Axiomatic Design Based Association Network Mining Method for Complex Mechanical and Electrical Products

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Abstract. Complex mechanical and electrical products have complex functions and structures, and simple customer requirements often hide the complex relationship between components. In order to effectively analyze the relationship between components of complex mechanical and electrical products and better deal with the problem of adaptive design, from the perspective of product requirements, a method of mining association network of components of complex mechanical and electrical products based on axiomatic design is proposed. Firstly, based on the whole life cycle of the product, the product use environment of product environment designer interaction is constructed, and the product requirements are obtained based on the product use environment; then, the axiomatic design of different domain mapping relationship is used to mine the association relationship of product parts, and the association network between product parts is constructed, and the association network is expressed structurally. Finally, taking the segment assembly machine of shield machine as an example, the effectiveness of the proposed method is verified.

Keywords: Product Requirements, Product Environment, Axiomatic Design, Life Cycle

1. Introduction
With the development of production technology, products from mass production mode into personalized customization mode, accurate access to product demand is the basis for enterprises to occupy the market. In the process of new product development and adaptive design of existing products, product requirements run through the whole life cycle of products, reflecting the expectations of enterprises and customers for product function, structure, green degree, reusability and other performance. Driven requirements of complex mechanical and electrical products, the coupling design process determines that in the development of new products and adaptive design, it needs to accurately grasp the product requirements and the correlation network between product parts [1].

Demand is the primary problem in product development and adaptive design. In order to obtain product demand more conveniently and comprehensively, some scholars apply Web technology to product demand acquisition. For example, Guo Wei analyzed product market information through web technology, established corresponding quantitative processing rules based on product life cycle feature
information classification, and formed a complete method of demand information processing and acquisition based on Web technology [2]. In order to obtain the requirement information conveniently, Dan bin et al formalized the domain expert experience knowledge into fuzzy reasoning rules. Based on this, an online architecture of intelligent requirement acquisition method for heterogeneous customers was established, and finally the accurate customized requirement information of heterogeneous customers was output [3]. In order to improve the accuracy of demand acquisition, Ji Xue proposed an online comment mining and demand acquisition method considering the hierarchy of product attributes [4]. Sun Wei and others put forward a prototype system model of online product demand acquisition and processing method based on design warehouse by using the knowledge base and product database, customer feedback, maintenance and other information in online design warehouse [5]. The above scholars have effectively expanded the scope and efficiency of demand acquisition through web technology, but the demand of complex mechanical products has the characteristics of strong professionalism, complex knowledge data, strong functional structure coupling and so on, so it is difficult to extract customer demand from website forum by using technology. Aiming at the problems of product demand information expression and model construction, scholars put forward different methods from different angles. For example, Wang Chen and others, aiming at the problems of insufficient demand information acquisition and low reuse rate, established the existence expression model of requirements based on multiple demand acquisition models, and finally expressed the user requirements with ontology [6]. Zhai Lili et al. Proposed an ontology based information system requirements acquisition method based on ontology mapping, semantic concepts and their relationships, and ontology reasoning rules to solve the problems of fuzziness, professional limitations, and natural language expression of requirements acquisition [7]. Cheng Xianfu et al. Aimed at the abstractness and fuzziness of the demand information in the process of building the customer demand model, constructed the model describing the customer demand based on axiomatic design, quantified the demand by joint analysis method and established the design relevance matrix, and finally achieved the optimal planning of the product family through the cluster analysis of the design relevance matrix [8]. In order to meet the needs of customers, Zhang Dong and others proposed a packaging design model based on QFD research framework [9]. Zeng Qingzhen and others proposed to build a demand model based on the combination of joint analysis and QFD in view of the lack of systematic theory and method to build a demand model for high-speed trains [10].

In the above related literature, different methods proposed by scholars for product demand acquisition, expression and model construction have achieved good results, but they are not suitable for complex mechanical and electrical product demand, and the relationship network between components hidden behind the product demand is also mentioned. Therefore, in the adaptive design of mechanical and electrical products, the reuse of product knowledge still has some problems, such as unclear and fuzzy parts relationship. In view of the above problems, this paper proposes a method based on Axiomatic Design for mining association network of complex mechanical and electrical products parts from the perspective of demand.

2. Requirement Acquisition Based on Product Environment

2.1 Product Demand Analysis
The main method of product demand acquisition is to obtain product demand by means of manual Market Research, including market research, policy and patent analysis, etc. with the continuous development of network technology, it has become the mainstream to obtain product demand information through network technology. The above product demand acquisition methods are applied to products with wide range of users and simple function structure, and have good results, such as refrigerators and other household appliances. Complex mechanical and electrical products have the following characteristics: 1) special and specific use, less orders in practical application; 2) complex functional structure, strong professionalism; 3) complex product knowledge and data, design process including a large number of coupling design tasks; 4) product requirements involving new technology,
new ideas and so on [11]. The characteristics of the requirements determine that the above product requirements acquisition methods cannot be processed, so this paper proposes an improved product requirements acquisition method based on customer use environment.

2.2 Product Demand Acquisition
Product demand acquisition and product use environment have a significant impact on product function, structure and other performance, especially for complex mechanical and electrical products. With the development of production technology, customers' demand for products is no longer limited to the traditional requirements such as function, structure and recyclability, and gradually pay attention to the performance of products in the actual working environment, which leads to the concept of customer environmental demand. Product demand includes enterprise demand and customer demand. Product environment change involves product design, manufacturing, material selection, recycling and other life cycle links. Product design based on product environment will greatly improve product function, green degree and other product performance in the actual environment, and further improve customer satisfaction.

Product life cycle covers the whole process from product demand analysis, conceptual design, detailed design, manufacturing, sales, after-sales service to product scrap recovery. The improved product requirements acquisition method based on customer use environment takes the product life cycle as the theme, constructs the product environment at different stages, and obtains the product requirements through the interaction between designers and environment, product object-oriented behavior. With the theme of product design, manufacturing, sales and after-sales, different product environments are constructed for each theme. The product interaction objects and product working conditions change with the change of product environment. Different interaction objects put forward different requirements for products according to their own conditions and product working conditions. Therefore, product requirements can be accurately obtained through the interaction between designers and environment, product object-oriented behavior. At the same time, product designers have professional knowledge and clear product function structure, which can solve the complex mechanical and electrical product requirements characteristics that cannot be corresponding to traditional methods. The specific acquisition process is shown in Figure 1.

![Flow chart of product requirement acquisition](image)

**Figure 1.** Flow chart of product requirement acquisition

3. Product Component Association Network Based on Axiomatic Design

3.1 Mining Association Relationship of Product Parts
The inheritance of function and structure of complex mechanical and electrical products determines the reuse of product knowledge and parts in the development process of new products. For example,
shield machine is often designed according to the adaptability of product to environmental changes in the development process of new products. The complexity of the functional structure of complex mechanical and electrical products determines that there are a large number of coupling design tasks in the design of products. The unclear coupling network will lead to the lack of organization of the relationship between product parts in the adaptive design to cope with the changes of product requirements, which eventually leads to the problems of product requirements can not be met, and conflicts between parts. This paper uses axiomatic design based demand driven model of complex mechanical and electrical products to solve the above problems.

In the axiomatic design world, the left domain in the adjacent domain expresses the product requirements, and the Z-shaped mapping is used to solve the problem between the adjacent domains, and the relationship between the two is expressed by matrix. Taking functional domain and structure domain as examples, functional domain expresses product functional requirements, structure domain describes how to meet product functional requirements, structure domain describes how to meet product functional requirements, uses \( \{\text{FR}\} = \text{[DM]} \{\text{DP}\} \) to express the coupling relationship between them, and \( \text{[DM]} \) is axiomatic design matrix. In order to solve the problem of visualization of complex product parts association network, Z-shaped mapping between axiomatic design neighborhood is used to mine product requirements in different stages, and finally the complex coupling association network between product parts is obtained.

3.2 Complex Association Network between Product Components

Demand is the basis of product development and design, and the premise of product configuration. The requirement model can help designers accurately understand and grasp the personalized requirements, quickly locate the user requirements and find the corresponding design resources, so as to generate the comprehensive information model and design scheme of the concept product. From the point of view of requirements, the construction of association network between complex product parts will greatly improve the degree of reuse of product knowledge and parts department, and speed up the design process.

In the association network mining based on ad theory, the hidden customer demand relevance, component function relevance and physical structure relevance will be displayed in the "Z" shape mapping. At the same time, in the process of mining, customer requirements will be mapped to each part of the product, which can improve customer satisfaction and reduce the impact of customer demand changes on product design. The diversity of product requirements determines the existence of the same parts in the product requirements mapping; the coupling characteristics of product parts determine that the association network between the parts obtained from the requirements mapping needs to be combed based on the professional knowledge of designers, and finally the association network between the complex product parts is obtained.

4. Application Cases

Taking the segment assembler of earth pressure balance shield machine for shield construction in east section of Guangzhou Metro Line 1 as an example. Firstly, according to the geological conditions, engineering environment and geological exploration, the shield machine design environment is constructed, with the chief engineer and parts engineer as the interactive objects to obtain the requirements of product design stage; according to the design performance and design parameters, combined with the enterprise production conditions, the shield machine production environment is constructed, and the workshop production personnel as the interactive objects to obtain the requirements of product manufacturing, assembly, debugging and other manufacturing stages.

Due to the high production cost and long cycle, the sales of complex mechanical products usually adopt the "tailor-made" sales mode. Therefore, the sales market environment of products mainly depends on the application of new technology, new concept and product performance parameters to win customers. Taking the sales of shield machine as an example, the customers select products mainly based on the solutions proposed by the suppliers for the key and difficult points of construction, the application of new technologies and new concepts in the key technologies in the construction
process, and the green degree of products. Based on the working conditions of the shield machine, combined with the main components and system parameters, the maintenance and repair environment of the shield machine is constructed, and the demand of after-sales management and maintenance stage is obtained through mutual communication with the maintenance and repair personnel. Mature complex mechanical and electrical products have certain inheritance in function, performance and structural design principles and knowledge [11]. Based on the remanufacturing market environment of key parts of shield machine, the remanufacturing requirements of key parts of shield machine are obtained through the interaction between designers and remanufacturing companies. The specific analysis is shown in Table 1.

**Table 1. Example of demand acquisition for segment assembler of EPB shield machine**

| Product Cycle       | Working Condition       | Object-oriented | Demand                                         |
|---------------------|-------------------------|-----------------|------------------------------------------------|
| Design              | Conceptual design       | Engineer        | Grasp; Lift; Rotate; Translate; Fine tune      |
| Manufacture         | Manufacturing           | Production personnel | Simple structure; Easy to assemble and disassemble |
| Sale                | Sale                    | Customer        | Safety; Economy;                               |
| After-sale          | Management and maintenance | Management     | Easy to detect and replace;                   |
|                     | Rovery                  | Remanufacturing company | Recyclable; removable;                        |

In the whole life cycle of the product, the product parts information management model with customer demand as the main line is established to integrate customer demand and enterprise demand information for management. In the process of adaptive design, product requirements can be decomposed and mapped according to the function and structure of the product to form a complex interlaced network. The final result is shown in Figure 2.
5. Conclusion
In this paper, a method of mining association network of complex mechanical and electrical products based on axiomatic design is proposed. Based on the product use environment, taking the use object as the theme, taking the designer as the center, the interaction environment of product environment designer is constructed, taking the whole life cycle of the product as the main line to obtain the product demand information; secondly, based on the "Z" transformation among axiomatic design demand domain, function domain, structure domain and process domain, the product parts association network is constructed. Finally, based on the designer's professional knowledge, the coupling of parts between requirements is sorted out, and the association network between product parts is obtained. In this paper, the segment assembler of earth pressure balance shield machine is taken as an example to build the association network between the components of segment assembler, and the effectiveness of the proposed method is verified by China Railway Equipment Group Co., Ltd. Based on the research, analysis and application of component association network, we need to further analyze the impact of component association network on product module partition and configuration from the perspective of demand, which is the next issue to be studied in this paper.

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