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Research on Index System of Industrial Design and Development in Manufacturing Enterprises

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Abstract. In recent years, the central leaders and relevant ministries and commissions have issued guidelines for the development of China's industrial design, and the development of industrial design in manufacturing enterprises has attracted more attention. At present, the development level of industrial design in various regions and industries in China is uneven. No institution or organization can accurately provide nationwide survey data, and the existing regional or industry-related survey data lack uniformity and continuity, which cannot provide sufficient reference for the country to formulate relevant policies. This paper mainly describes the building of index system of industrial design and development in manufacturing enterprise. The paper builds the framework based on literature at home and abroad, two rounds of questionnaire, expert interview and field research, selects indexes through Delphi method, analytic method and frequency analysis approach and then revises index system according to the expert evaluation of regional pilot. It attempts to connect with national statistical framework, so as to grasp the problems and trends of the development of industrial design. The establishment of index system of industrial design and development in manufacturing enterprise plays an important role in the future development of China's industrial design and the formulation of economic transformation policies.

1. Introduction

In recent years, Sino-US trade friction has been continuously upgraded, with the focus on the strategic layout of “Made in China 2025” aimed to upgrade China's manufacturing industry. As is known to all, industrial design is the primary link in the chain of productive service industry. It is of great strategic significance for the transformation and upgrading of manufacturing enterprises. It is an important indicator of the level of industrialization. The central leaders have emphasized to encourage and support the development of industrial design, and the governments at all levels have also intended to formulate supportive policies in hope of the rapid development of the industrial design. [1] However, at present, the level of industrial design and development in various regions and industries in China is uneven. No institution or organization can accurately provide nationwide survey data. The existing regional or industry-related research data lack uniformity and continuity, which cannot provide a sufficient reference for the government to formulate relevant policies [2] .

Under such a background, how to scientifically describe the development mode of industrial design of different types of manufacturing enterprises and how to accurately evaluate their development level has become an inevitable issue in the development of industrial design industry. We have deeply probed into the basic situation of industrial design in the development of manufacturing enterprises based on the analysis of the existing research results at home and abroad, field research of typical



enterprise in different areas, questionnaire and expert interviews. We hope to build index system of industrial design and development in manufacturing enterprise, and effectively reflect the basic situation of China's industrial design and regional development.

2. Research process of index system

2.1. The design principle of index system

In order to highlight the basic state and industry characteristics of industrial design in manufacturing enterprises, and to ensure the objective and systematic evaluation of industrial design applications and development status of manufacturing enterprises, the design of index system of industrial design and development in manufacturing enterprise mainly follows five principles: reasonability, system optimization, universal comparability, practicality, and goal-oriented principle.

2.1.1. Reasonability. Reasonability is embodied in the combination of theory and actual situation and the scientific methods adopted. The index system can not only meet the theoretical requirements, but also reflect the objective reality of the evaluation object. Theoretical guidance can make the index system rigorous, reasonable and more targeted in the basic concept and logical structure.

2.1.2. System optimization. System optimization means that the evaluation object must be measured by several indicators, which are interrelated and mutually restrictive. There are horizontal linkages between some indicators, reflecting the mutual constraint relationship from different aspects, and vertical linkages between some indicators, reflecting the inclusion relationship at different levels. Meanwhile, the boundaries of indicators at the same level are as clear as possible and the indicators are designed to avoid internal connection in the same group. Hence, these indicators are highly systematic.

2.1.3. Universal comparability. Universal comparability refers to the comparison between periods and objects, namely vertical comparison and horizontal comparison. Vertical comparison means the comparison of the same object in different periods. This requires that the index system and the connotation of various indicators remain stable, and the reference values (standard values) for calculating indicators remain unchanged. Horizontal comparison means comparing different objects, so as to find common points and design the index system according to them.

2.1.4. Practicality. Practicality refers to be practical, feasible and operable. Firstly, indicators should be simplified; the method should be easy enough. And the index system should be as simple as possible on the premise of an objective and comprehensive evaluation result. Secondly, the data should be easy to obtain and collect. Whether for a qualitative evaluation indicator or a quantitative evaluation indicator, the source of information must be reliable and easy to obtain. In addition, all evaluation indicators and their corresponding calculation methods must be regulated and standardized. Thirdly, the data must be accurate and reliable. [3]

2.1.5. Goal-oriented principle. The goal-oriented principle embodies the purpose of the evaluation, namely, to guide and encourage the evaluated object to develop in the right direction. The purpose of the indicator system is to promote the better development of industrial design in manufacturing enterprises. Therefore, both design indicators and data collection should be oriented towards this purpose.

2.2. Research process of the indicator system

2.2.1. Source of indicators. With the confirmation of the definition and extension range of industrial design, we have conducted research on the management model, evaluation indicators and data of industrial design in developed countries such as Norway, Germany, the United States, Japan and South

Korea. We also have referred to relevant domestic research on the development of industrial design in some industries. With reference to the conventional statistical index system of developed countries and above-mentioned researches, we have initially summarized and sorted out 109 indicators of industrial design and development in China. Through subsequent expert interviews and field research, some necessary deletion and supplementation are made to the indicators. [4-12]

2.2.2. System construction and index screening. The construction of the index system is a thinking process from the concrete to the abstract and to specific dialectical logic. It is also the process that people gradually deepened understanding of the overall quantitative characteristics of the phenomenon. The screening methods adopted in the index system of industrial design and development in manufacturing enterprises are the Delphi method, comprehensive analysis method and frequency analysis approach. [13-15] The Delphi method is based on a series of systematic procedures, with the way of speaking on condition of anonymity anonymous methods of opinion. In other words, experts should not discuss with each other, but could only communicate with the investigators. After repeated consultation, induction and modification, the opinions of experts on the questions raised in the questionnaire are collected into basically consistent opinions, which can be regarded as the results of prediction. As a subjective and qualitative method, Delphi method, on the one hand, integrates the knowledge, experience and judgment of experts, which can help to get a conclusion reflecting the real state of evaluation objects. On the other hand, it also expands the screening scope of indicators, and can effectively deal with the subjective qualitative indicators that are fuzzy, uncertain and subjective. With a wider range of indicators screening, the system is much more applicable. Delphi method can not only be used in forecasting, but also be widely used in the establishment of various evaluation index systems and the determination of specific indicators. Comprehensive analysis method is to divide the overall goal of evaluation into several different components or different aspects (namely subsystems), and gradually subdivide, until each part and aspect can be described and realized with specific statistical indicators. This is one of the most basic and commonly used methods to construct the evaluation index system. Frequency analysis approach is the study of frequency of relevant reports and papers concerning industrial design at present. Hence, we can select those indexes with high frequency, so as to make the index system more comprehensive and accurate.

2.2.3. Working procedures. According to the working procedure of the Delphi method, the construction of the index system of industrial design and development in manufacturing enterprise mainly goes through the following procedures, as shown in Figure 1:

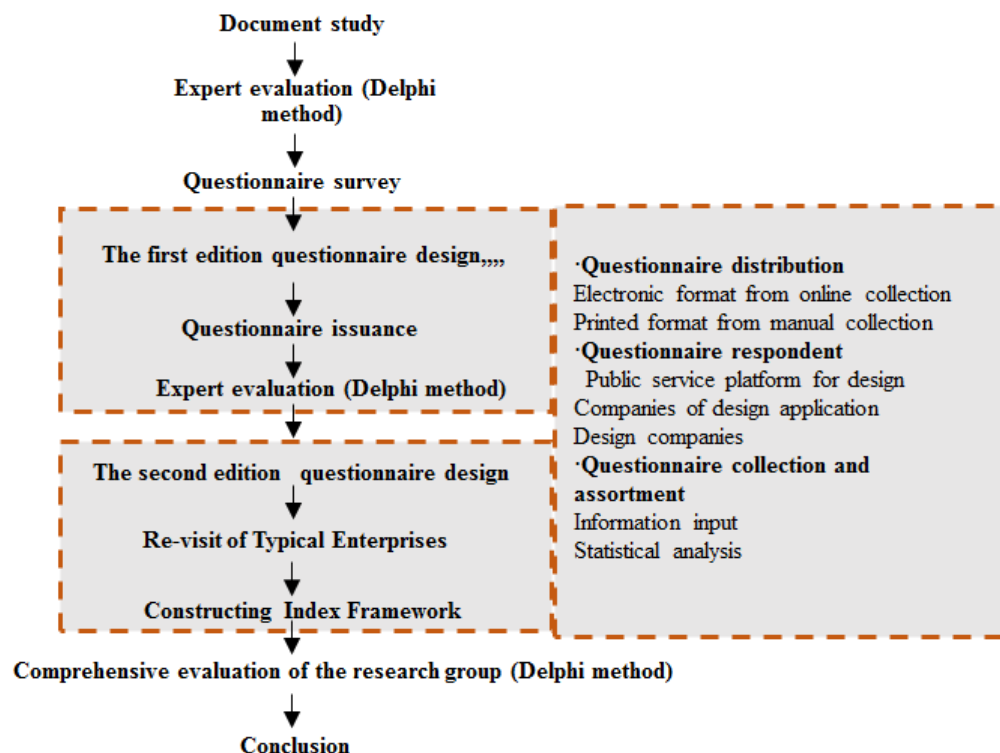


Figure 1 Working procedures of the index system of industrial design and development in manufacturing enterprises

The first procedure is literature review. Through domestic and international journals and magazines, 152 monographs and papers on manufacturing enterprise and index system of industrial design are collected. More than 50 papers are selected and 25 websites are selected from 63 relevant websites. With the method of frequency analysis, we have summarized 159 indicators as the design material for the first edition of the questionnaire from relevant literatures and opinions put forward by experts. Then, we have conducted a small-scale trial in Beijing and made adjustments to the content. At last, the first edition of the questionnaire is determined.

The first round of questionnaire distribution is in the form of electronic format and printed format. The questionnaires are distributed to experts in industrial design across the country, including the heads of industrial design related departments of manufacturing companies, the heads of industrial design companies, freelance designers, leaders from industrial design associations and relevant government departments, heads of industrial design related institutes, heads of design park, and experts from colleges and universities. A total of 119 valid samples are obtained. Valid questionnaires are screened for information entry and a preliminary screening of indicators. In this round of Delphi expert consultation, the boundary value method is mainly used to screen the evaluation indicators. The frequency of full score, arithmetic mean and variable coefficient are calculated according to the importance of each indicator. For inappropriate indicators, the experts of the research group will make adjustments based on the principles of comprehensiveness, reasonability, and feasibility. At the same time, the adjustment of the indicators also fully considers the additional opinions put forward by the experts. According to the results of the first round of surveys and the expert evaluation, the overall model of the index system of China's industrial design is initially determined. With reference to domestic and international design-related index system of industry evaluation and statistical habits in manufacturing enterprises, we demonstrate the overall status of evaluated object from three aspects: basic status, input and output. [16]

The second round of survey is mainly carried out by field research and face-to-face interview, with the key enterprises and institutions in the industries concerned by the ministry of industry and information technology as the research objects. Meanwhile, the deficiencies in the industries and the number of respondents in the previous round of questionnaire are balanced. In this survey, a total of 39 people from 21 enterprises or institutions are interviewed, including senior managers of manufacturing enterprises, directors of industrial design departments, senior designers, and managers of financial and personnel departments. Through three rounds of research and three rounds of expert evaluation, we have revised the overall framework and three-level index system of China's industrial design and development. Based on simplicity, comparability, manipulability, verifiability and sustainability, and the final index system of industrial design and development in manufacturing enterprises is completed, with the assortment of indicators.

3. Establishment of index system

Through the previous rounds of questionnaire and expert evaluation, we have preliminarily designed the index system of industrial design and development in manufacturing enterprises. The index system is divided into three levels, of which the first level contains the basic situation, input and output. The basic situation reflects the most distinct characteristics of the development of industrial design, and the input and output reflect the annual change of the development of industrial design. [17] The specific indicators are shown in table 1.

Table 1. Index system of industrial design and development in manufacturing enterprises.

Level 1 index	Level 2 index	Level 3 index	Details
Basic situation (A1)	Research and development needs (B1)	Design requirement (C1)	The demand for industrial design in the development of new products and upgrade products
	Organization structure (B2)	Department setup (C2)	Independent industrial design department setting
		Department level (C3)	The organizational structure of an industrial design department in an enterprise
			The decision-making power of the industrial design department in the development of new products
		Department structure (C4)	Settings in the industrial design department
	Personnel (B3)	Personnel quantity (C5)	Number of personnel in the R&D department and the industrial design department
		Personnel structure (C6)	The ratio of technicians, designers and researchers in the R&D department to the total number of R&D personnel
			Age composition of industrial designers
		Personnel qualifications (C7)	Titles of industrial designers
			Education backgrounds of industrial designers
	Equipment	R&D assets (C8)	Total amount of fixed assets for R&D department

Input (A2)	and facilities (B4)	Office environment (C9)	Environment and equipment of industrial design department
			Investment amount of high-tech equipment for product development (such as rapid prototyping machine)
		Professional equipment (C10)	Investment amount of design equipment for product development (such as computer, graphics tablet)
	Capital investment (B5)		Investment amount of equipment for product development (such as eye tracker, audio instrument)
		R&D investment (C11)	Annual total investment in product R&D
		Project proportion (C12)	Proportion of annual industrial design application project investment
			Proportion of annual industrial design pre-research project investment
		Cooperative research and development (C13)	Annual outsourcing status of industrial design project
			Research and development cooperation with other enterprises or research institutes
		Innovation protection (C14)	Protection cost and method of innovate design
	Talent investment (B6)	Personnel training (C15)	On-the-job training of industrial designers
			Design course training of non-designer
		Learning & exchanging (C16)	Participation and discussion in the design exhibitions
		Personnel income (C17)	Average annual labor compensation for employees in the industrial design department
		Incentive mechanism (C18)	The internal incentive forms in the company
	Equipment and trial production input (B7)	R&D investment equipment (C19)	Annual total investment in product development and professional equipment
		Trial production investment (C20)	Annual total model investment for product development
			Annual total mold investment for product development
	Policy support (B8)	Capital support (C21)	Relevant support fund from the government
		Policy support (C22)	Whether enjoy relevant support policies
Output (A3)	Innovation ability (B9)	New product development (C23)	The growth rate of new product development

Economic benefits (B10)	Achievement transformation (C24)	The growth rate of the transformation of patents
	Patent application (C25)	The patents produced through the industrial design
	Awards (C26)	Important industrial design awards
	Profit growth ratio (C27)	Enterprise profit growth
	Value ratio of new products (C28)	New product annual sales revenue share of product sales
	Brand competitiveness (C29)	The influence of industrial design on product differentiation positioning The influence of industrial design on brand recognition The influence of industrial design on consumer loyalty
Social benefits (B11)	Environmental benefits (C30)	The influence of industrial design on environmental protection

4. Description and discussion

The index system of industrial design and development in manufacturing enterprises is divided into three levels. The first level is to summarize the indicators of industrial design in manufacturing enterprises into three aspects: basic situation, input and output. The second level is the eleven major influence factors, which are further refined into 30 third-level indicators. [18-19]

4.1. The basic situation.

The first level is the basic information and living status reflecting the application of industrial design in manufacturing enterprises, including five factors: R&D needs, organizational structure, personnel status, equipment and facilities. The research and development needs are the demands of manufacturing enterprises for industrial design, which is mainly divided into two cases of new product development and product upgrade. The organizational structure presents the departmental structures of manufacturing companies, checking whether they have independent industrial design departments and internal structures, and the decision-making capabilities in product development. The personnel status shows the number, structure and qualifications of personnel in the design and R&D department as well as the proportion and experience of the R&D personnel. Equipment and facilities show the fixed assets, office environment and professional equipment of the industrial design department in the manufacturing enterprise and the various types of equipment and office facilities that have been invested.

4.2. Input.

The input reflects the annual investment of manufacturing enterprises in industrial design, which mainly includes capital investment, talent investment, equipment and trial production investment, and support policies. The capital investment demonstrates the R&D investment, project proportion, cooperative R&D and innovation protection of the manufacturing enterprise, reflecting the degree of emphasis on product R&D. It also shows the types of projects, the amount and quantity of project cooperation and the cost and method of innovation protection. The talent investment shows the learning and exchanging, personnel training, personnel income and incentive mechanism in

manufacturing enterprises, and on-the-job training of designers, design course training of non-designer, the design-related exhibitions and seminars as well. Equipment and trial production investment is to investigate the investment in R&D equipment and trial production of manufacturing enterprises, and to have the knowledge of the annual investment in equipment, model, and mold in product R&D of manufacturing company. Support policies shows the extent of government support for manufacturing enterprises and the policies and the amount of money for industrial design innovation.

4.3. Output.

The output reflects the annual output of industrial design in manufacturing enterprises, including innovation ability, economic and social benefits. Innovation ability shows the new product development, achievement transformation, patent application and awards in design of manufacturing enterprises, reflecting the important role of industrial design in the development of new products and patents application and the recognition of those high-level design competitions. The economic benefits, namely, profit growth ratio and value ratio of new products when applying industrial design demonstrate the changes of profits brought by new product research and development. Social benefits, namely, brand competitiveness and social environmental benefits, are implicit and difficult to quantify. Social benefits demonstrate that industrial design can promote product differentiation positioning, brand identification, consumer loyalty and environmental protection.

5. Conclusions

The index system of industrial design and development in manufacturing enterprises is a visual scale to measure the development level of industrial design between enterprises and the development characteristics between regions. It can reflect the corresponding relationship between industrial design and relevant concepts in national statistical system, and clarify the indicators of input and output and the way to assume value in industrial design of enterprises in product development process. The main features of the index system of industrial design and development in manufacturing enterprises constructed in this paper are as follows.

Firstly, the setting of the index system is highly objective. It is mainly based on the annual statistical data of the enterprise. The subjective factors and human factors are excluded as much as possible, and the industrial design and development of manufacturing enterprises is objectively reflected.

Secondly, the logic is simple and clear and the indicators are divided into progressive layers. It is of strong relevance. Thus, it is easy to accept and easy to analyse.

Thirdly, comprehensiveness. It reflects the overall situation of industrial design and development of manufacturing enterprises from multiple angles and through multiple indicators.

At the same time, we have seen some shortcomings in this research. First of all, this is the first nationwide evaluation of manufacturing enterprises. The indicators cover a wide range and need a large amount of statistical data. Secondly, some qualitative indicators are difficult to express in the form of a unified data. Finally, the weight determination of the index system and the calculation of mathematical model should be supplemented and improved in the following research.

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