

BILATERAL MATCHING PROCESS AND DECISION ANALYSIS FOR QoS-BASED MANUFACTURING SUPPLY CHAIN PARTNER SELECTION

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Abstract. Manufacturing industry is the material foundation of national economy, the traditional supply chain in a single value creation mode makes the manufacturing industry in the global value chain competition in the “low-end lock” predicament, to create a highly efficient, intelligent supply chain, is the manufacturing industry in the global competition to gain an advantage in the key. In the process of “Digital to Intelligent Reform”, the matching mechanism and decision-making method of supply chain heterogeneity partner selection is the focus of manufacturing supply chain transformation to be solved urgently. This paper takes the manufacturers and suppliers of manufacturing secondary supply chain as the research object, takes service quality as the important influence factor of partner selection, and explores the supply chain partner matching evaluation model under the three modes of unilateral decision-making, bilateral decision-making, and optimization of bilateral decision-making. The study shows that the bilateral matching decision-making mechanism based on QoS can obtain a higher matching completion rate, while digital transformation helps to improve the efficiency and stability of supply chain partner selection. The study can provide a decision basis for heterogeneous partner selection in manufacturing supply chain, and then improve the overall performance of manufacturing supply chain.

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1. LITERATURE REVIEW

Smart manufacturing, as a new manufacturing model of human-machine-object collaboration [1], is an inevitable trend in the development of manufacturing industry. Since the 1960s, the pursuit goal of manufacturing systems has gradually shifted from scale, cost, quality, speed, and service to intelligence, and from Germany’s Industry 4.0, the United States’ Advanced Manufacturing, and France’s New Industrial France program to China’s Made in China 2025 [2], smart manufacturing has attracted extensive attention from academics in various countries. In the process of promoting the intelligentization of the manufacturing industry, the competition among enterprises has gradually developed into the competition among supply chains, and creating an efficient and intelligent supply chain is the key for manufacturing enterprises to gain an advantage in the market competition [3]. An efficient supply chain requires fast response between upstream and downstream enterprises

Keywords. Manufacturing supply chain, QoS, partner selection, matching mechanism, decision analysis.

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and more stable cooperative relationship between enterprises to reduce the risk of chain disruption [4], thus the matching and selection of heterogeneous subject partners in the supply chain become the focus of the problem.

Heterogeneous partner selection in supply chain is an important part of supply chain management in the context of smart manufacturing [5]. Research on manufacturing supply chain partner selection mainly includes two aspects: the perspective of decision-making and the basis of decision-making. From the perspective of decision-making: traditional supply chains have made useful explorations of partner selection based on knowledge collaboration [6] and collaborative product innovation [7], but these studies mostly focus on the unilateral matching mechanism of partner selection, and there are certain limitations in the decision analysis of matching. Existing bilateral decision-making studies mainly focus on the service provider and the demand side, exploring the influencing factors of mutual selection between the two parties on demand from the dimensions of sustainability [8], security capability [9] and service subject trust [10], but seldom adopt service quality for partner selection. In terms of the basis for decision-making: traditional manufacturing comprehensively evaluates enterprises from the dimensions of enterprise competitiveness, product competitiveness, and industry competitiveness [11]; green manufacturing adds evaluation indexes such as green innovation environment capability, green communication input capability [12], and green innovation capability [13] on this basis. Due to the different research focuses, the evaluation indexes used are not generalizable; while under smart manufacturing, scholars mainly evaluate from the perspective of service quality with the indexes of time, cost, reliability, and availability [14], and some scholars, although considering the perspective of service quality, mainly focus on the design of the cloud platform enterprises, and seldom involve the traditional enterprises, so that the research objects lack of breadth and universality.

Digital transformation of supply chains has an important role in improving supply chain resilience and stability [15], and integrating digital transformation into the evaluation of service quality contributes to the improvement of overall supply chain performance [16]. Yin and Ran [17] investigated the impact of the depth and breadth of digital transformation on supply chain resilience; Li *et al.* [18] used an evolutionary game model to study the impact of digital transformation on supply chain stability; Nasiri *et al.* [19] explored the performance of the supply volume from the perspective of digital transformation to promote the development of smart technologies; and Ma *et al.* [20] used a structural equation model to study the impact of digital transformation on the overall performance of supply chain, but the above studies seldom deal with the study of digital transformation on the matching and selection of supply chain partners. Although some supply chain partnership studies have considered service quality [21] and explored the impact of sharing economy [22], information sharing and trust [23] on service quality improvement in the partner selection process, they have not considered the digital transformation factors' influence. Therefore, it is necessary to explore the optimization of the matching process and decision-making mechanism of supply chain partners by digital transformation based on the service quality perspective.

In the process of "digital and intelligent transformation", not only the decision basis for partner selection, but also the completion degree of matching and the satisfaction of decision-making after matching are particularly important. From the perspective of supply chain partner matching completion: scholars mainly use neural network method [24], link prediction [25], cluster analysis [26], integer planning [27] and other methods to explore the unidirectional matching mode between two subjects, but most of the existing studies consider the unidirectional matching mode of a single subject, and seldom take the completion degree of matching between two subjects and the decision satisfaction as the optimization condition for evaluating the model. In terms of decision satisfaction: it has been argued that artificial neural network methods can improve the efficiency of supply chain partner selection and evaluation [28]; cloud operation systems can improve service satisfaction [29]; and multi-objective optimization models provide decision makers with a means to consider partner satisfaction [30], but the above studies only explore the improvement of decision-making efficiency and satisfaction in a single model. The comparative analysis of different decision-making models to reveal the mechanism of manufacturing supply chain partnership matching and decision-making is of great importance to improve the matching completion and satisfaction of supply chain partner selection.

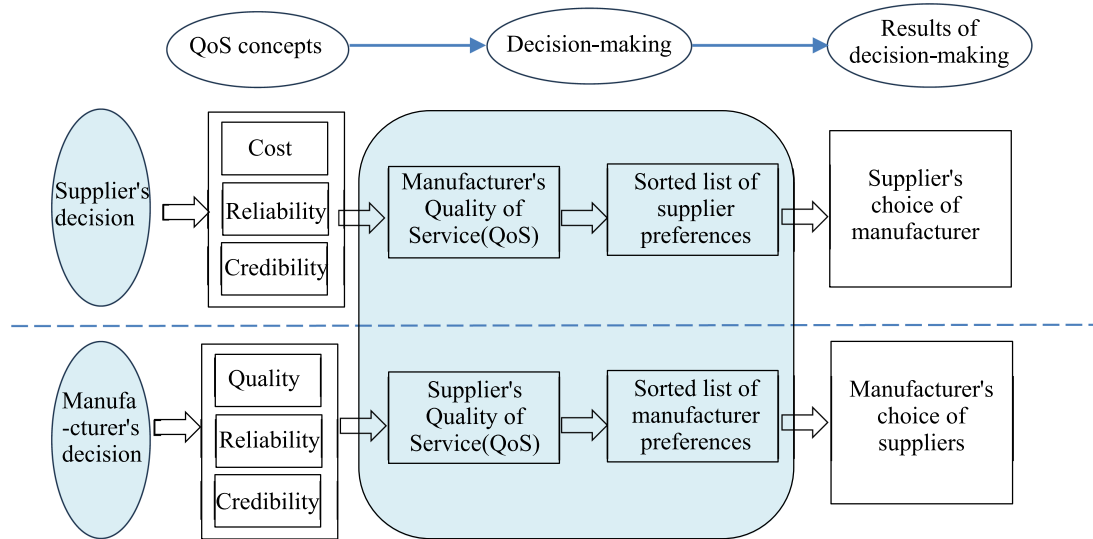


FIGURE 1. Conceptual behavioral model of manufacturing supply chain partner selection.

In view of this, this paper takes manufacturers and suppliers of manufacturing secondary supply chain as research objects, considers the impact of service quality on partner selection, analyzes the matching process and decision-making mechanism of manufacturing supply chain partner selection based on QoS, constructs a QoS evaluation model of bilateral matching between suppliers and manufacturers, and then uses the Gale–Shapley algorithm to design the bilateral matching decision-making analytical model, and comparatively analyzes the differences between the three kinds of decision-making modes of unilateral decision-making, bilateral decision-making, and optimization of bilateral decision-making, with a view to providing guidance to the partner selection of the manufacturing supply chain.

2. MECHANISM ANALYSIS OF QoS-BASED MANUFACTURING SUPPLY CHAIN PARTNER SELECTION

2.1. Analysis of factors influencing the selection of supply chain partners in QoS-based manufacturing industry

Under smart manufacturing, manufacturing capability [31], collaborative transformation capability, collaborative embedding capability and collaborative aggregation are the influencing factors for manufacturer and supplier partner selection, however, this paper takes service quality as the basis for supply chain partner selection based on the relevant research of [32]. According to the perception-behavior model, perception is the precursor of behavior, and behavior is governed by the subject's perception [33]. In a manufacturing supply chain composed of suppliers and manufacturers, the “selection” behavior of suppliers or manufacturers should first be based on the QoS of the selected object, and then based on the QoS ranking list of partner selection decisions. The conceptual behavior model of manufacturing supply chain partner selection is shown in Figure 1.

According to Figure 1, for manufacturers, most of the existing studies evaluate service quality characteristics in terms of cost [34], reliability [35], and payment speed. Based on this, this paper focuses on the three dimensions of cooperation cost, reliability and credibility to measure the service quality of manufacturers. This is because: firstly, the cooperation cost will affect the stability of the cooperative relationship [36], which in turn affects the supplier's satisfaction evaluation; secondly, the service reliability reflects the matching relationship of the response function between the service and the manufacturing task [37], and the reliability of the manufacturer in

terms of the payment speed, the order cycle, and so on, affects the quality of its service; thirdly, manufacturer's credibility will provide security for its solvency [38], which in turn affects the manufacturer's service quality.

For suppliers, scholars mostly evaluate the service quality characteristics in terms of reliability, credibility [39], time, quality, and availability [40]. Based on this, this paper measures suppliers' service quality in terms of three dimensions: product quality, reliability and credibility. This is because: firstly, the supplier's product quality will have an impact on the manufacturer's final product quality and revenue, etc. [41], which is an important indicator for the manufacturer to consider when choosing a partner; secondly, the supplier's reliability will bring the effects of stronger market capability, faster product output, and shorter cycle time of providing the product, which is an important factor for the manufacturer to consider the stability of the cooperative influencing factors [42]; thirdly, the supplier's credibility includes the supplier's solvency and business cycle, etc., and a low credibility means that the service provided lacks guarantee in terms of time and cost.

Therefore, the partner selection process in manufacturing supply chain is a process in which suppliers or manufacturers rank partners' service quality characteristics according to their respective criteria based on QoS concepts and make partner selection based on preference ranking.

2.2. Impact of digital intelligence transformation on manufacturing supply chain partner selection

With the continuous emergence of Artificial Intelligence, Blockchain, Cloud Computing, Big Data and other technologies, manufacturing industry is transforming and upgrading from traditional to intelligent, and digitization and intellectualization are gradually becoming an important breakthrough point for innovation and change of the global enterprises [43].

First of all, a firm's level of digitalization can increase the speed and reliability of manufacturing supply chain partner selection [44]. The higher the degree of digital transformation among similar firms, the richer the digital technologies they have, the more digital infrastructure devices they have, and the more efficiently they update and iterate their products [45]. At the same time, the stronger the digital technology of the firms in the supply chain, the more rapid the communication with partner firms and the more responsive the supply chain [46]. The higher the frequency of the corresponding digitized word frequency in the corporate culture, the stronger the reference to previous decisions and the higher the accuracy of the decisions. Therefore, the digitization level of a firm is one of the important factors to consider when choosing a partner [47].

In the second place, the intelligence of the enterprise can improve the efficiency and accuracy of manufacturing supply chain partner selection, the more intelligent the supply chain enterprise is, the more efficient the evaluation of a large number of to-be-selected partner enterprises [48]. Firms with higher levels of intelligence are richer in smart technologies and smart tools, and are more favorable in terms of the cost and efficiency of partner selection [49]. Intelligence represents the intelligence of the enterprise's production process, which means that the more extensive the mass production of its products, the higher the efficiency of product production, the more guaranteed the quality, and at the same time, the cost of intelligent production instead of manual labor is reduced accordingly, and the enterprise has more competitiveness in the partner matching [50]. Therefore, the intelligentization capability of enterprises is one of the important factors to consider when choosing partners [51].

2.3. Matching process analysis for QoS-based manufacturing supply chain partner selection

Combining the analyses in Sections 2.1 and 2.2, the partner selection in manufacturing supply chain can be categorized into unilateral decision-making and bilateral decision-making modes. In the unilateral decision-making mode, the partner selection process of manufacturing supply chain is a behavioral mode in which suppliers or manufacturers rank the service quality characteristics of partners according to their respective criteria based on the QoS concept and make decisions based on the ranking satisfaction. Digital intelligence transformation can improve the breadth of information required for manufacturing supply chain partner selection, enhance

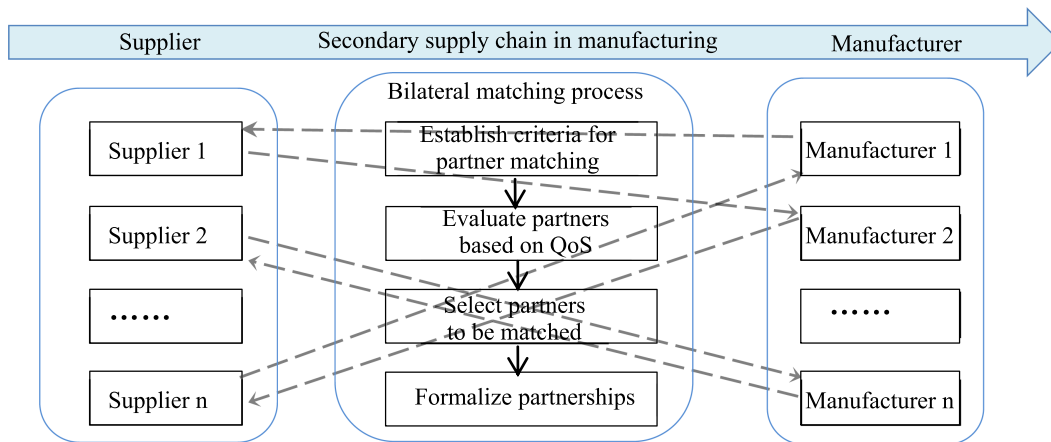


FIGURE 2. Process of bilateral matching between manufacturers and suppliers.

the efficiency of supply chain partner selection decision-making, and advance the bilateral matching behavioral model of supply chain partner selection to a certain extent.

Under smart manufacturing, suppliers and manufacturers in the secondary supply chain of the manufacturing industry, using QoS as the criteria for partner matching, evaluate the QoS of manufacturers and suppliers respectively, and rank them according to their QoS scores from high to low, thus obtaining a supplier preference list and a manufacturer preference list, screen partners based on the preference list, and formally establish a partnership after completing the matching. The bilateral matching process between suppliers and manufacturers is shown in Figure 2.

As can be seen from Figure 2, the specific process of bilateral matching between manufacturers and suppliers is as follows.

First, establish partner matching criteria. Input the indicator datasets of supplier and manufacturer QoS influencing factors respectively, the supplier dataset is the manufacturer's QoS, including the cost of cooperation, the manufacturer's reliability and credibility; the manufacturer dataset is the supplier's QoS, including the supplier's product quality, reliability and credibility.

Second, partners are evaluated based on QoS. The QoS scores of manufacturers and suppliers are calculated based on the metrics dataset, and the scores are sorted in descending order to construct their respective preference lists.

Again, the partners to be matched are selected. For example, if a supplier sends a cooperation request to the manufacturer at the top of its preference list first, there are two scenarios. Scenario 1: the manufacturer accepts the supplier's request if the supplier has not yet been selected by the manufacturer; Scenario 2: if the manufacturer has already accepted a partnership offer from another supplier, the manufacturer compares the supplier with his existing partners and chooses either to reject the supplier's request or to terminate the existing partnership.

Finally, the partnership is formalized. The preferred sorted list of suppliers and manufacturers is updated and the selection is re-run, *i.e.*, suppliers and manufacturers that have completed the pairing are removed from the list. The partnership is formalized when all suppliers and manufacturers have been matched and the matching results are output.

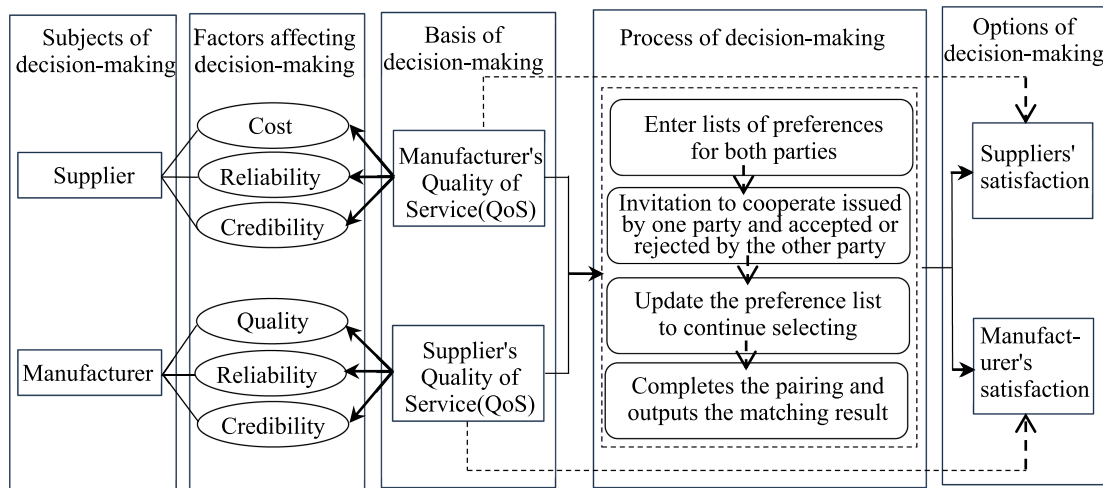


FIGURE 3. Decision-making mechanism for matching manufacturers and supplier partners.

2.4. Decision-making mechanisms for QoS-based manufacturing supply chain partner selection

The decision-making mechanism of manufacturing supply chain partner selection is the process of decision-making subject, comprehensively considering the decision-making influencing factors, ranking the partner's service quality characteristics according to the QoS standard of service quality, and making decision-making selection based on the matching satisfaction. Among them, supply chain partner selection is influenced by four aspects: cooperation cost, product quality, reliability, and credibility. Manufacturers and suppliers form a preference list of QoS evaluation scores in ascending order according to the QoS influencing factors of service quality as a basis for decision-making, and accordingly make bilateral matching, and then make decision-making selection based on satisfaction. The decision-making mechanism for partner selection of heterogeneous subjects in the supply chain is shown in Figure 3.

As can be seen from Figure 3, the decision-making mechanism for QoS-based manufacturing supply chain partner selection includes the four decision-influencing factor analysis – decision-making basis – decision-making process – decision-making selection link. Among them,

The first link is based on the analysis of Section 2.1 that the supplier's decision is influenced by the cost of cooperation with the manufacturer, the reliability of the manufacturer and the credibility of the manufacturer, and the manufacturer's decision is influenced by the quality of the supplier's products, the reliability of the supplier and the credibility of the supplier.

In the second session, based on the analysis of the influencing factors of suppliers' and manufacturers' decisions, the QoS of manufacturers' service quality and the QoS of suppliers' service quality are measured, which are used as the decision-making basis for the selection of supply chain partners in the manufacturing industry.

The decision-making process in the third session is divided into four steps: first, the manufacturer's service quality QoS from the second session is sorted in descending order and transformed into a supplier preference sorted list, and the supplier's service quality QoS is sorted in descending order and transformed into a manufacturer's preference sorted list; second, one party sends out the request for cooperation first, and the other chooses whether to accept or reject it; and, again, the supplier's and the manufacturer's preference sorted lists are updated, and the reselection, *i.e.*, removing suppliers and manufacturers from the list for which matching has been completed. Finally, the matching is completed and the matching result is output.

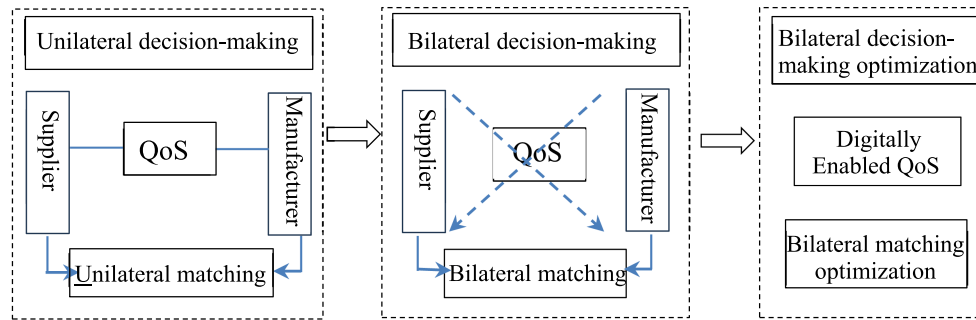


FIGURE 4. Research design idea.

In the fourth session, the decision maker makes a decision based on the matching results. Since the decision is affected by multiple factors, the final choice of the decision maker is uncertain.

3. RESEARCH DESIGN

3.1. Research ideas and variable design

3.1.1. Research ideas

According to Section 2, the mechanism analysis of manufacturing supply chain partner selection, starting from the influencing factors of service quality, constructing QoS evaluation model, based on which, exploring the matching completion and decision-making results of supply chain partner selection under three different decision-making modes: unilateral decision-making – bilateral decision-making – bilateral decision-making optimization. The research design idea is shown in Figure 4.

As can be seen from Figure 4, unilateral decision-making is a decision-making behavior mode in which the decision-making subject directly sends out cooperation invitation after unidirectional evaluation of the QoS of service quality of the selected party. In unilateral decision-making, due to information asymmetry, access to information needs to pay time, energy and cost and other factors, the completion of the match between the manufacturer and the supplier can not be guaranteed.

Bilateral decision-making is based on the QoS evaluation of unilateral decision-making service quality, considering the evaluation results of the selecting party and the selected party on each other's service quality QoS, one party sends out a request for cooperation, and the other party makes an acceptance or rejection decision until all the participants complete the matching of the decision-making behavior mode. Due to the development of enterprise informatization, bilateral decision-making increases the completion of matching between manufacturers and suppliers to a certain extent.

And the optimization of bilateral decision-making is a decision-making behavioral pattern in the context of smart manufacturing, taking into account the impact of enterprise digitalization and intelligence on the selection of manufacturing supply chain partners, and after incorporating digitalization indexes in the QoS evaluation dimensions of the quality of service of bilateral decision-making. Since informatization, digitization, and intelligence are the three development stages of enterprise digital transformation, the introduction of digitization indicators in the QoS evaluation dimension can reveal the difference in the impact of enterprise digitization level on bilateral decision-making behavior.

3.1.2. Variable design

According to Section 2.1, it is known that the service quality of manufacturers and suppliers is affected by several factors: the service quality of suppliers is affected by product quality, reliability and credibility; the service quality of manufacturers is affected by the cost of cooperation, reliability and credibility, of which

TABLE 1. QoS variable design.

Tier 1 indicator variable name	Tier 1 indicator variable codes	Tier 2 indicator variable name	Tier 2 indicator variable codes
Reliability	Rel	Business Performance	B
		Market Capacity	M
Credibility	Cre	Basic Corporate Information	I
		Solvency	S
Cost	Cos	Prices	P
Quality	Qua	Enterprise Technical Capacity	C

reliability and credibility are factors to be considered by both parties when they select each other. Based on the studies of [52, 53], this paper takes the business performance and marketability of the enterprise as a measure of reliability; according to [54], the basic information and solvency of the enterprise are taken as a measure of credibility.

It should be specified that cooperation cost is an important dimension for suppliers to measure the service quality of manufacturers [55], including logistics cost, time cost and labor cost, etc., and based on the study of [56], this paper takes the service price as a measure of cooperation cost; and product quality is an important dimension for manufacturers to measure the service quality of suppliers [57], based on the study of Zeng *et al.* [58], the technological capability of enterprises is used as a measure of product quality.

In summary, the variable design of QoS is shown in Table 1.

3.2. Construction of the evaluation indicator system

3.2.1. Selection and measurement of QoS evaluation indicators

According to Table 1, reliability can be measured by business performance and marketability, which are measured based on annual trading volume and market share, respectively [59]. Credibility can be measured by basic corporate information and solvency, which are measured based on registered capital and years of registration [60], accounts receivable turnover and gearing ratio [61]. The cost of cooperation can be measured by the price of services, and its measurement is derived from the distance between the two parties [62], the farther the distance, the logistics speed, time and cost of the supplier's delivery service will be increased proportionally, which indirectly affects the supplier's creditworthiness value and the manufacturer's satisfaction with it. Product quality can be measured by the technical capability of the enterprise, and its measurement is based on the technology share and technology influence [63], the more patents applied for by the supplier for inventions in a certain field, the higher the number of citations, and the higher the influence, which indicates that its technical level is higher and product quality is more guaranteed. From this, Table 2 can be obtained.

As can be seen from Table 2, the formula for the three levels of metrics, as measured by the manufacturer's QoS variable, is as follows:

$$\text{Market share: } MS_i = \frac{AS_i^{(t)} - AS_i^{(t-1)}}{AS_i^{(t-1)}} \quad (3.1)$$

$$\text{Receivables turnover ratio: } RA_i = \frac{CI_i^{(t)} - NI_i^{(t)}}{(BR_i^{(t)} + ER_i^{(t)})/2} \times 100\% \quad (3.2)$$

$$\text{Asset-liability ratio: } RL_i = \frac{TL_i}{TA_i} \times 100\%. \quad (3.3)$$

TABLE 2. QoS variable measurement index system.

Tier 1 indicators	Tier 2 indicators	Tier 3 indicators	Definition or formula	Variable unit
Reliability (Rel)	Business performance (B)	Annual Transaction Volume (MT)	Total annual sales revenue of the enterprise	Dollars
	Market capacity (M)	Market Share (MS)	(Current year's sales – prior year's sales)/prior year's sales	%
Credibility (Cre)	Basic Corporate Information (I)	Registered Capital (RC)	Capital for business registration	Dollars
		Registered Year (RY)	Year of business registration	Year
	Solvency (S)	Receivables Turnover Ratio (RA)	Revenue from main operations/(opening balance of accounts receivable + closing balance of accounts receivable)/2	%
Cost (Cos)	Prices (P)	Distance (DI)	Calculated from manufacturer and supplier latitude and longitude	None
		Technology Share (TS)	Number of patents filed for supplier j inventions/overall number of patents filed for inventions	%
Quality (Qua)	Technical capability (C)	Technical Influence (TI)	Proportion of supplier j invention application patents with citation number greater than or equal to 1 in the sample firm's invention application patents	%

Distance between manufacturer and supplier's place of registration:

$$DI_i^j = R \cdot \arccos[\sin(\text{Lat}_i) \cdot \sin(\text{Lat}_j) + \cos(\text{Lat}_i) \cdot \cos(\text{Lat}_j) \cdot \cos(\text{Lon}_i - \text{Lon}_j)]. \tag{3.4}$$

In equation (3.4), DI_i^j denotes the distance between manufacturer i and supplier j , Lat_i and Lon_i denote the latitude and longitude of the manufacturer, and Lat_j and Lon_j denote the latitude and longitude of the supplier, respectively.

$$\text{Technology share: } TS_j = \frac{P_j}{p} \tag{3.5}$$

$$\text{Technical influence: } TI_j = \frac{P_j^{(1)}}{P^{(1)}}. \tag{3.6}$$

In equation (3.6), $P_j^{(1)}$ denotes the total number of patents of the supplier that have been cited more than or equal to 1 in the aggregate, and $P^{(1)}$ denotes the total number of patents that have been cited more than or equal to 1 in the aggregate.

The above formula also applies to the supplier QoS metrics calculation, where i denotes the manufacturer and j denotes the supplier.

3.2.2. Selection of digitized QoS evaluation metrics

Enterprises' digital-intelligent transformation will roughly go through the three stages of informatization [64], digitization, and intelligence, given that most of the enterprises are currently in the stage of digital transformation [65], and thus, according to Table 2, based on Han and Zhang's [66] related study, the service quality

TABLE 3. Digital QoS evaluation index system.

Tier 1 indicators	Tier 2 indicators	Tier 3 indicators	Explanatory note on indicators
Digitize (Dai)	Digital Transformation Index (D)	Strategy Leadership Score (SL)	Measuring digital innovation at corporate management level
		Technology-driven Score (TD)	Measuring enterprise digital technology word frequency statistics
		Organizational Empowerment Score (OE)	Measuring digital engagement in business
		Environmental Support Score (ES)	Measuring the industry in which the company operates and the digital construction of the city
		Digitized Results Score (DR)	Measuring enterprise technology, process and business innovation word frequency statistics
		Digital Application Score (DA)	Measuring the digitalization results achieved by enterprises

evaluation system is added with a digitization dimension in order to facilitate further examination of the impact of digital transformation on supply chain partner selection. Based on the digital transformation index measurement and related data provided by the CSMAR database (<https://www.gtarsc.com/>), the digital transformation index of the 70 sample enterprises in this study up to 2021 is obtained to obtain the digital QoS evaluation index system, as shown in Table 3.

3.3. Sample selection and data sources

The research data of this paper comes from CSMAR database (<https://www.gtarsc.com/>), CNDRS database (<https://www.cnrds.com/>) and annual reports of listed companies provided by the official website of “Xueqiu” (<https://xueqiu.com/>). Among them, Annual Transaction Volume, Registered Capital and Registered Year are obtained directly from CSMAR database; Market Share, Receivables Turnover Ratio, Asset-liability Ratio and Distance are calculated from CSMAR database after obtaining the corresponding data; and Technology Share and Technology Influence are calculated by querying the patent information of enterprises provided by CNDRS database. Strategy Leadership Score, Technology-driven Score, Organizational Empowerment Score, Environmental Support Score, Digital Results Score and Digital Application Score are obtained from CSMAR database. The authenticity of the above data was verified by downloading the annual reports from the official website of “[Snowball.com](https://www.snowball.com/)”.

In view of the completeness and availability of the data, 70 enterprises in the metal, automobile and general equipment manufacturing industries were selected as samples, taking into account the characteristics of the evaluation indicators. Relevant data were collected from 2011 to 2022, and the QoS value of each enterprise for each year was calculated. Due to the missing nature of the publication of the data on the degree of digital transformation, as of 2023 only the data of 2021 and before are published, so the data on the degree of digital transformation in 2022 in this paper is supplemented by interpolation. The distribution of registration years of the sample enterprises is shown in Figure 5; the distribution of registered capital is shown in Figure 6.

Figure 5 shows that most of the 70 sample enterprises were registered between 1996 and 2005, which indicates that most of them are mature and stable. Figure 6 shows that the registered capital of the sample enterprises is mostly distributed between 50 and 100 million dollars, which indicates that the sample enterprises are large in scale and have a good reputation.

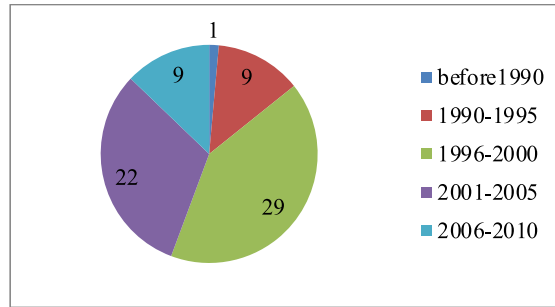


FIGURE 5. Distribution of registered years.

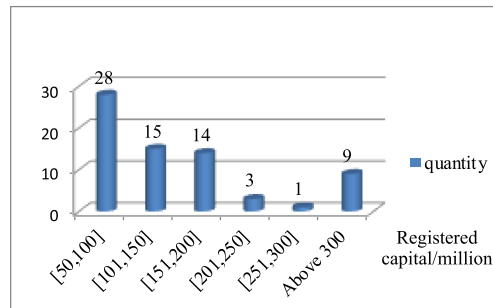


FIGURE 6. Distribution of registered capital.

4. DECISION-MAKING MODELS FOR QOS-BASED MANUFACTURING SUPPLY CHAIN PARTNER SELECTION

4.1. Unilateral decision-making models

For the attributes selected for QoS, Annual Transaction Volume, Market Share, Registered Capital, Receivables Turnover Ratio, Technology Share and Technology Influence in service quality are positive indicators, and the larger the value, the better the QoS attribute; while Registered Year, Asset-liability Ratio and Distance are negative indicators. In this paper, The Method of Interest Rate Difference Transformation is used to standardize the raw data values.

$$\text{For positive indicators: } z_{ij} = \frac{z_{ij} - \min\{z_{1j}, \dots, z_{nj}\}}{\max\{z_{1j}, \dots, z_{nj}\} - \min\{z_{1j}, \dots, z_{nj}\}} \tag{4.1}$$

$$\text{For negative indicators: } z_{ij} = \frac{\max\{z_{1j}, \dots, z_{nj}\} - z_{ij}}{\max\{z_{1j}, \dots, z_{nj}\} - \min\{z_{1j}, \dots, z_{nj}\}} \tag{4.2}$$

The unilateral decision-making model mainly considers the QoS scores of the manufacturer and the supplier's quality of service, and makes a decision by unilateral matching in the order of the size of the scores.

Based on the analysis in Sections 3.1.2 and 3.2.1, the QoS-based evaluation model for manufacturers and suppliers is shown below:

$$\begin{aligned} \text{Manufacturer's QoS: } QoS_i &= Cos_i \times Rel_i \times Cre_i \\ &= P_i \times (B_i + M_i) \times (I_i + S_i) \\ &= DI_i^j \times (MT_i + MS_i) \times (RC_i + RY_i + RA_i + RL_i) \end{aligned}$$

$$\begin{aligned}
&= D_i^j \times \left(MT_i + \frac{AS_i^{(t)} - AS_i^{(t-1)}}{AS_i^{(t-1)}} \right) \\
&\quad \times \left[RC_i + RY_i + \left(\frac{AS_i^{(t)} - AS_i^{(t-1)}}{AS_i^{(t-1)}} \times 100\% \right) + \left(\frac{TL_i}{TA_i} \times 100\% \right) \right] \quad (4.3)
\end{aligned}$$

$$\begin{aligned}
\text{Supplier's QoS: } QoS_j &= Qua_j \times Rel_j \times Cre_j \\
&= P_j \times (B_j + M_j) \times (J_j + S_j) \\
&= DJ_j^j \times (MT_j + MS_j) \times (RC_j + RY_j + RA_j + RL_j) \\
&= (TS_j + TL_j) \times \left(MT_j + \frac{AS_j^{(t)} - AS_j^{(t-1)}}{AS_j^{(t-1)}} \right) \\
&\quad \times \left[RC_j + RY_j + \left(\frac{AS_j^{(t)} - AS_j^{(t-1)}}{AS_j^{(t-1)}} \times 100\% \right) + \left(\frac{TL_j}{TA_j} \times 100\% \right) \right]. \quad (4.4)
\end{aligned}$$

On the basis of the QoS evaluation model, the manufacturer or supplier makes the decision of partner selection directly based on the high or low QoS score result, *i.e.*, unilateral decision.

4.2. Bilateral decision-making models

Since unilateral decision-making only the selecting party makes partner selection decision according to the QoS score of the selected party, the information is asymmetric, and when the selecting party is rejected, it can only select blindly according to the QoS score, which is inefficient in matching, and the completion of matching can not be guaranteed. In order to improve the completion of matching, the manufacturer data and supplier data in the manufacturing supply chain can be stored in the cloud platform at the same time, the information is sufficient and open, and the selecting party can obtain the information of the selected party that has not yet completed the matching from the platform after it has been rejected and send a request for cooperation to it, so as to optimize the unilateral decision-making to bilateral decision-making.

In the bilateral decision model, the QoS ranking model is the same as in Section 4.1, where suppliers and manufacturers make their initial partner selections based on a ranked list of QoS evaluation preferences for quality of service, match bilaterally using the Gale–Shapley algorithm, and compute the total satisfaction of the final matching result. The advantage of bilateral matching over unilateral matching is that a manufacturer or supplier that has been matched successfully will not try to end the current match and attempt to match with a manufacturer or supplier from another category that has been matched successfully. The bilateral decision model is as follows:

$$\text{Manufacturers' Collection: } Z = \{z_1, z_2, \dots, z_i\}, \quad i = 35 \quad (4.5)$$

$$\text{Suppliers' Collection: } G = \{g_1, g_2, \dots, g_j\}, \quad j = 35. \quad (4.6)$$

Sorting supplier QoS scores in descending order yields a list of manufacturer preferences.

$$\text{Manufacturers' Preference List: } Z_{\text{list}} = \begin{bmatrix} g_{11} & g_{21} & g_{i1} \\ \vdots & \vdots & \vdots \\ g_{1j} & g_{2j} & g_{ij} \end{bmatrix}, \quad i = 35, \quad j = 35. \quad (4.7)$$

Sorting manufacturer QoS scores in descending order yields a list of supplier preferences.

$$\text{Suppliers' Preference List: } G_{\text{list}} = \begin{bmatrix} z_{11} & z_{21} & z_{j1} \\ \vdots & \vdots & \vdots \\ z_{1i} & z_{2i} & z_{ji} \end{bmatrix}, \quad i = 35, \quad j = 35. \quad (4.8)$$

After obtaining the preference list through the QoS evaluation model of Section 4.1, the Gale–Shapley algorithm is used to bilaterally match the supply chain manufacturers and suppliers, and the bilaterally matching model follows the steps below:

- Step 1.** Calculate the QoS value of the manufacturer according to equation (4.3), and sort it in descending order according to the size of QoS to get the preference list G_{list} of the supplier;
- Step 2.** Calculate the QoS value of the supplier according to equation (4.4), and sort it in descending order according to the size of QoS to get the preference list Z_{list} of the manufacturer;
- Step 3.** Start the first matching;
- Step 4.** If the manufacturer does not receive a request from the supplier, it remains unadapted;
- Step 5.** If the manufacturer receives requests for service resources from multiple suppliers, the manufacturer selects the top-ranked supplier in its preference list $Z_{\text{list}}(g_j)$ to complete the adaptation;
- Step 6.** Remove the manufacturers and suppliers that have completed the adaptation from the preference sorted list and update the lists to get Z'_{list} and G'_{list} ;
- Step 7.** Keep cycling the matching until both parties stop updating the list;
- Step 8.** Output the matching results and calculate the total satisfaction of manufacturers and suppliers.

When the matching of suppliers and manufacturers is stable, *i.e.*, when all suppliers and manufacturers have been successfully matched and no more suppliers have sent requests for cooperation, the matching results are outputted, and the satisfaction of manufacturers and suppliers with the matching is calculated separately, and the final total satisfaction is the sum of suppliers' and manufacturers' satisfaction, which is calculated by the following formula:

$$\text{Sat}_{\text{total}} = \sum_{i=1}^{35} \text{Sat}_i + \sum_{j=1}^{35} \text{Sat}_j \tag{4.9}$$

$$\text{Sat}_i = \frac{1}{\text{rank}_i(j)} \tag{4.10}$$

$$\text{Sat}_j = \frac{1}{\text{rank}_j(i)} \tag{4.11}$$

where $\text{Sat}_{\text{total}}$ is the total satisfaction, Sat_i is the satisfaction of manufacturer i , Sat_j is the satisfaction of supplier j , $\text{rank}_i(j)$ denotes the rank of supplier j matched by manufacturer i in the manufacturer preference list, and $\text{rank}_j(i)$ denotes the rank of manufacturer i matched by supplier j in the supplier preference list. The larger $\frac{1}{\text{rank}_i(j)}$ indicates the higher satisfaction of manufacturer i , and the larger $\frac{1}{\text{rank}_j(i)}$ indicates the higher satisfaction of supplier j .

4.3. Optimization of bilateral decision-making models under digital conditions

Considering the impact of digital transformation, the evaluation can be done by incorporating the relevant metrics of digital transformation in the Section 4.2 Bilateral Decision Model. The optimization of the evaluation model based on digital QoS is shown below:

$$\begin{aligned} \text{Digital QoS for Manufacturers: } \text{QoS}_i &= \text{Cos}_i \times \text{Rel}_i \times \text{Cre}_i \times \text{Dai}_i \\ &= P_i \times (\text{B}_i + \text{M}_i) \times (\text{I}_i + \text{S}_i) \times \text{D}_i \\ &= \text{DI}_i^j \times (\text{MT}_i + \text{MS}_i) \times (\text{RC}_i + \text{RY}_i + \text{RA}_i + \text{RL}_i) \times \text{D}_i \\ &= \text{D}_i^j \times \left(\text{MT}_i + \frac{\text{AS}_i^{(t)} - \text{AS}_i^{(t-1)}}{\text{AS}_i^{(t-1)}} \right) \\ &\quad \times \left[\text{RC}_i + \text{RY}_i + \left(\frac{\text{AS}_i^{(t)} - \text{AS}_i^{(t-1)}}{\text{AS}_i^{(t-1)}} \times 100\% \right) + \left(\frac{\text{TL}_i}{\text{TA}_i} \times 100\% \right) \right] \\ &\quad \times \text{D}_i \end{aligned} \tag{4.12}$$

$$\begin{aligned}
\text{Digital QoS for Suppliers: } QoS_j &= Qua_j \times Rel_j \times Cre_j \times Dai_j \\
&= P_j \times (B_j + M_j) \times (J_j + S_j) \times D_j \\
&= DJ_j^j \times (MT_j + MS_j) \times (RC_j + RY_j + RA_j + RL_j) \times D_j \\
&= (TS_j + TL_j) \times \left(MT_j + \frac{AS_j^{(t)} - AS_j^{(t-1)}}{AS_j^{(t-1)}} \right) \\
&\quad \times \left[RC_j + RY_j + \left(\frac{AS_j^{(t)} - AS_j^{(t-1)}}{AS_j^{(t-1)}} \times 100\% \right) + \left(\frac{TL_j}{TA_j} \times 100\% \right) \right] \\
&\quad \times D_j. \tag{4.13}
\end{aligned}$$

Optimization of bilateral decision-making model under digital conditions compared with the bilateral decision-making model, on the basis of the QoS evaluation model, adding digital indicators in line with the development requirements of the times makes the QoS score more reflective of the reality, with a view to obtaining more stable bilateral matching results to guide decision-making.

5. ANALYSIS OF EVALUATION RESULTS

5.1. Ranking results for supplier and manufacturer preferences

5.1.1. Analysis of results without considering the digitization case

According to Section 4.1 Unilateral Decision Model and Section 4.2 Bilateral Decision Model, the QoS evaluation values of manufacturers and suppliers for a total of 11 years from 2012 to 2022 can be obtained, which are the preference lists of suppliers and manufacturers from 2012 to 2022. It should be noted that the preference lists of the 35 manufacturers studied in this paper are consistent in the same year, which is determined by the supplier's QoS, while the preference lists of the 35 suppliers are different for different suppliers in different years, which is determined by the manufacturer's QoS, which is due to the correlation between the manufacturer's QoS and the distance between suppliers. Due to space limitation, this paper only shows the preference list for the year 2021, and for comparison, the QoS is normalized and then sorted in descending order to obtain the corresponding preference lists of suppliers and manufacturers, as shown in Table 4.

As can be seen from Table 4, the supplier's preference list corresponds to the manufacturer's QoS, and the manufacturer's preference list corresponds to the supplier's QoS. For supplier HYYS in 2021, the quality of service for individual manufacturers is concentrated between 0.2 and 0.7, which is higher overall, while for individual manufacturers in 2021, the supplier's QoS is concentrated between 0.005 and 0.1, which is a higher overall quality of service Lower.

5.1.2. Analysis of results under digitized conditions

According to Section 4.3 Optimization of Bilateral Decision Model under Digitization Conditions, the digital QoS evaluation values of manufacturers and suppliers for a total of 11 years from 2012 to 2022 can be obtained, which is the preference list of suppliers and manufacturers under digitization conditions. Due to space limitation, only the preference lists of suppliers and manufacturers under digitization conditions in 2021 are shown here, as shown in Table 5.

As shown in Table 5, in 2021, the overall QoS of manufacturers under digitization conditions is greater than the QoS of suppliers, where most of the manufacturers' QoS is at [0.2, 0.6] and most of the suppliers' QoS is at [0.01, 0.2], which may be due to the fact that suppliers are weaker than manufacturers in terms of their overall level of reliability, credibility, and degree of digital transformation.

TABLE 4. Ranked list of preferences of suppliers and manufacturers in 2021.

Preferred list of supplier HYYS in 2021						Preferred list of manufacturers in 2021					
Ranking	Manufacturers	QoS	Ranking	Manufacturers	QoS	Ranking	Suppliers	QoS	Ranking	Suppliers	QoS
1	HQLB	1.0000	19	WLGF	0.3540	1	JFKJ	1.0000	19	JSST	0.0148
2	KYDT	0.7840	20	SZHJ	0.3493	2	SHGF	0.2283	20	HDSK	0.0146
3	HKD	0.7728	21	YWGF	0.3085	3	GDTY	0.1982	21	SDJL	0.0139
4	HXNY	0.6960	22	NFGF	0.2757	4	TQQZ	0.1914	22	SYJC	0.0127
5	NFBY	0.6792	23	HLMD	0.2663	5	XZGF	0.1130	23	JHDL	0.0115
6	XRGF	0.6566	24	ZHGY	0.2456	6	KLDT	0.1008	24	YNDL	0.0098
7	SJZN	0.6534	25	SDZG	0.2455	7	HYJX	0.0951	25	CRGF	0.0094
8	YHSK	0.6517	26	WZB	0.2399	8	DAHJ	0.0896	26	TEZG	0.0069
9	YJGF	0.6355	27	YHZK	0.2249	9	ZYKJ	0.0703	27	KSGF	0.0068
10	HZSK	0.5812	28	JSKJ	0.2015	10	HGGF	0.0690	28	DLGF	0.0065
11	JQR	0.5415	29	RQGF	0.1807	11	RBGF	0.0394	29	SHCD	0.0060
12	SKGF	0.4797	30	ZDLG	0.1347	12	HYYS	0.0316	30	HZJJ	0.0060
13	LXBY	0.4667	31	SYGF	0.1163	13	TQGF	0.0296	31	BSGJ	0.0057
14	BDZG	0.4479	32	JSGF	0.0972	14	ZHKJ	0.0279	32	RFSM	0.0053
15	TYZG	0.4434	33	JTL	0.0690	15	YTBL	0.0258	33	XYZC	0.0025
16	LYD	0.4226	34	BTL	0.0040	16	HLZG	0.0252	34	XBZC	0.0005
17	NFZC	0.3944	35	HDZJ	0.0000	17	QCFZ	0.0199	35	SCCA	0.0000
18	RLGF	0.3879				18	TMGF	0.0161			

5.2. Analysis of results of matching

5.2.1. Unilateral decision-making

According to Section 5.1.1 Supplier and Manufacturer Preference Lists (Tab. 4), the results of unilateral matching of suppliers and manufacturers in the full information case, for example in 2021, are shown in Tables 6 and 7.

As shown in Table 6, in the case of complete information, the supplier’s unilateral match is the manufacturer that is ranked first in the supplier’s preference list, but due to the influence of the geographical location between the supplier and the manufacturer, the cost of each supplier for the cooperation between different manufacturers is slightly different, which leads to differences in the supplier’s evaluation of the manufacturer’s QoS, and therefore, in 2021, each supplier through unilateral matching chooses different manufacturers to cooperate with. However, QoS may be affected by reliability and credibility at the same time, and under the combined effect of these factors, some suppliers have the same QoS evaluation results for the same manufacturer, and thus prefer the same manufacturer at the top of the preference list, thus favoring the same matching results.

As can be seen from Table 7, the manufacturers’ unilateral matching results converge without considering digitization. This is because the manufacturer’s unilateral matching is to the supplier at the top of the manufacturer’s preference list, and since the supplier’s QoS score is affected by product quality, reliability, and credibility, each supplier’s QoS score has only one value in the same year, and the preference lists are the same for different manufacturers. Under the condition of insufficient information, manufacturers unilaterally match with the first supplier in their own preference lists, which may lead to multiple manufacturers sending cooperation requests to the same supplier, and without knowing the supplier’s preference, some manufacturers are rejected by the supplier several times, which will lead to an increase in the decision-making cost of the manufacturer.

TABLE 5. List of preferences of suppliers and manufacturers under digitized conditions in 2021.

Preferred list of supplier HYYS under digital conditions in 2021						Preferred list of manufacturers under digital conditions in 2021					
Ranking	Manufacturers	QoS	Ranking	Manufacturers	QoS	Ranking	Suppliers	QoS	Ranking	Suppliers	QoS
1	HZSK	1.0000	19	SDZG	0.3128	1	JFKJ	1.0000	19	HLZG	0.0205
2	JQR	0.9069	20	JSKJ	0.3072	2	GDTY	0.3750	20	JSST	0.0192
3	HQLB	0.8829	21	BDZG	0.3068	3	TQQZ	0.3001	21	SYJC	0.0179
4	TYZG	0.8066	22	RQGF	0.295	4	SHGF	0.2213	22	JHDL	0.0154
5	HKD	0.6816	23	SJZN	0.2637	5	KLDT	0.1643	23	YNDL	0.0154
6	XRGF	0.6183	24	WLGf	0.2515	6	DAHJ	0.1186	24	CRGF	0.0137
7	NFBY	0.6096	25	LXBY	0.2344	7	XZGF	0.1144	25	SHCD	0.0131
8	HXNY	0.602	26	NFGF	0.2335	8	HYJX	0.1130	26	SDJL	0.0122
9	RLGF	0.558	27	JSGF	0.209	9	ZYKJ	0.1121	27	TEZG	0.0110
10	KYDT	0.5381	28	YHZK	0.1884	10	HGGF	0.0749	28	DLGF	0.0084
11	YHSK	0.5242	29	ZDLD	0.1829	11	HYYS	0.0484	29	KSGF	0.0076
12	YWGF	0.4547	30	ZHGY	0.1526	12	TQGF	0.0482	30	RFSM	0.0064
13	NFZC	0.4333	31	WZB	0.1281	13	RBGF	0.0457	31	BSGJ	0.0059
14	YJGF	0.4183	32	BTL	0.1045	14	QCFZ	0.0350	32	HZJJ	0.0058
15	HLMD	0.405	33	HDZJ	0.0401	15	ZHKJ	0.0345	33	XYZC	0.0013
16	LYD	0.3711	34	SYGF	0.0094	16	TMGF	0.0303	34	XBZC	0.0001
17	SKGF	0.3581	35	JTL	0.0000	17	YTBL	0.0262	35	SCCA	0.0000
18	SZHJ	0.3258				18	HDSK	0.0213			

TABLE 6. Supplier unilateral matching results in 2021.

Serial number	Matching result	Serial number	Matching result	Serial number	Matching result
1	HYYS-HQLB	13	TQGF-HQLB	25	TEZG-HQLB
2	SYJC-JQR	14	DAHJ-HQLB	26	KLDT-HQLB
3	DLGF-JQR	15	ZYKJ-HXNY	27	KSGF-HQLB
4	SCCA-HQLB	16	SHGF-HQLB	28	JSST-HQLB
5	XBZC-HXNY	17	TMGF-HQLB	29	SHCD-HQLB
6	XYZC-HXNY	18	GDTY-KYDT	30	XZGF-HXNY
7	ZHKJ-HQLB	19	HZJJ-HQLB	31	RBGF-HQLB
8	YTBL-JQR	20	JFKJ-HXNY	32	RFSM-HQLB
9	JHDL-HQLB	21	HDSK-JQR	33	TQQZ-KYDT
10	QCFZ-HXNY	22	HLZG-HQLB	34	HYJX-HQLB
11	SDJL-JQR	23	CRGF-HXNY	35	HGGF-HQLB
12	YNDL-HXNY	24	BSGJ-JQR		

TABLE 7. Manufacturer unilateral matching results in 2021.

Serial number	Matching result	Serial number	Matching result	Serial number	Matching result
1	HLMD-JFKJ	13	YHZK-JFKJ	25	NFGF-JFKJ
2	BDZG-JFKJ	14	SZHZ-JFKJ	26	JQR-JFKJ
3	NFZC-JFKJ	15	HKD-JFKJ	27	JSGF-JFKJ
4	YWGF-JFKJ	16	WLGJ-JFKJ	28	SYGF-JFKJ
5	SDZG-JFKJ	17	LXBY-JFKJ	29	JTL-JFKJ
6	HXNY-JFKJ	18	ZDLD-JFKJ	30	RQGF-JFKJ
7	SKGF-JFKJ	19	YHSK-JFKJ	31	NFBY-JFKJ
8	XRGF-JFKJ	20	YJGF-JFKJ	32	RLGF-JFKJ
9	HDZJ-JFKJ	21	SJZN-JFKJ	33	HZSK-JFKJ
10	LYD-JFKJ	22	ZHGY-JFKJ	34	TYZG-JFKJ
11	BTL-JFKJ	23	WZB-JFKJ	35	JSKJ-JFKJ
12	KYDT-JFKJ	24	HQLB-JFKJ		

From the combination of Tables 6 and 7, unilateral matching does not guarantee that all suppliers and manufacturers are matched to the right objects, and the matching completion is not high. This is because in the case of digitalization is not taken into account, the matching results of unilateral decision-making depends largely on the decision-making body to master the degree of information, and access to information needs to pay time, energy and cost, so in the case of asymmetric information, suppliers and manufacturers can only be known or familiar with the matching object to seek a partner, and decision-making will also be affected by the distance between the two sides, decision-making preferences, the subject of the decision-making is also affected by the distance between the two sides, decision-making preferences, the subject of the code of conduct and other factors, which leads to the reality of unilateral decision-making results will not necessarily be the same as the list of matching results of the situation.

5.2.2. Bilateral decision-making

Firstly, according to Section 5.1.1 Supplier and Manufacturer Preference List (Tab. 4), the Gale–Shapley algorithm code is designed, and then the python software is applied to match the sample firms, so as to get the bilateral matching results from 2012 to 2022. Taking 2021 as an example, the bilateral matching results of suppliers and manufacturers, as shown in Table 8.

As can be seen from Table 8, bilateral matching using the Gale–Shapley algorithm ensures that every supplier and every manufacturer are matched, and the matching completion rate reaches 100%. Bilateral matching after multiple rounds of matching, each set of matching results are not the same, matching stability is higher than unilateral matching. Due to the multiple matching on the information platform, the process is open and transparent, which leads to a lower cost of matching for both suppliers and manufacturers compared to unilateral matching, and the chance of bilateral matching results as a bilateral decision-making choice will increase.

5.2.3. Optimization analysis of bilateral decision-making under digital conditions

According to the list of supplier and manufacturer preferences in the digitization scenario of Section 5.1.2 (Tab. 5), python software is used to match the sample firms to obtain the optimized bilateral matching results from 2012 to 2022. Taking 2021 as an example, the optimized bilateral matching results of suppliers and manufacturers are shown in Table 9.

As can be seen from Table 9, after adding the digitization indicators, there are obvious differences in the QoS scores of service quality due to the fact that the decision-making subjects may be in different stages of digital transformation, making the preference lists different, which leads to different matching results and final decision-making choices than in the case of bilateral decision-making in Section 5.2.2. However, as the level of

TABLE 8. Bilateral matching results in 2021.

Serial number	Matching result	Serial number	Matching result	Serial number	Matching result
1	HYYS-HQLB	13	TQGF-BDZG	25	TEZG-YHZK
2	SYJC-JQR	14	DAHJ-SKGF	26	KLDT-XRGF
3	DLGF-WZB	15	ZYKJ-LXBY	27	KSGF-ZDLD
4	SCCA-NFBY	16	SHGF-SJZN	28	JSST-YWGF
5	XBZC-HXNY	17	TMGF-LYD	29	SHCD-SYGF
6	XYZC-HZSK	18	GDTY-KYDT	30	XZGF-RLGF
7	ZHKJ-HKD	19	HZJJ-SZJH	31	RBGF-RQGF
8	YTBL-WLGF	20	JFKJ-TYZG	32	RFSM-JTL
9	JHDL-YHSK	21	HDSK-HLMD	33	TQQZ-JSGF
10	QCFZ-YJGF	22	HLZG-NFZC	34	HYJX-HDZJ
11	SDJL-ZHGY	23	CRGF-JSKJ	35	HGGF-BTL
12	YNDL-NFGF	24	BSGJ-SDZG		

TABLE 9. Optimized bilateral matching results in 2021.

Serial number	Matching result	Serial number	Matching result	Serial number	Matching result
1	HYYS-HZSK	13	TQGF-XRGF	25	TEZG-BDZG
2	SYJC-JQR	14	DAHJ-NFZC	26	KLDT-RQGF
3	DLGF-TYZG	15	ZYKJ-YJGF	27	KSGF-HDZJ
4	SCCA-NFBY	16	SHGF-KYDT	28	JSST-SJZN
5	XBZC-YHSK	17	TMGF-LYD	29	SHCD-YHZK
6	XYZC-BTL	18	GDTY-HKD	30	XZGF-JSKJ
7	ZHKJ-HQLB	19	HZJJ-ZDLD	31	RBGF-ZHGY
8	YTBL-HLMD	20	JFKJ-SDZG	32	RFSM-JTL
9	JHDL-YWGF	21	HDSK-WLGF	33	TQQZ-NFGF
10	QCFZ-HXNY	22	HLZG-SZJH	34	HYJX-JSGF
11	SDJL-SKGF	23	CRGF-LXBY	35	HGGF-SYGF
12	YNDL-RLGF	24	BSGJ-WZB		

enterprise digitization improves, the channels for decision-making subjects to obtain information will be wider, the speed of information transmission and updating will be more convenient, the efficiency of all parties to complete the matching will be improved, and the scientificity and stability of decision-making will be higher.

5.3. Satisfaction analysis of decision-making

5.3.1. Unilateral decision-making

Unilateral decision-making is prone to preference failure situations due to unequal status and asymmetric information, etc. Decision makers can only choose the objects they are familiar with or know about to make choices, therefore, the preference list after service quality evaluation is the result of unilateral matching. At the same time, the result of unilateral decision-making is also unstable, and due to insufficient information, there is no way to know the supplier and manufacturer satisfaction after decision-making, and the total satisfaction of decision-making is even more unknowable.

TABLE 10. Satisfaction with bilateral matching decisions in 2021.

Pairing	Supplier satisfaction	Manufacturer satisfaction	Pairing	Supplier satisfaction	Manufacturer satisfaction	Pairing	Supplier satisfaction	Manufacturer satisfaction
1	1.0000	0.0833	13	0.0714	0.0769	25	0.0385	0.0385
2	1.0000	0.0455	14	0.1000	0.1250	26	0.1429	0.1667
3	0.2500	0.0357	15	0.0714	0.1111	27	0.0333	0.0370
4	0.5000	0.0286	16	0.5000	0.5000	28	0.0526	0.0526
5	1.0000	0.0294	17	0.0714	0.0556	29	0.0323	0.0345
6	0.1429	0.0303	18	1.0000	0.3333	30	0.0833	0.2000
7	0.1667	0.0714	19	0.0588	0.0333	31	0.0385	0.0909
8	0.2500	0.0667	20	0.5000	1.0000	32	0.0323	0.0313
9	0.1000	0.0435	21	0.1111	0.0500	33	0.0345	0.2500
10	0.3333	0.0588	22	0.0667	0.0625	34	0.0294	0.1429
11	0.0667	0.0476	23	0.0476	0.0400	35	0.0294	0.1000
12	0.0909	0.0417	24	0.0714	0.0323			

5.3.2. Bilateral decision-making

In order to avoid the situation of unilateral matching decision resulting in preference failure, the bilateral matching decision model based on QoS preference can be used, according to equations (4.9)–(4.11) can be obtained after the bilateral matching decision of the manufacturer and supplier satisfaction, as an example, in the year of 2021, the bilateral matching decision satisfaction, as shown in Table 10.

As can be seen from Table 10, the total satisfaction in the bilateral matching decision in 2021 is 8.12 for suppliers and 4.15 for manufacturers, which ultimately yields an overall satisfaction of 12.27 for the bilateral matching decision. The supplier satisfaction is higher than the manufacturer satisfaction for each set of pairings due to the fact that the supplier, as the initiator, first sends out the invitation for cooperation, and if the manufacturer is the initiator then the manufacturer satisfaction should be higher than the suppliers; however, in this study, since the 35 manufacturers had the same preference list in the same year and the suppliers had different preference lists, the bilateral matching was done with the suppliers as the active party in order to obtain a higher overall satisfaction.

5.3.3. Optimization of bilateral decision making under digital conditions

The satisfaction formula (4.9)–(4.11) in Section 4.2 are applied to obtain the optimized manufacturer and supplier decision satisfaction after bilateral matching optimization under digitization conditions, and the optimized decision satisfaction, as an example, for the year 2021, is shown in Table 11.

Table 11 shows that the total satisfaction of the manufacturer is 4.15, the total satisfaction of the supplier is 7.50, and the total satisfaction of the bilateral matching under the digitization condition is 11.65. Under the premise that the supplier sends out the cooperation invitation first, the total satisfaction of the supplier is higher than that of the manufacturer. Combined with the logic of the Gale–Shapley algorithm, it can be seen that the party that takes the initiative in bilateral matching will obtain greater satisfaction.

5.4. Comparative analysis of results

5.4.1. Comparative analysis of manufacturer and supplier QoS without considering digitization

According to the results of Section 5.1.1 QoS scores of manufacturers and suppliers without considering digitization, the QoS scores of suppliers and manufacturers can be compared and analyzed for the period 2012–2022. Among them, the supplier’s QoS score for 2012–2022, as shown in Figure 7; since the manufacturer’s QoS is different for different suppliers each year, this study takes the supplier HYYS as an example and comparatively analyzes its manufacturer’s QoS score for the period 2012–2022, as shown in Figure 8.

TABLE 11. Satisfaction with bilateral matching results under digitized conditions in 2021.

Pairing	Supplier satisfaction	Manufacturer satisfaction	Pairing	Supplier satisfaction	Manufacturer satisfaction	Pairing	Supplier satisfaction	Manufacturer satisfaction
1	1.0000	0.0909	13	0.1667	0.0833	25	0.0500	0.0370
2	1.0000	0.0476	14	0.0833	0.1667	26	0.0556	0.2000
3	0.5000	0.0357	15	0.0714	0.1111	27	0.0303	0.0345
4	0.2000	0.0286	16	0.1111	0.2500	28	0.0435	0.0500
5	0.1429	0.0294	17	0.0667	0.0625	29	0.0417	0.0400
6	0.0313	0.0303	18	1.0000	0.5000	30	0.0714	0.1429
7	0.5000	0.0667	19	0.0400	0.0313	31	0.0385	0.0769
8	0.2000	0.0588	20	0.2000	1.0000	32	0.0294	0.0333
9	0.1429	0.0455	21	0.0833	0.0556	33	0.0500	0.3333
10	1.0000	0.0714	22	0.0667	0.0526	34	0.0385	0.1250
11	0.0500	0.0385	23	0.0714	0.0417	35	0.0286	0.1000
12	0.2500	0.0435	24	0.0476	0.0323			

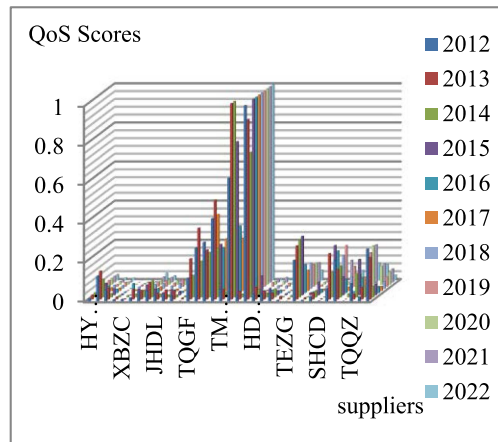


FIGURE 7. Comparison of supplier QoS scores 2012–2022.

As can be seen from Figure 7, suppliers with high QoS scores from 2011 to 2022 are mostly the same few companies, and the QoS scores among suppliers are uneven, with a very small number of companies with scores above 0.4, and most of them with scores below 0.2. As can be seen from Figure 8, the QoS scores of manufacturers are mostly distributed in [0.1–0.5], which is more evenly distributed. This indicates that when suppliers choose manufacturers, there can be more than one manufacturer at the same time whose service quality meets suppliers’ needs. When the manufacturer selects the supplier, there will be a situation that all the manufacturers send cooperation invitation to the first few suppliers at the same time, and the rest of the suppliers with lower scores can only receive the cooperation request in the second round, or even receive the request later. Therefore, the distribution of QoS scores of manufacturers and suppliers affects the final selection result.

5.4.2. Comparative analysis of manufacturer and supplier QoS considering digitization

Based on the results of the QoS scores of manufacturers and suppliers under digitization conditions in Section 5.1.2, the digitized QoS scores of suppliers and manufacturers for the period 2012–2022 were compared and analyzed as shown in Figures 9 and 10.

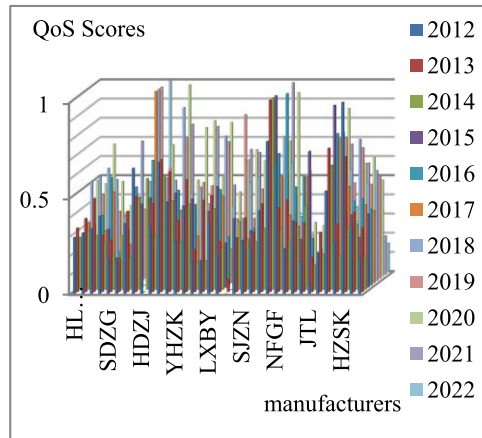


FIGURE 8. Comparison of manufacturer QoS scores 2012–2022 for supplier HYYS.

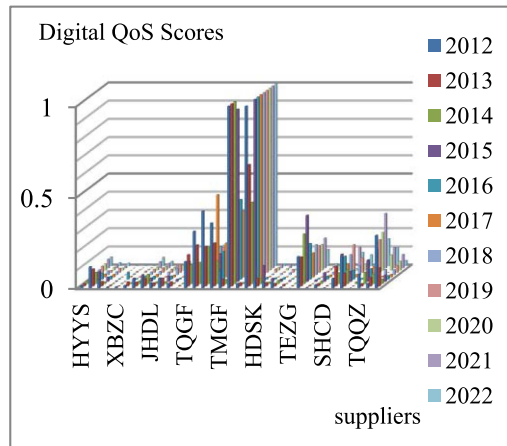


FIGURE 9. Supplier Digital QoS 2012–2022.

As can be seen in Figures 9 and 10, the QoS distribution of both suppliers and manufacturers is uneven in the digitalization scenario. It can be seen that digital transformation has a greater impact on the quality of service of suppliers and manufacturers, due to the different degree of digital transformation of each enterprise, its corresponding technical capabilities and market capabilities are affected, and under the combined effect of multiple factors, the difference in digital QoS is gradually widened.

5.4.3. Comparative analysis of manufacturers' QoS in different scenarios

Considering the impact of digital transformation on the overall performance of the supply chain, based on the score results in Tables 4 and 5, the differences in the quality of manufacturers' services in the two scenarios without considering digital transformation and digital transformation are explored, respectively, in the year 2021, based on the results of the scores in Tables 4 and 5. The comparison is shown in Figures 11 and 12.

As can be seen in Figures 11 and 12, the horizontal axis represents 35 suppliers, the vertical axis represents the QoS score, and each color bar represents one manufacturer, for a total of 35 manufacturers. By comparison, it can be found that manufacturers with lower QoS scores are affected by digitization and their digitization level

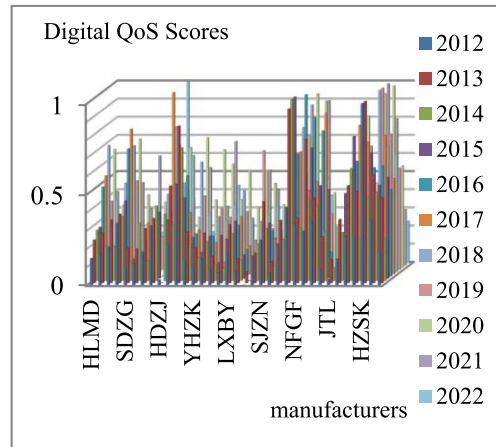


FIGURE 10. Manufacturer Digital QoS 2012–2022 for supplier HYYS.

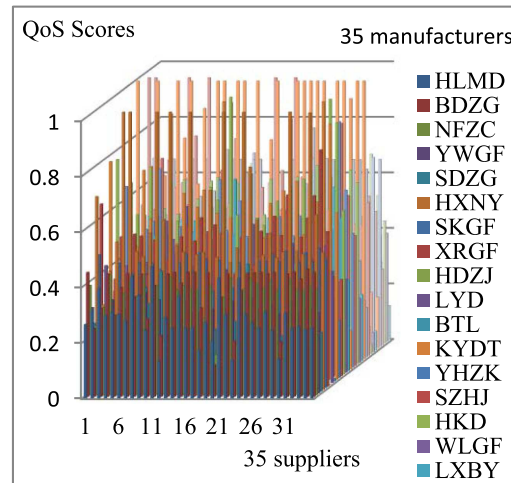


FIGURE 11. Manufacturer QoS comparison in 2021 without considering digitization.

is not high, which does not have a significant impact on QoS in the digitization case; whereas for manufacturers with higher digitization level, their QoS in the digitization case has a significant upward trend relative to the QoS in the case where digitization is not considered.

5.4.4. Comparative analysis of unilateral versus bilateral decision-making

Unilateral decision-making is based on service quality only, while bilateral decision-making considers the characteristic advantages of both subjects, *i.e.*, service quality, and transforms the comprehensive advantages into the preference order of both subjects, which in turn yields a bilateral matching decision-making method based on service quality. Comparing Sections 5.3.1 and 5.3.2, it can be seen that unilateral decision-making has no way of knowing the satisfaction of both parties due to the uncertainty of the decision-making result. While the results of bilateral decision-making have stability and multiple rounds of matching are carried out, the total satisfaction of bilateral matching where the selected party has the right of rejection is higher, indicating that

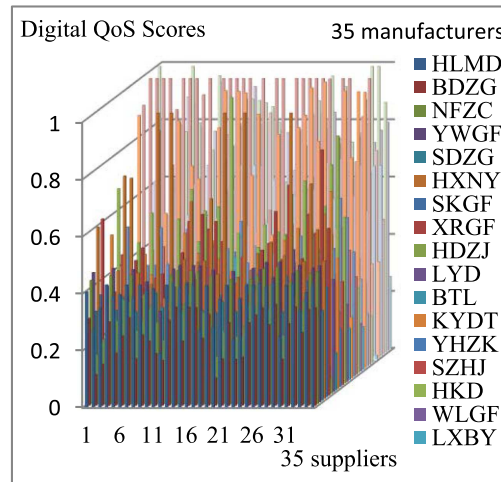


FIGURE 12. Manufacturer QoS comparison for 2021 in the digitization scenario.

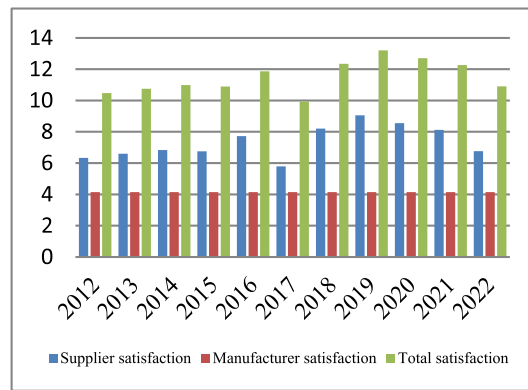


FIGURE 13. Satisfaction analysis of bilateral matching.

the bilateral matching model based on the Gale–Shapley algorithm has a good effect in dealing with partner selection between heterogeneous subjects in the supply chain.

5.4.5. Comparative analysis of bilateral decision-making and digital optimization decision-making

According to Table 10 of Section 5.3.2 and Table 11 of Section 5.3.3, a comparative analysis of decision satisfaction after bilateral matching and bilateral matching optimization can be obtained for the years 2012–2022, as shown in Figures 13 and 14.

As can be seen in Figures 13 and 14, supplier satisfaction is greater than manufacturer satisfaction in all cases. The distance between suppliers and manufacturers greatly affects suppliers’ judgment of manufacturers’ service quality. When multiple manufacturers send out service requests, the closer the supplier, the faster the response time, the lower the logistics cost, time cost and labor cost required to deliver the service, which leads to greater manufacturer satisfaction. For manufacturers, the quality of the supplier’s product directly affects the manufacturer’s service satisfaction. Problems with a supplier’s products can significantly reduce a manufacturer’s satisfaction by causing a loss of credibility, an increase in product recall costs, and an increase in switching costs for replacement partners.

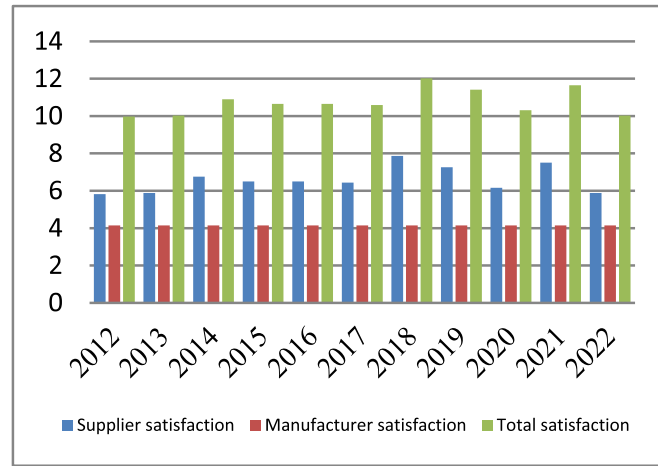


FIGURE 14. Satisfaction analysis after bilateral matching optimization.

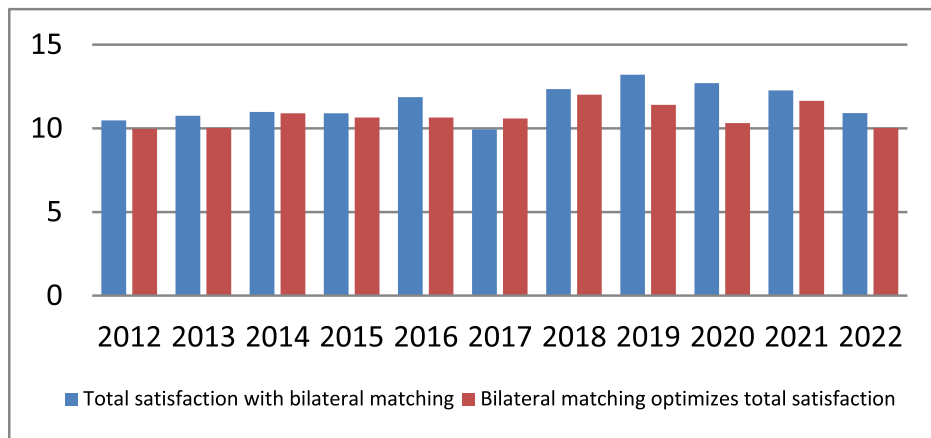


FIGURE 15. Comparison of total satisfaction after optimization of bilateral matching and bilateral matching.

5.4.6. Comprehensive comparative analysis

Based on the decision satisfaction in Sections 5.3.2 and 5.3.3, a comparative analysis of the total satisfaction of decision making after bilateral matching and bilateral matching optimization for the years 2012–2022 can be obtained, as shown in Figure 15.

As can be seen from Figure 15, the total satisfaction after optimization of bilateral matching is slightly lower than the total satisfaction of bilateral matching. This is due to the fact that after the digital transformation of enterprises, the interaction of information is more convenient and efficient, the information transparency is higher, the difference of QoS between enterprises is reduced, the preference lists of different suppliers and manufacturers are converged, the competitive pressure in the bilateral matching process is greater, and the chances of suppliers sending cooperation requests to a certain manufacturer at the same time are increased, and the satisfaction of decision-making is reduced accordingly.

6. ENHANCEMENT STRATEGIES FOR BILATERAL SELECTION OF SUPPLY CHAIN PARTNERS UNDER DIGITAL TRANSFORMATION

6.1. Enhancement of service quality to increase satisfaction with partner selection decisions

Quality of service (QoS) is an important influence on supply chain partner selection, and the improvement of QoS not only gives enterprises a stronger competitive advantage in the market, but also serves as an important basis for supply chain partner matching. In order to enhance the stability of supply chain partner matching, we can start from the reliability, credibility, product quality and cooperative logistics costs to improve the quality of service and increase the satisfaction of supply chain partner selection.

- (1) To continuously improve the reliability and credibility of enterprises. Under the trend of product homogenization, it is necessary to build the unique competitive advantage of enterprises from reliability and credibility. On the one hand, strengthen the application of intelligent manufacturing technology in enterprises and promote the construction of enterprise reliability system. On the other hand, from the sound internal management system of the enterprise itself, improve the enterprise's operation and development ability, service ability to start, enhance the credibility of the enterprise.
- (2) Continuously improve product quality stability and production efficiency. Through digital transformation, stimulate enterprise innovation vitality, and then promote product quality. At the same time, strengthen the construction of digital platform, through the international – domestic, horizontal – vertical heterogeneous knowledge cycle iteration, for the node enterprise knowledge power to provide sustainable power to climb, and constantly stimulate the generation of enterprise innovation consciousness and motivation, to promote the existing product features, process technology and production processes are constantly optimized, improved and upgraded.
- (3) Effective cost control to promote the overall performance of enterprises. From the packaging of goods, warehousing, transportation, distribution and circulation processing and other aspects of the implementation of relevant methods and strategies to effectively reduce the cost of each link, to achieve the overall efficiency of the manufacturing supply chain cooperation enterprises.

6.2. Optimize partner selection decision-making mechanisms to improve partner matching efficiency

The service quality of the enterprise as a basis for decision-making has an important impact on the decision-making of supply chain partner selection. And the improvement of service quality can enhance the partners' perception of service value, which directly affects their cooperation choice decision. In the complex and fast-changing environment, the high-level decision-making efficiency of the enterprise is an indispensable prerequisite for rapid response to the environment, and the decision-making satisfaction is the guarantee for the enhancement of the execution power of the enterprise in the fierce competition. Partner selection decision satisfaction is affected by the decision basis and decision matching process.

- (1) Big data technology empowerment. Strengthen the investment in technological innovation, promote the development of big data labeling technology and data mining technology, combined with the decision-making subject preference, before the decision-making with the help of big data technology to identify personalized needs, which is conducive to the enterprise to lock the partner to carry out the expected demand decision-making, in order to enhance the decision-making satisfaction.
- (2) Improve the decision support system. Optimizing the system structure of the quick response decision support system based on the subject's preference and optimizing the speed of evaluation of decision-making solutions can help to improve the enterprise's cognition, help it to predict the partner's needs and incorporate these behaviors into the decision-making process, so as to improve the speed and accuracy of decision-making.
- (3) Optimize the matching process. Strengthening the application of intelligent recommendation algorithms and matching algorithms helps enterprises to comprehensively and efficiently manage complex global supply

chains, optimize the overall decision-making process of the supply chain, accelerate product innovation, avoid potential risks, and improve the efficiency of partner selection and matching process.

6.3. Strengthening digitalization to enhance the stability of supply chain partner collaboration

Digital transformation facilitates the exchange and transfer of information and knowledge among similar enterprises, and has a great impact on the integration and sharing patterns of information and resources among enterprises, which in turn affects the selection decisions of supply chain partners. In order to enhance the stability of supply chain partner cooperation, it is necessary to strengthen the digital transformation of the supply chain.

- (1) Strengthen the construction of industry digital information platform. The industry digital information platform should be linked to enterprise-oriented information service systems, and the resources of each system should be transformed into data format through the platform to realize the open reorganization of resources to a certain extent, and form the resource sharing for the users of the industry, related industries and institutional users, so as to reduce the cost of obtaining information for the enterprises; improve the construction of intelligent supply chain of enterprises, which can help to improve the transparency of the whole industry, enhance the symmetry of information among enterprises, and improve the cooperation between partners. Symmetry of information between them, and enhance the quality and efficiency of partner selection decisions.
- (2) Increase the construction of enterprise digital infrastructure. Increase the pace of digital infrastructure construction such as sensor terminals, big data centers, artificial intelligence, cloud computing and other digital infrastructures in the regions where manufacturing enterprises are located, so as to provide the necessary communication technology conditions and information communication guarantee for the digital participation of enterprises. At the same time, digital infrastructure construction embeds digital technology into enterprise business decision-making, and enhances information symmetry and realizes the rapid response of the main body through the mining and processing of big data.
- (3) Increase the investment of digital transformation construction resources and process management. First, it is necessary to initially establish a reliable intelligent management mechanism, including the initial establishment of a reliable management process, the initial introduction of reliable methods and the establishment of a reliable information system, as well as the cultivation of intelligent talents. Secondly, the improvement of intelligent management mechanism, the in-depth application of intelligent tools and methods, and the expansion of the depth and breadth of intelligent work management. Finally, the formation of a self-improvement mechanism to ensure the continuous improvement of service quality.

7. RESEARCH FINDINGS AND INNOVATIVE VALUE

7.1. Conclusions of the study

Digital intelligence transformation is the key for manufacturing supply chain to gain global competitive advantage, while the scientific nature of chain partner selection and efficient allocation of service resources play a pivotal role in the high-quality development of manufacturing industry. This paper takes the manufacturing secondary supply chain as the research object, considers the influence of service quality on partner selection, proposes the decision-making mechanism of manufacturing supply chain partner selection based on QoS, and explores the evaluation model of supply chain partner matching under the three modes of unilateral decision-making, bilateral decision-making, and optimization of bilateral decision-making, and then explores the differences in matching efficiency and stability of the different decision-making modes of supply chain partner selection in the context of traditional manufacturing and digital and intellectual transformation. The main work and conclusions of the study are as follows:

- (1) A QoS-based manufacturing supply chain partner selection decision-making mechanism is proposed. According to the conceptual-behavioral model, the mechanism of bilateral matching is analyzed with service quality

as the measurement standard. The study shows that the decision-making mechanism of manufacturing supply chain partner selection is a process in which the decision-making body, considering decision-making influencing factors comprehensively, ranks the service quality characteristics of partners according to the QoS standard of service quality and makes a decision on selection based on matching satisfaction.

- (2) Construct manufacturing supply chain QoS evaluation model. From the four dimensions of cooperation cost, product quality, reliability and credibility to build QoS evaluation index system, designed unilateral decision-making, bilateral decision-making, bilateral decision-making optimization of three modes of supply chain partner matching evaluation model. The study shows that: taking QoS as the evaluation standard of supply chain heterogeneous partner matching, bilateral matching considering both parties' preferences can obtain higher matching completion and greater satisfaction; and the G-S algorithm can provide an effective basis for supply chain heterogeneous partner matching, which in turn improves the overall performance of the supply chain.
- (3) Explore the differences in matching efficiency and stability of different supply chain partner selection decision-making modes under two scenarios of traditional manufacturing and digitalization transformation. The study shows that: QoS under digital empowerment has a higher level of QoS score than that under the condition of not considering digitalization; bilateral decision making and bilateral decision optimization have a higher degree of match completion than unilateral decision making; bilateral decision optimization reduces the QoS difference between enterprises under the influence of digitalization, and thus decision satisfaction is reduced.

7.2. Innovative value

- (1) Research method innovation. Breaking through the limitations of unilateral decision-making of traditional supply chain partner selection, taking QoS as an important basis for partner selection, considering multiple influencing factors of service quality of heterogeneous subjects, and combining with the trend of digital and intellectual transformation, constructing a bilateral matching evaluation index system and an evaluation model for manufacturing supply chain, which is not only an innovation of the perspective of previous supply chain partner selection, but also an enrichment and supplementation to the method of supply chain partner selection.
- (2) Research perspective innovation. In the past, the decision analysis of partner selection only considered the subject's own willingness to choose from the perspective of a single subject, and rarely involved the matching willingness of the selected party. This study takes QoS as an important influencing factor of partner selection, through comprehensive consideration of the subject's willingness of the manufacturer and the supplier, takes the QoS evaluation results of the supplier and the manufacturer as the basis for decision-making, and applies the G-S algorithm to design the bilateral matching decision analysis process to optimize the partner selection decision, in order to maximize the satisfaction of the decision-making after matching.
- (3) Research content innovation. General equipment manufacturing industry as a research sample, through data collection and model analysis, verify that the matching mechanism and decision-making model designed in this paper has strong practicability, which not only provides a method for partner selection of manufacturing supply chain under intelligent manufacturing, but also provides a theoretical basis for reducing the supply chain loss brought by replacing the partner, and then improve the overall performance of the supply chain.

Of course, this study has some limitations. This study takes manufacturers and suppliers in the secondary supply chain as the research object, and does not consider the matching mechanism between distributors and consumers in the supply chain, which can be further explored in this direction in the future; in the acquisition of data, this paper mainly takes manufacturers and suppliers in the manufacturing supply chain as the source of sample data, and the future research can also study the partner matching between supply chains of different industries from the perspective of cross-industry and cross-field, in order to meet the diversified development needs. In addition, this paper uses the G-S algorithm in the decision-making model of bilateral matching, and

the algorithm can be optimally designed for multi-subject matching in the future to improve the scope of application of the algorithm.

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