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Research on Quality Competitiveness of Manufacturing Enterprises Based on System Dynamics

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***Abstract*—As China's economy enters a new stage of high-quality development, the improvement of the quality of manufacturing enterprises has become the key to improving the quality and efficiency of China's economy. This paper takes Nanjing manufacturing enterprises as an example to reconstruct the quality competitiveness indexes and uses system dynamics to model and analyze the important factors affecting the quality competitiveness of enterprises. MATLAB software was used to regress and fit the causal equations corresponding to the modeling indexes. Then，the indexes and equations were input into Vensim software for system dynamics modeling to simulate the changes in quality competitiveness under different scale manufacturing enterprises. It is found that the larger the scale, the greater the quality competitiveness, and the factors affecting the quality competitiveness are different. Finally, some suggestions are put forward to improve the quality competitiveness of manufacturing enterprises.**

Keywords—quality; quality competitiveness; enterprise; system dynamics

I. INTRODUCTION

At present, China is facing the realistic problem that the development quality and benefit of enterprises are not high enough and the overall level of product quality is not high either. Therefore, China has put forward the quality power strategy when implementing the quality power strategy is an inevitable choice for our country. In 2015, China released the "Made in China 2025" strategic plan. The plan believes that the key task to improve the development level of manufacturing enterprises is to improve the quality capability, and quality competitiveness is an important index to evaluate the quality capability of enterprises. As an important part of the real economy, manufacturing enterprises bear the heavy responsibility of improving product quality. The high-quality development of manufacturing enterprises is related to the overall situation of the high-quality development of China's economy. Under this background, it is of great value to use the concept of quality competitiveness to measure the quality development of Chinese manufacturing enterprises and to explore the influencing factors of manufacturing enterprises' quality competitiveness.

Since the quality competitiveness was first proposed by Shanghai Academy of Quality Management in 2001, different scholars have carried out relevant researches on this issue. On the relationship between quality and competitiveness, Cheng et al. hold that quality and competitiveness are logically consistent in theory[1]; Sun et al. think service quality is found to significantly drive global competitiveness and its impact is stronger for large service firms when the global environment is characterized as low munificence, high dynamism, or high complexity[2]; Khafizov et al. believe that product quality is the main factor to improve competitiveness[3]; Cruz et al. used case study method to explore measures to improve the quality and competitiveness of coastal tourism areas[4]. In terms of influencing factors of quality competitiveness, Yu et al. studied the influence of five factors on the quality competitiveness of regional manufacturing industry, including industrial chain support, financial support, proportion of high-tech industry in industrial structure and transportation opportunity, and believe that environmental effect and random error had a significant impact on the quality competitiveness of regional manufacturing industry[5]; Wang et al. analyzed the influence mechanism of quality competitiveness qualitatively, and believe that enterprises should start from the overall quality competitiveness to improve systematically and dynamically[6]; He et al. hold that we should start from the domestic supply side, pay attention to the balanced development of the internal economic development quality system, efficiency system and power system in the manufacturing industry, and optimize the supply structure of the production and service industry[7]. In terms of the research models and methods of quality competitiveness, Kumar put forward QCI model and Kano put forward Kano quality model; Yang and Wang analyzed the quality competitiveness by factor analysis and entropy information weighting method[8-9].

The above scholars have made certain achievements in their researches on the connotation, influencing factors and research methods of micro-quality competitiveness. However, the above researches mainly focus on the argumentative research on quality competitiveness, and there are obvious deficiencies in the quantitative research on quality competitiveness. Based on this, the following mainly take Nanjing manufacturing

enterprise as an example to carry out simulation research on the quality competitiveness of enterprises.

II. QUALITY COMPETITIVENESS ANALYSIS OF MANUFACTURING ENTERPRISES

Enterprise quality competitiveness is a relatively macro concept and a comprehensive concept of enterprise quality and competitiveness. It is necessary to classify and analyze the quality competitiveness indicators of manufacturing enterprises from the perspectives of systematization, uniqueness, comparability and feasibility. Here, the indexes of quality competitiveness are decomposed into design elements, process elements and market elements. Design elements are the core part of the factors affecting the enterprise quality competitiveness and the indexes of quality competitiveness can be analyzed from three aspects: technology, management and organization. The technical elements are research and development (R&D) capability and technological innovation, the management elements are continuous quality improvement, and the organizational elements are quality personnel. Process elements are considered by manufacturing enterprises from the whole process of production and manufacturing, from the quality control of materials supplied by suppliers, to the quality of production process, automation level, measurement and testing, product qualification rate, on-time delivery rate and other aspects of analysis. Market elements are important elements to reflect the competitiveness of products. Market share can directly reflect the market reflection of products, and can reflect consumers' satisfaction with products and price advantages.

Based on the analysis of the above three factors, the influencing factors of quality competitiveness are divided into three parts: determining construction factors, primary selection indicators and optimization indicators. The construction was carried out, and finally a table of factors affecting the quality competitiveness as shown in TABLE I was formed.

TABLE I. QUALITY COMPETITIVENESS INFLUENCING FACTORS

Elements for Modeling	Corresponding Factors
Quality competitiveness *Z*	Improvement effect of quality personnel training Y_1 Improvement effect of standardization Y_2 Improvement effect of technological innovation Y_3 Position of product quality competitiveness Y_4 Market competitiveness of products Y_5 Operation of the quality management system Y_6
Improvement effect of quality personnel training Y_1	Quality personnel training efforts X_{11} Quality personnel training expenses as a percentage of sales revenue X_{12} Effectiveness of quality training X_{13}: number of personnel in quality department, number of qualified vocational qualifications, number of "quality engineer", number of "green belt", number of "black belt" Organization for quality personnel training X_{14}.
Improvement effect of standardization Y_2	Standard quantity of major industrial products X_{21} Lead/participate in standard revision quantity X_{22}.
Improvement effect of technological innovation Y_3	Proportion of funds for technological transformation X_{31} Proportion of R&D expenditure X_{32} Ability to develop new products X_{33} Number of patents X_{34}
Position of product quality competitiveness Y_4	Proportion of quality control for incoming materials X_{41} Does process capability index(CPK) meet customer and process requirements? X_{42} Completeness of measuring and testing equipment X_{43} Qualification rate of one inspection X_{44} On-time delivery rate X_{45} Automation of production and operation process X_{46}
Market competitiveness of products Y_5	Price of the product compared with similar products X_{51} Market share of core products X_{52} Customer satisfaction X_{53} Government quality supervision check pass rate X_{54}
Operation of the quality management system Y_6	Employee participation in quality improvement X_{61} Annual quality improvement results X_{62}: what systems have been adopted? quality management model and method used by enterprises, quality tools, software tools Quality management information, big data analysis and application X_{63}: Quality data collection quantity and automatic collection ratio Support for quality work from top management X_{64} Economic benefits brought by quality management X_{65} Willingness to pass voluntary product certification quality system X_{66} What quality professional qualifications or certificates do employees have? X_{67}

III. EMPIRICAL ANALYSIS

The data in this paper comes from the online questionnaire survey, mainly using the wjx.cn platform to distribute questionnaires to quality managers and related personnel of manufacturing enterprises in Nanjing, and 150 valid questionnaires were collected.

A. Construction of System Dynamics Model

According to the analysis of the quality competitiveness indexes of manufacturing enterprises, the causal relationship between each index was analyzed reasonably, and the dynamics flow diagrams of manufacturing enterprise quality competitiveness system were established by using Vensim software, as shown in Figure 1 to Figure 3, in which quality competitiveness Z is the stock, the increase rate of quality competitiveness z is the flow rate, and Y_1, Y_2, Y_3, Y_4, Y_5 and Y_6 in TABLE I are auxiliary variables, and the rest are constants.

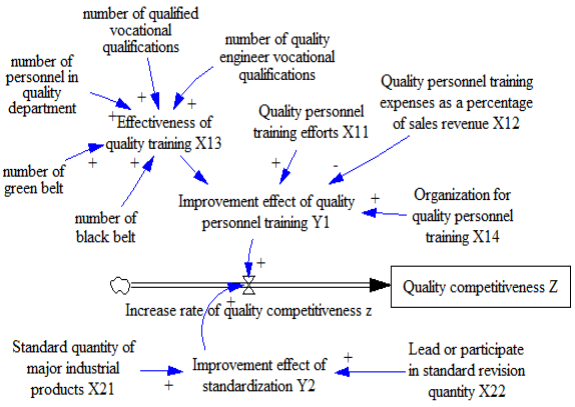

Fig.1 System Dynamics Flow Diagram of the Influence of Y_1 and Y_2 on Quality Competitiveness.

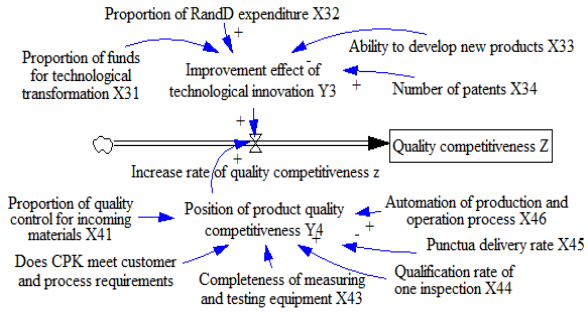

Fig.2 System Dynamics Flow Diagram of the Influence of Y_3 and Y_4 on Quality Competitiveness.

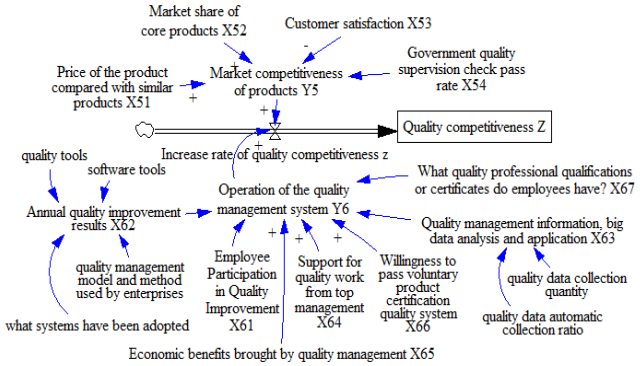

Fig.3 System Dynamics Flow Diagram of the Influence of Y_5 and Y_6 on Quality Competitiveness.

B. *Fitting Dynamic Causality*

In order to analyze the quality competitiveness of manufacturing enterprises under different scales, the samples are divided into four categories according to the scale of enterprises: less than 100 employees, 100-499 employees, 500-1999 employees, and more than 2000 employees. MATLAB software was used to perform regression fitting to obtain relevant calculation expressions. For the convenience of calculation and the intuitive analysis of graphs, it is assumed that there is a linear relationship between the indicators. MATLAB programming was used to obtain the value of regression coefficient *b* of each causal relationship. Here, the causality calculation of "improvement effect of quality personnel training on quality competitiveness" is taken as an example to illustrate:

$$X_{11}=[1.2,1.72,1.75,2.7];\ X_{12}=[2,2.06,1.92,2.5];$$
$$X_{13}=[2.6,2.89,2.58,3.6];\ X_{14}=[1.2,3.2,3.25,5];$$
$$y=[2.5,3.33,3.17,3.8];$$
$$X=[ones(length(y),1),x_{11}',x_{12}',x_{13}',x_{14}'];$$
$$Y=y';$$
$$[b,bint,r,rint,stats]=regress(Y,X);$$
$$X_{11}=[1.2,1.72,1.75,2.7];$$

The causal relationship between various indicators of improvement effect of quality personnel training on quality competitiveness can be calculated:

$$Y_1=1.6316*X_{11}-0.9939*X_{12}+0*X_{13}+0.5165*X_{14}+0.5985? \quad (1)$$

Similarly, the same method can be used to calculate the relationship between several indicators of Y_2, Y_3, Y_4, Y_5 and Y_6. The causality formulas of each index are obtained as follows:

$$Y_2=1.8121*X_{21}+2.1874*X_{22}-1.2430 \quad (2)$$
$$Y_3=0*X_{31}+0.5103*X_{32}-0.0797*X_{33}+1.1861*X_{34}-0.6339 \quad (3)$$
$$Y_4=0*X_{41}+0*X_{42}+0*X_{43}+0.2343*X_{44}-0.4267*X_{45}+0.2032*X_{46}+1.0745? \quad (4)$$
$$Y_5=2.6736*X_{51}+1.9203*X_{52}-0.1435X_{53}+0*X_{54}-1.2802? \quad (5)$$
$$Y_6=0*X_{61}+0*X_{62}+0*X_{63}+0.3968*X_{64}+0.4500*X_{65}+0*X_{66}+0.0244*X_{67}+0.0184 \quad (6)$$

Simulation Analysis of Quality Competitiveness Evolution

Assuming that the initial value is 2 and the increase rate of quality competitiveness is linear with its influencing factors. The coefficients are distributed according to the degree of influence of the indexes, and the average values of these indexes are calculated as: 3.05, 3.3925, 3.14, 3.7375, 3.3675, 2.865. Using formulas (1)-(6) to calculate the coefficients of increase rate of quality competitiveness of manufacturing enterprises are: 0.156, 0.174, 0.16, 0.191, 0.172, 0.147. Therefore, the calculated equation is:

$$z=0.156*Y1+0.174*Y2+0.16*Y3+0.191*Y4+0.172*Y5+0.147*Y6 \quad (7)$$

According to the above calculation equation, Vensim software was used to carry out five-year system dynamics simulation on the quality competitiveness of four types of manufacturing enterprises. The simulation results are shown in TABLE II below. After plotting the changes in the quality competitiveness of four different scale enterprises, the results of the following six factors influencing quality competitiveness were obtained by Vensim software, as shown in TABLE III below.

C. *Analysis of research results*

According to the calculation results of TABLE II and TABLE III, the changes of quality competitiveness in manufacturing enterprises of different scales are analyzed, and the following results are obtained:

TABLE II. TREND OF QUALITY COMPETITIVENESS

Time（Year）		1	2	3	4	5
Enterprise scale（number of people）	Below 100	6.00227	10.0045	14.0068	18.0091	22.0113
	100-499	7.09409	12.1882	17.2823	22.3764	27.4704
	500-1999	7.60253	13.2051	18.8076	24.4101	30.0127
	More than 2000	8.77649	15.553	22.3295	29.106	35.8824

TABLE III. QUALITY COMPETITIVENESS

Influencing factors		Quality personnel	Standardization	Market competition	Quality management	Peer status	Technological innovation
Enterprise scale（number of people）	Below 100	1.34337	7.87435	9.26778	2.57012	0.64731	1.92354
	100-499	2.56086	7.98179	12.2768	2.99848	0.748301	3.70740
	500-1999	2.49071	8.79424	14.4383	2.85490	1.05573	3.20736
	More than 2000	3.60372	12.4925	13.9353	3.42448	1.11351	5.73881

First, when the influencing factors are the same, the degree of increase in quality competitiveness varies with the scale of the enterprise. In the sample, the overall quality competitiveness becomes larger as the scale increases. The larger the scale of the enterprise, the larger the corresponding index value, and the quality competitiveness is greater. That is, quality competitiveness is closely related to quality personnel training, standardization work, technology innovation, product quality competitiveness, product market competitiveness, quality management system, etc., and is positively correlated with its total value.

Second, among the four scales, the difference in quality competitiveness of adjacent scale enterprises is about 5. The difference in final quality competitiveness value of enterprise with 100-499 employees and enterprise with 500-1999 employees is the smallest, about 2.5. From the index values, enterprise with 500-1999 employees leads in standardization, market competition and competitiveness, and is behind in quality personnel, quality management and technological innovation.

Third, the quality competitiveness of enterprises with more than 2,000 employees is the strongest, and the value of each index is the largest in the sample except for market competition.

IV. CONCLUSION

This paper mainly analyzes the influencing factors of quality competitiveness from the actual situation of manufacturing enterprises, and establishes an evaluation index system of quality competitiveness by taking Nanjing manufacturing enterprises as an example. In view of the above simulation analysis, the following suggestions are given for the improvement of the quality competitiveness of manufacturing enterprises:

1) On the existing basis, we should introduce more quality talents, increase the quality of personnel training, and at the same time invest more training funds to strengthen the quality personnel team of the enterprise.

2) According to the actual production and operation needs, develop more standards, organize the implementation of standards, and supervise and inspect the implementation of standards.

3) Increase the intensity of technological innovation, increase the proportion of R&D funds, promote R&D capacity, and eventually the results will be shown in the form of patents, so as to obtain more patents.

4) Production and operation should be tackled with both hands. From the production process to the sales process, the quality of raw materials and service must be strictly controlled. A complete quality management system should be formed within the enterprise , and the process and resources should be organically combined with the actual situation of the enterprise to carry out effective and systematic management and form organizational documents.

5) For small and medium-sized enterprises, more investment should be made in training of quality personnel, improvement of quality management level, technological innovation level and R&D expenditure, and the increase in scale should be transformed into effective quality competitiveness. For large-scale enterprises, while maintaining the current input of various factors, the focus should be on improving the market competitiveness, improving the degree of automation in the process of production and operation, and ensuring the pass rate and on-time delivery rate.

Of course, in the research process of this paper, there are some problems, such as the limitation that the survey samples are limited to manufacturing enterprises in Nanjing, and the distribution of data samples is not perfect. These problems need to be improved in the further research.

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