturing width = inner diameter + cardboard thickness; Manufacturing height = inner diameter height + cardboard thickness
*2; Expansion length: Manufacturing length *2+ manufacturing width *2-1.5+ tongue (three layers 30, five layers 40): Expansion width: Manufacturing height + manufacturing width + coefficient (3 layers: 0, 5 layers 2)

The area is calculated based on whether the expansion width is greater than 450 mm, as shown in the following table.

**Table 3. Formula for calculating the area of a flat box**

| The width of the carton is >450mm. | (Carton expansion length +10mm) * carton expansion width |
|------------------------------------|--------------------------------------------------------|
| The width of the carton is ≤450mm. | (Carton expansion length +15mm) * (carton expansion width +15mm). |

Configure an expression in the product parameter table according to the foregoing formula description, as shown in Table 4.

**Table 4. Configuration of the formula for calculating the parameters of the flat box**

| Name                        | Code          | expression                                                                 |
|-----------------------------|---------------|----------------------------------------------------------------------------|
| Inner diameter length       | length_inner  |                                                                            |
| Inner diameter width        | width_inner   |                                                                            |
| Inner diameter height       | height_inner  |                                                                            |
| Cardboard thickness         | thick         |                                                                            |
| Manufacturing length        | Length        | ${\text{length}\_inner}+{\text{thick}}                                    |
| Manufacturing width         | width         | ${\text{width}\_inner}+{\text{thick}}                                    |
| Manufacturing height        | height        | ${\text{height}\_inner}+{\text{thick}}*2                                 |
| Expansion length            | length\_expand| ${\text{length}}*2+{\text{width}}*2-1.5+30                               |
| Expansion width             | width\_expand | ${\text{height}}+{\text{width}}+0                                      |
| Area                        | Area          | if(${\text{width}\_expand}>450) \{(${\text{length}\_expand}+10)*{\text{width}\_expand}\} \text{else}\{(${\text{length}\_expand}+15)*({\text{width}\_expand}+15)\} |
| Paper procurement unit price| surface\_paper\_price |                                                            |
| Cardboard weight per gram   | surface\_paper\_weight |                                                        |
| Corrugated paper price per ton| corrugated\_paper\_price |                                                        |
| Corrugated paper weight     | corrugated\_paper\_weight |                                                        |
| Corrugated paper ratio      | corrugated\_paper\_ratio |                                                        |
| Unit price of inside paper procurement | inside\_paper\_price |                                                        |
| Inside paper weight         | inside\_paper\_weight |                                                        |
| Cardboard square meter unit price | price\_unit | ${\text{surface}\_paper\_price}/1000000*${\text{surface\_paper\_weight}}+${\text{corrugated\_paper\_price}}/1000000*${\text{corrugated\_paper\_weight}}*${\text{corrugated\_paper\_ratio}}+${\text{inside\_paper\_price}}/1000000*${\text{inside\_paper\_weight}} |
| Increase ratio              | ratio         | 0.05                                                                      |
| Total cost of raw materials | Cost          | ${\text{price}\_unit}*{\text{area}}/1000000*(1+{\text{ratio}})            |

In the preceding parameter expressions, the parameter value of the product is the length of the inner diameter, width of the inner diameter, and height of the inner diameter. The related parameters of the
paper, paper, and corrugated paper are the parameter values of the materials (raw materials). They are used as the original parameter values to provide input for the product parameter calculation engine, and finally calculate the total cost of raw materials. The parameter calculation process is configured in script mode to avoid the traditional hard coding process. If the formula needs to be changed, you can directly modify the expression configuration. If the expression is expanded, more parameters can be obtained.

5. Conclusions
This paper presents a configurable BOM model for product customization, which can be used to abstract key entities such as product, product attribute, material, material brand and material attribute, and provide a model basis for BOM expansion. To calculate the key parameters of the product, the calculation engine based on the expression configuration is designed based on the model. The engine uses the product parameter value and material parameter value as input and uses the Mozilla Rhino script calculation to implement real-time calculation. The calculation logic is decoupled from the business logic to further reduce the impact caused by the product BOM change.

The model and computing engine have been used in a carton manufacturing enterprise. The flexible BOM expression, dynamic parameter configuration and real-time operation provide the basis for the customization of customized products. In the next step, the BOM of the product can be expressed in knowledge graph. The parameter calculation can be used to calculate the BOM. This can further improve the visual expression capability and BOM search capability, and improve the self-update capability of the product.

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