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# Service Satisfaction Evaluation of Customer Preference-Driven Public Warehousing Product Service Systems for Small- and Medium-Sized Enterprises in an Industrial Park

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**ABSTRACT** Facing fierce market competitions and fast technological transformation, manufacturing enterprises eagerly aspire to cut down investments in non-core businesses with the low return such as logistics, warehousing, and machine maintenance. In the context of service-oriented manufacturing (SOM), these non-core businesses are expected to be undertaken by third-party service providers in a centralized product + service manner. Supported by SOM principles, public warehousing product-service system (PW-PSS) is defined as integration of public warehouses and related warehousing services (e.g., raw material purchasing, work-in-progress storing/sorting/monitoring, and finished products packaging/distribution) for different manufacturing enterprises in an industrial park (IP). PW-PSS especially benefits for small- and medium-sized enterprises (SMEs) who are suffering from a heavy investment and management burden of self-built warehouses. To well operate the PW-PSS, third-party service providers must improve the service satisfaction degree of customers (i.e., manufacturing enterprises) to attract their continuous cooperation. This paper proposes a service satisfaction evaluation (SSE) method considering customer preferences to ensure the PW-PSS solutions more reliable and reasonable. First, the standard impact loss method is adopted to determine the initial weights of SSE indexes, and then the Kano model is used to adjust the above weights based on the consideration of customer preferences. Second, according to whether an SSE index is profit-oriented or cost-oriented, a positive or negative distance is obtained based on a distance average solution method. Finally, an example is given to verify the proposed method. It is expected that SSE can provide a decision-making basis for SMEs in an IP to choose optimal PW-PSS solutions.

**INDEX TERMS** Customer preference, product service system (PSS), public warehouse, service-oriented manufacturing (SOM), service satisfaction evaluation (SSE).

## I. INTRODUCTION

Today's manufacturing industry is facing individualized customer requirements, high labor cost, and low profit ratio. Servitization that combines product manufacturing with various product-related services has been put in an important position to deal with the above trends [1]. Service-oriented manufacturing (SOM) has been listed as a vital strategy in many countries' plans and initiatives to upgrade the manufacturing industry [2]. Product-service system (PSS), as a key component of SOM, is defined as a new business model that integrates products with certain services to generate comprehensive product-service solutions for customers [3]. PSS can endow the products with more added value and help to achieve a higher customer satisfaction degree. It has been widely applied in industrial products

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(e.g. machine tools [4], cutting tools [5], high energy-consuming equipment [6], aerospace [7]) and consumer products (e.g. autonomous vehicle [8], mobile phone [9]).

As an important component of the manufacturing industry, warehouses store raw materials, work-in-progress (WIP), finished products, and assistant tools. Considering that warehouse construction and management needs a big and continuous investment of capitals, workers, places, and information systems, thus the return on investment (ROI) is relatively low for manufacturing enterprises to build and manage warehouses by themselves, especially for the small and medium-sized enterprises (SMEs) because their business may change along with the market trend. For example, parts in different outsourcing orders may differ in sizes and shapes, thus their warehouses need to be reconfigured to adapt to the changing orders, which will cause extra costs. In this situation, third-party warehouses and services are urgently required by the SMEs in an industrial park (IP) to sharply cut down their warehousing cost [10].

To deal with this requirement, PSS is introduced into the warehousing area. SMEs are viewed as customers, public warehouses are viewed as products provided to customers, and warehousing services such as storing, monitoring, sorting, packaging, and even raw material procurement and goods distribution are bundled with the products. On that basis, a new warehousing service model called Public Warehousing Product Service System (PW-PSS) can be generated, the organizational structure of which is described in Figure 1. PW-PSS is operated by a third-party service provider in a centralized and uniform manner [11]. Compared with the traditional warehousing service models, PW-PSS has the following advantages:

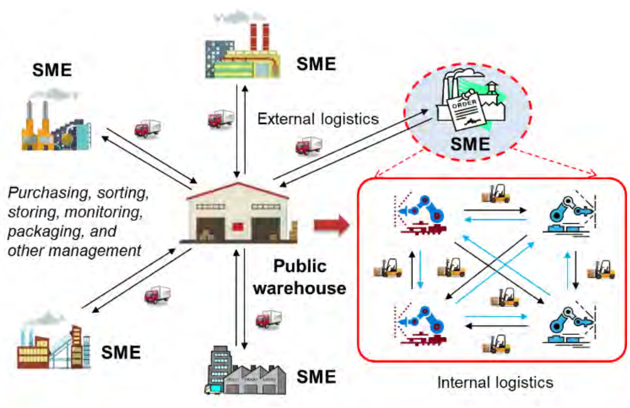


**FIGURE 1. PW-PSS model. Public warehouses and the corresponding product-services are provided by third-party providers to SMEs.**

(1) Global optimum of warehousing cost: In an IP, there are many SMEs troubled with a heavy burden of warehouse management and maintenance. By applying the PW-PSS, the lifecycle design, investment, and reconfiguration of public warehouses are operated by the third-party service providers, which will alleviate the burden of SMEs on the fixed assets investment. For the PW-PSS providers, they can benefit from a scale economy effect by operating the same public warehouses to serve for different SMEs. Therefore, SMEs and PW-PSS providers can reach a global win-win situation where SMEs can cut down warehousing cost and PW-PSS providers can achieve profits.

(2) Reconfigurable and continuous warehousing solution: SMEs may change their businesses along with the market trend. The corresponding warehousing services should be reconfigured accordingly, which needs continuous investment. For the SMEs, they only want to achieve directly a low-cost warehousing solution no matter who owns and operates the warehouses. PW-PSS is exactly designed for this reason. In the PW-PSS, third-party service providers will continuously reconfigure the public warehouses and services to satisfy long-term and dynamic requirements of SMEs. In this situation, SMEs in the IP can achieve a reconfigurable and continuous warehousing solution from the PW-PSS providers to support their production business.

(3) Tight collaboration among SMEs: The materials, finished parts, and products from different SMEs are always highly related. For example, part A from enterprise A and part B from neighborhood enterprise B need to be delivered to enterprise C for assembly. Traditionally, enterprise A and B will store and deliver part A and B separately. In the PW-PSS, part A and B are stored in the same warehouse and they are delivered by the same truck, which can cut down the operational costs. Therefore, the tight relationship between part A and B can be used for warehousing and transportation optimization. This is another benefit of applying the PW-PSS. Except for the inter-enterprise warehousing services, PW-PSS can also provide intra-enterprise production logistics services for SMEs, as shown in the red box in Figure 1. In this situation, PW-PSS providers will help to optimize the transportation of WIP and assistant tools among different workstations and provide related services. Furthermore, based on the PW-PSS, information of raw materials, WIP, finished products, and assisted tools are centrally managed and shared among SMEs to facilitate their collaborative production operations.

In the PW-PSS, the evaluation of SMEs' service satisfaction on the warehousing solutions is a key problem for third-party PW-PSS providers to make decisions on the design and construction of public warehouses, together with the configuration, composition and lifecycle management of warehousing services. It is a multi-attribute and multi-objective evaluation problem that should consider SMEs' preferences. The reason is that different SMEs may propose different requirements on the storage space, duration time, goods distribution strategy, and others. To deal with this problem, customer preferences data should be accurately analyzed for the configuration and operations management of PW-PSS. Meanwhile, a variety of PW-PSS warehousing solutions should be designed for SMEs to choose.

In this paper, a method for service satisfaction evaluation (SSE) is proposed. In this method, an SSE index set is defined according to the requirements of SMEs. The initial weight

**TABLE 1. Comparison of weight determination methods.**

| Types | Classical Methods | Advantages | Disadvantages |
|---|---|---|---|
| Subjective weight determination methods | Survey Method [16] | Experts can reasonably determine the ranking of attribute weights based on actual decision-making problems and their own experience, so as to avoid the situation that the weights are contrary to reality. | The evaluation results are very subjective, which increases the burden of decision makers' analysis and has strong subjectivity in practical application. |
| | Analytic Hierarchy Process [17] | | |
| | Binomial Coefficient Method [18] | | |
| | Decision Alternative Ratia Evaluation [19] | | |
| | Least Square Method [20] | | |
| Objective weight determination methods | Principal Component Analysis [21] | According to the objective relationship between the original data to determine the weight, there is a strong theoretical basis for mathematics. | Without considering the subjective intentions of decision-makers, the calculation is complicated and the generality and participation of decision-makers are poor. |
| | Entropy Method [22] | | |
| | Deviation and Mean Square Deviation Method [23] | | |
| | Multi-objective Programming [24] | | |
| Combinatorial weight determination methods | Multiplication Integration Method [25] | Weights are determined based on the objective relationship between evaluation index data and the subjective decision-making evaluation index of decision makers. | It is difficult to determine the distribution of weights by combining subjective and objective methods, and the operation and application are poor. |
| | “Addition” Integration Method [26] | | |

of each SSE index is calculated by using a standard impact loss method and then adjusted by using the Kano model considering customer preferences. A distance average solution method is further used to evaluate the PW-PSS warehousing solutions provided by the PW-PSS provider. Based on the SSE evaluation results, SMEs will select an optimal solution. Finally, an industrial case is studied to verify the proposed method.

The main contribution of this paper include: (1) propose a PW-PSS model for SMEs to cut down their warehousing costs by sharing public warehouses and services provided by third-party service providers; (2) introduce a customer preference-driven SSE method for SMEs to select an optimal PW-PSS warehousing solution.

The rest of this paper is organized as follows. Section II presents a brief review of PSS/PW-PSS and customer demand analysis. Section III proposes the main procedures of SSE to evaluate the PW-PSS warehousing solutions. Section IV studies an industrial case to verify the proposed model and method. Finally, discussions and conclusion are given in Section V and VI, respectively.

## II. LITERATURE REVIEW

### A. PSS AND PW-PSS

PSS that integrating products with services has been applied in various industrial areas. Mont built a theoretical framework for PSS and identified three main uncertainties for implementing PSS [12]. Zhu et al. combined CNC machine tools with various implementation services to provide an integrated machining solution for enterprises [4]. Sun et al. proposed a cutting-tool PSS and discussed a cutting-tool service scheduling problem to ensure correct cutting-tools can be delivered to correct enterprises with high efficiency and low cost [5]. Zhang *et al.* explored a PSS framework for high energy-consuming equipment (HECE) and proposed an evaluation tool which combines life cycle assessment and life cycle costing to support the development of PSS for HECE [6]. Hernandez-Pardo *et al.* studied the sustainable PSS involving SMEs and explored the organizational aspects that can contribute to developing sustainable PSS in SMEs [13]. Maleki *et al.* discussed an ontology-based framework enabling smart PSS and defined an embedded sensing system of industrial machinery to provide customized services of smart PSS [14]. Li *et al.* proposed a bi-level coordinated optimization framework to support PSS configuration design, in which upper-level optimization is built for service configuration and lower-level optimization is formulated for product configuration [15]. Referring to the PW-PSS, Cao and Jiang studied the modeling of warehouse service capability maturity and resource configuration for PW-PSS based on an Analytical Target Cascading method [10]. Zhang et al. discussed a distributed warehouse configuration scheme of PW-PSS according to different requirements of manufacturing and service enterprises [11].

### B. CUSTOMER DEMAND ANALYSIS

Aiming at customer demand analysis, many methods can be used to determine the weights of different demands. According to the data source of evaluation weights, the determination methods can be divided into subjective weighting method, objective weighting method, and combinatorial weighing method. Specific representative methods of each type and their advantages/disadvantages are compared in Table 1.

For example, quality function deployment (QFD) is a customer-oriented product development tool for turning customer demands into engineering characteristics to achieve higher product performance and customer satisfaction [27,28]. A linear goal programming approach was used to determine the relative importance weights of customer requirements in QFD [29]. However, the weight of the evaluation indexes mainly considers the importance of customer demands, and seldom takes into account the satisfaction degree of customer preferences. For Kansei quality of the product, evaluation grid method and regression analysis method are used to evaluate the customer preference [30]. A way to measure the relative indifference between different characteristics called Fuzzy Indifference Degree (FID) is proposed to select the product closest to their preferences [31]. Based on the preference order from the economic theory, Nishino used Frequent Shopper Program data of a large shopping mall in Japan to optimize the variety of shops, which can satisfy various customer preferences at a reasonable profit level [32]. Fuzzy regression methods have commonly been used to develop consumer preference models, which link the engineering characteristics with consumer preferences regarding a new product. The consumer preference models provide a platform, whereby product developers can decide the engineering characteristics in order to satisfy consumer preferences prior to develop the products. Recent work shows that these fuzzy regression methods are commonly used to model customer preferences. However, these approaches have a common limitation that they seldom investigate an appropriate polynomial structure, which includes significant regressors with only significant engineering characteristics. Besides, they cannot generate interaction or high-order regressors in the models. The inclusion of insignificant regressors is not an effective approach when developing the models. Exclusion of significant regressors may affect the generalization capability of the consumer preference models [33]. Kano model is an efficient tool to solve the problem of customer demands classification and preference ranking [34]. Based on the impact of customer demands on its satisfaction, it reflects the non-linear relationship between service performance and customer satisfaction.

### C. RESEARCH GAP AND OUR NOVELTY

The research gap can be analyzed from the following twofold:

(1) From section II-A, we can conclude that PSS has inherent advantages of low cost, high sustainability, and high customer satisfaction. Although it has been widely applied in some industrial areas, only two to three literature discussed the application of PSS in the public warehousing area. Besides, they only studied the service configuration and modeling of PW-PSS. The service satisfaction evaluation considering customer preferences has never been discussed in the PW-PSS.

(2) From Section II-B, we can conclude that there are a lot of methods to transfer customer requirements into engineering characteristics and analyze the importance of each customer requirement. It is of great importance to evaluate the service satisfaction of PW-PSS warehousing solutions, especially when considering the customer preferences. However, there is little work devoted to it. In the PW-PSS, due to different SMEs in the IP have different customer preferences in storage time, storage space, distribution strategy, and others, efficient methods to combine customer preferences with SSE should be developed to recommend optimal public warehousing solutions. However, the reviewed methods are either not available or too complex to deal with that.

This paper deals with the SSE method of PW-PSS considering customer preferences, introduces the standard impact loss method to determine the initial weights of SSE indexes, and applies the Kano model to adjust the initial weights. A distance average solution method is further adopted to evaluate the given PW-PSS warehousing solutions. Therefore, the novelty of this paper exists in (1) propose a PW-PSS model for SMEs in an IP to achieve a win-win situation; (2) propose an SSE method considering customer preferences to evaluate the PW-PSS warehousing solutions; (3) study an industrial case to verify the proposed model and method.

## III. SSE OF PW-PSS WAREHOUSING SOLUTIONS

### A. MAIN PROCEDURES

The main procedures to evaluate the service satisfaction of PW-PSS warehousing solutions are described in Figure 2.

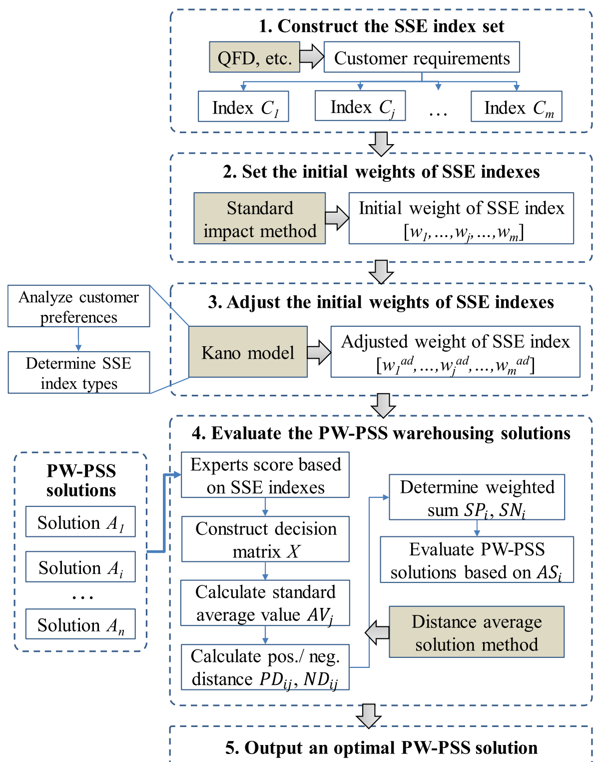


**FIGURE 2.** Main procedures of SSE to evaluate the PW-PSS warehousing solutions.

(1) by analyzing various customer requirements, an SSE index set $C = \{C_1, C_2, \ldots, C_m\}$ is constructed.

(2) The standard weight $w_j$ of $j$-th SSE index $C_j$ is determined by adopting a standard impact loss method, and the standard weight set $w = \{w_1, w_2, \ldots, w_m\}$ is initialized.

(3) According to the customer preferences, the Kano model is used to adjust the initial weight of each SSE index as the adjusted weight $w_j^{ad}$, forming an adjusted weight set $w^{ad} = \{w_1^{ad}, w_2^{ad}, \ldots, w_m^{ad}\}$.

(4) Third-party provider proposes a variety of PW-PSS warehousing solutions $A = \{A_1, A_2, \ldots, A_n\}$ according to the various customer requirements. The domain experts are invited to score the warehousing solutions $A$ according to the SSE index set $C$. Thereafter, a decision matrix $X$ is constructed, the average value $AV_j$ of each SSE index $C_j$ for a warehousing solution $A_j$ is calculated, and the positive or negative distance average value $AV_j$ of each $C_j$ is calculated according to the type of SSE index (*i.e.* profit-oriented or cost-oriented). Here, profit-oriented SSE indexes are defined as a kind of indexes that highly relate to achieving profits, while cost-oriented SSE indexes are defined as a kind of indexes that will output costs.

(5) The weighted sum of positive or negative distances of SSE indexes is used to evaluate each warehousing solution, and the optimal solution that satisfies the customer preferences will be achieved.

### B. CONSTRUCT THE SSE INDEX SET

It is known that PW-PSS provider can provide a series of warehousing services to SMEs in the IP such as purchasing, sorting, storing, monitoring, packaging, and distribution of raw materials/WIP/finished products/tools. SMEs can choose flexibly one warehousing service or a set of warehousing services according to their actual requirements. Therefore, SSE indexes can be classified into four types, *i.e.*, storage space satisfaction, storage time satisfaction, cooperation mode satisfaction, and distribution mode satisfaction. Each type of SSE indexes can be decomposed into more specific ones for evaluating the warehousing services satisfaction degree.

### C. SET THE INITIAL WEIGHT OF SSE INDEXES

First, we maximize the minimum standard value to reach the optimum, as described in Eq. (1).

$$\bar{r_{ij}} = \frac{min\left(r_{ij}\right)_i}{r_{ij}} \tag{1}$$

where $r_{ij}$ denotes an element in the matrix; $\left(r_{ij}\right)_i$ denotes the maximum value of the $i$-th column in the matrix.

Set a new matrix as $X = \left\|x_{ij}\right\|$. The maximum value of each SSE index (*i.e.,* the maximum value in each column of matrix $X$) can be denoted as $x_j = max\left(x_{ij}\right)_j = x_{k_j j}$, where $k_j$ is the row number of the largest element in the $j$-th column.

Square matrix $A = \left\|a_{ij}\right\|$ is composed of the value $x_{k_j j}$ of the $k_j$-th row of matrix $X$ and the maximum value of the corresponding $j$-th index,*i.e.,* $a_{jj} = x_j$, $a_{ij} = x_{k_j j}$, $\forall i, j \in (1, 2, \ldots n)$, where $n$ denotes the total amount of SSE indexes, which means that the maximum value of all SSE indexes can be obtained from the main diagonal line of square matrix $A$. The $i$-th row of square matrix $A$ denotes the elements of the $k_j$-th row of matrix $X$. It can be noted that square matrix $A$ has the same amount of rows as matrix $X$ because the maximum values of the various SSE indexes are found in the same row, and they belong to the same warehousing solution.

Therefore, the significance relative loss matrix $P = \left\|p_{ij}\right\|$ of the SSE indexes is shown in Eq. (2).

$$p_{ij} = \frac{x_j - a_{ij}}{x_j}, \quad i, j = 1, 2, \ldots n \tag{2}$$

where the element $p_{ij}$ of matrix $P$ denotes the decreased significance of the $j$-th SSE index when the $i$-th SSE index is selected as the best one. Obviously, $p_{ii} = 0$. Based on the Pareto principle, the above matrix shows how much significance the SSE indexes have lost in a certain warehousing solution.

The weight set $q = (q_1, q_2, \ldots, q_m)$ can be obtained from $Fq = 0$. Matrix $F$ can be denoted as:

$$F = \begin{pmatrix} -\sum_{i=1}^{n} p_{i1} & \cdots & p_{1n} \\ \vdots & \ddots & \vdots \\ p_{n1} & \cdots & -\sum_{i=1}^{n} p_{in} \end{pmatrix} \tag{3}$$

Therefore, the element $p_{ij}$ in the significance relative loss matrix $P$ of SSE indexes is close to zero when there is no significant difference in the value of SSE indexes. Instead, it suggests that SSE indexes have a great influence on the selection of warehousing solutions when the weights of SSE indexes increase. Of course, all the relative losses and total losses are equal to zero when the value of the SSE index is the same in all alternatives.

### D. ADJUST THE WEIGHT OF SSE INDEXES

In the PW-PSS, different customers have different demands and preferences for warehousing services. Considering the customer preferences in the SSE model is conducive to further improve comprehensive customer satisfaction. Four types of demands in Kano model, *i.e.,* exciting demand (A), expectation demand (O), basic demand (M), and irrelevant demand (I), are used to denote the customer demands and preferences, and the maximum frequency rule is used to determine the type of SSE indexes. In the Kano model, exciting demand (A) should be considered first, followed by expectation demand (O) and basic demand (M), and finally irrelevant demand (I). Therefore, in order to better reflect the customer preferences and meet customer demands, it is essential to adjust the initial weight of SSE indexes. Set the adjustment parameters of SSE indexes' weight as $\xi = (\xi_1, \xi_2, \ldots, \xi_n)$. According to our expert's experience, the values of $\xi_j$ corresponding to the four types A, O, M, and I are set as 4, 2, 1, and 0, respectively. The adjusted weight $\omega_j^{ad}$ of SSE indexes can be obtained as:

$$\omega_j^{ad} = \frac{\omega_{j\xi_j}}{\sum_{j=1}^{n} \omega_{j\xi_j}} \tag{4}$$

### E. SSE BASED ON A DISTANCE AVERAGE SOLUTION METHOD

The distance average solution method is adopted to evaluate the service satisfaction of warehousing solutions provided by third-party PW-PSS provider. This method is similar to the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. In the TOPSIS, the distance between the evaluation object and the optimal solution (or the worst solution) is ranked. If the evaluation object is closest to the optimal solution and farthest away from the worst solution, it is optimal. Otherwise, it is not optimal. The SSE index values in the optimal solution reach the optimal value of each SSE index, and the SSE index values of the worst solution reach the maximum difference of each SSE index. That is to say, the best warehousing solution is selected by calculating the positive or negative distance from the ideal solution.

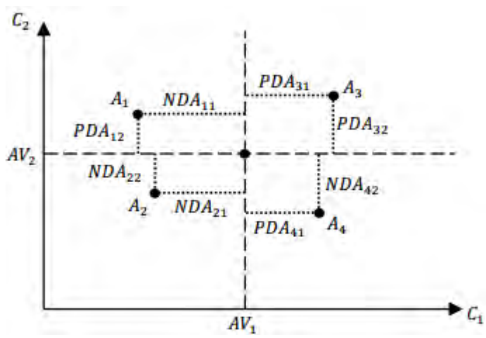


**FIGURE 3.** An example to analyze the PDA and NDA.

Here, the selection of the best solution is related to the distance from the average solution (AV). There is no need to calculate the optimal solution and the worst solution in the proposed method. Specifically, two measurements are used to evaluate the average distance value: (1) positive distance from the average (PDA), and (2) negative distance from the average (NDA). Figure 3 gives an example to explain the PDA and NDA. There are four alternative solutions ($A_1$, $A_2$, $A_3$, $A_4$), two EES index ($C_1$, $C_2$), and two average solutions ($AV_1$, $AV_2$). The alternative solution with positive PDA value is the optimal solution, i.e. $A_3$, the alternative solution with negative NDA value is the worst solution. While for $A_1$ (with positive PDA value and negative NDA value) and $A_4$ (with negative PDA value and positive NDA value), they will be evaluated further.

The SSE of the alternatives is based on the higher PDA value and the lower NDA value. At the same time, the distance average solution method is optimized considering the customer demands and preferences. The initial weight of each SSE index is optimized by using the adjusted weight in the Kano model, which makes the solution more objective and accurate. The specific steps are described as follows:

(1) Assume that there are $n$ warehousing solutions in a PW-PSS $A_i$ $(i = 1, 2, \ldots, n)$, and each solution corresponds to $n$ SSE index set $C = \{C_1, C_2, \ldots, C_m\}$, where $C_m$ denotes an SSE index. The customer adopts a deterministic value assignment method (1, 3, 5, 7, 9) to score the satisfaction degree of each solution according to SSE index. Among them, 1, 3, 5, 7, and 9 denote "very dissatisfied", "unsatisfied", "general", "satisfied", and "very satisfied". The SSE index value $x_{ij}$ of all solutions constitute the matrix $X$.

$$X = [X_{ij}]_{m\times n} = \begin{pmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{nm} \end{pmatrix} \tag{5}$$

where $X_{ij}$ denotes the $j$-th SSE index of the $i$-th solution, $i = 1, 2, \ldots n$, $j = 1, 2, \ldots, m$; $n$ denotes the total amount of the warehousing solutions, and $m$ denotes the total amount of SSE indexes.

(2) Calculate the average value $AV_j$ of SSE indexes.

$$AV = [AV_j]_{1*m}, \text{ where } AV_j = \frac{\sum_{i=1}^{n} x_{ij}}{n} \tag{6}$$

(3) According to the type of SSE index (profit-oriented or cost-oriented), the positive distance and negative distance between an SSE index $x_{ij}$ and the average solution value $AV_j$ are calculated.

If the $j$-th SSE index is profit-oriented, it is:

$$PD_{ij} = \frac{max(0, (x_{ij} - AV_j))}{AV_j} \tag{7}$$

$$ND_{ij} = \frac{\max\left(0, \left(AV_j - x_{ij}\right)\right)}{AV_j} \tag{8}$$

If the $j$-th SSE index is cost-oriented, it is:

$$PD_{ij} = \frac{max(0, (AV_j - x_{ij}))}{AV_j} \tag{9}$$

$$ND_{ij} = \frac{max(0, (x_{ij} - AV_j))}{AV_j} \tag{10}$$

where $PD_{ij}$ and $ND_{ij}$ denote the positive and negative distances under the $j$-th SSE index of the $i$-th warehousing solution, respectively.

(4) Determine the weight $w_j$ of SSE index $C_m$.

(5) Adjust the weight of SSE indexes. Using Eq. (4), the adjusted weight $\omega_j^{ad}$ of SSE indexes can be obtained.

(6) Determine the weight sums of all alternatives $PD_{ij}$ and $ND_{ij}$.

$$SP_i = \sum_{j=1}^{m} \omega_j^{adj} PD_{ij} \tag{11}$$

$$SN_i = \sum_{j=1}^{m} \omega_j^{adj} ND_{ij} \tag{12}$$

(7) Normalize the values of $SP_i$ and $SN_i$ of all the alternatives as

$$NSP_i = \frac{SP_i}{maxSP_i} \tag{13}$$

$$NSN_i = 1 - \frac{SN_i}{maxSN_i} \tag{14}$$

(8) Calculate the SSE value of all alternatives.

$$AS_i = \frac{1}{2}\left(NSP_i + NSN_i\right), \quad 0 \le AS_i \le 1 \tag{15}$$

where $AS_i$ is the SSE value of $i$-th warehousing solution.

**TABLE 2.** Details of power pump parts.

| Part items | Types | Numbers | Part items | Types | Numbers |
|---|---|---|---|---|---|
| Pump body | 1016S08C | 1/set | Rear cover | 303 | 1/set |
| Port plate-1 | 1016S08A-101 | 1/set | Bearing | 6203 | 2/set |
| Port plate-2 | 1016S08A-102 | 1/set | Cross-slider | 301 | 1/set |
| Stator | 1016S08A | 1/set | Oil-inlet | GB3452.1-92 | 1/set |
| Rotor | D20-300 | 1/set | Tag | D20-200 | 1/set |
| Blade | D20-302 | 1/set | Sealing ring | GB3452.1-92 | 7/set |
| Spring | D20-312 | 3/set | Retainer ring | 43407 | 3/set |
| Oil-outlet | GB3452.1-92 | 1/set | Screw | GB827-86 2*4 | 2/set |
| Sliding spool | D20-313 | 1/set | Gasket | D20-309 | 1/set |
| Steel-ball seat | D20-308 | 1/set | Washer | GB893.1-86 40 | 4/set |
| Screw plug | 44301 | 1/set | Steel ball | 4.0G200 | 1/set |
| Pressure-valveplug | 1316-311 | 1/set | Shaft | 1016S08C- 301 | 1/set |

Finally, according to the obtained $AS_i$, the given warehousing solutions are ranked, and the solution with the largest $AS$ is selected as the best choice.

## IV. CASE STUDY

The PW-PSS in an automobile IP is taken as an example to verify the feasibility and effectiveness of the proposed methods. This IP focuses on the design, manufacturing, distribution, and after-sale services of automobiles. It has brought together 79 high-tech service-oriented SMEs for automobile's spare parts manufacturing, and three other service-oriented enterprises. Figure 4 shows an explosive view of YB-series power pump in an automotive.

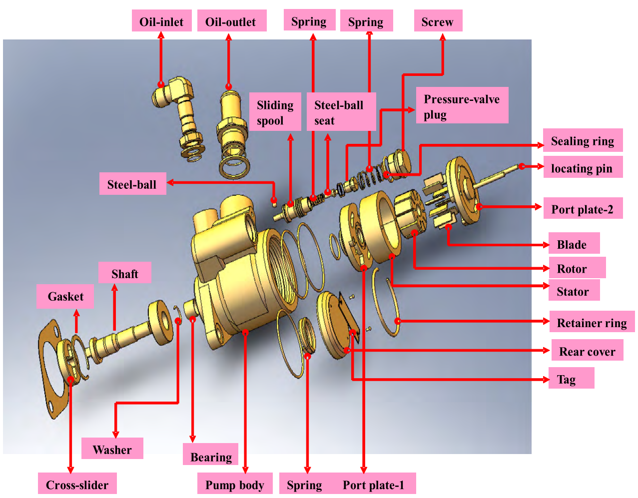


**FIGURE 4.** Explosive view of YB-series power pump in an automotive.

Power pump includes both general parts and non-general parts. Through analysis, we find that bars (20CrMnTi, $120*\Phi40mm$), castings (HT300, $120*120*130mm$), spring, sliding spool, screw plug, bearing, cross-slider, locating pin, sealing ring, retainer ring, nut/screw, gasket, washer, steel ball, pressure valve plug and other parts of the booster pump are general parts. While the pump body and pressure valve plug of the booster pump are non-general parts. Key parts such as stator, rotor, blade, and shaft belong to non-general parts. Specific parts are detailed in Table 2.

Aiming at the warehousing problem of the above parts, PW-PSS provider has provided 8 warehousing solutions $(A_1, A_2, \ldots, A_8)$ for these SMEs, which is shown in Table 3.

The customer demands can be described as: supply demand of general parts $C_1$, leasing demand of non-general parts $C_2$, cooperation time demand $C_3$, dynamic storage space demand $C_4$, and distribution timeliness demand $C_5$. These five parameters are selected to form the SSE index set of PW-PSS warehousing solution alternatives, which are denoted as $C = \{C_1, C_2, C_3, C_4, C_5\}$. According to the evaluation method, the above eight solutions are evaluated. The specific analysis processes are described as follows:

### 1) CONSTRUCT THE EVALUATION MATRIX X

The domain experts use a deterministic value assignment method to rate the service satisfaction degree of each solution relative to each SSE index. Scores 1, 3, 5, 7, and 9 represent different satisfaction values, in which "very unsatisfactory" scores 1 point, "unsatisfactory" scores 3 points, "general" scores 5 points, "satisfactory" scores 7 points, and "very satisfactory" scores 9 points. The higher the score is, the better the solution will be under the SSE index set. The initial evaluation matrix of each solution is established, which is shown in Table 4.

### 2) DETERMINE THE INITIAL WEIGHT $\omega_j$ OF EACH SSE INDEX

Use Eq. (3) to calculate the initial weights of SSE indexes, the results are given in Table 5.

### 3) ADJUST THE WEIGHT OF THE SSE INDEX USING THE KANO MODEL

First, customer preferences data is collected from 50 representative SMEs cooperating with the PW-PSS provider. They are selected for investigation, analysis, and classification statistics. Kano model is used to determine the type of customer preferences, as shown in Table 6.

**TABLE 3. Public warehousing service solution alternatives provided by third-party PW-PSS provider.**

| ID | Description |
|---|---|
| $A_1$ | General parts are not provided, short-term cooperation, non-general parts storage, and third-party distribution. |
| $A_2$ | General parts are provided, short-term or long-term cooperation, non-general parts leasing, and JIT distribution |
| $A_3$ | General parts are not provided, short-term cooperation, non-general parts storage, and third-party distribution |
| $A_4$ | General parts are not provided, short-term or long-term cooperation, non-general parts storage, and JIT distribution |
| $A_5$ | General parts are provided, short-term or long-term cooperation, non-general parts leasing, and third-party distribution |
| $A_6$ | General parts are provided, short-term cooperation, non-general parts storage, and JIT distribution |
| $A_7$ | General parts are provided, short-term or long-term cooperation, non-general parts storage, and JIT distribution |
| $A_8$ | General parts are provided, short-term long-term cooperation, non-general parts storage, and third-party distribution |

**TABLE 4. Evaluation decision matrix X.**

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| $A_1$ | 5 | 7 | 5 | 5 | 3 |
| $A_2$ | 3 | 9 | 7 | 1 | 7 |
| $A_3$ | 7 | 5 | 3 | 3 | 5 |
| $A_4$ | 5 | 3 | 5 | 5 | 3 |
| $A_5$ | 9 | 3 | 3 | 5 | 7 |
| $A_6$ | 7 | 7 | 5 | 3 | 9 |
| $A_7$ | 3 | 5 | 3 | 9 | 7 |
| $A_8$ | 9 | 7 | 5 | 3 | 9 |

**TABLE 5. Values of initial weight of SSE indexes.**

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| $\omega_j$ | 0.157 | 0.279 | 0.091 | 0.195 | 0.203 |

**TABLE 6. Kano classification based on customer preferences.**

| | A | O | M | I | R | Kano Type |
|---|---|---|---|---|---|---|
| $C_1$ | 44 | 62 | 42 | 52 | 0 | O |
| $C_2$ | 60 | 58 | 78 | 4 | 0 | M |
| $C_3$ | 103 | 63 | 22 | 10 | 2 | A |
| $C_4$ | 50 | 40 | 106 | 0 | 4 | M |
| $C_5$ | 50 | 96 | 24 | 30 | 0 | O |

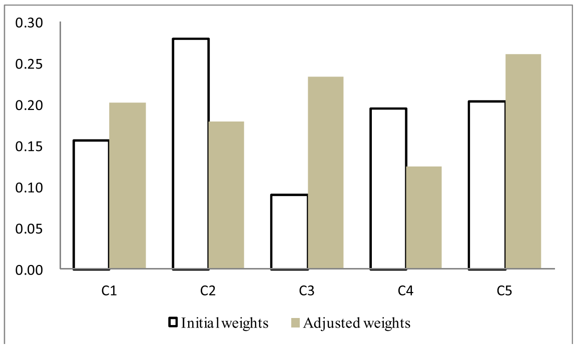


**FIGURE 5. Comparison of initial weights and adjusted weights.**

**TABLE 7. Adjusted values $AV_j$ of SSE indexes.**

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|---|
| $AV_j$ | 6.00 | 5.75 | 4.50 | 4.25 | 6.25 |

**TABLE 8. Values of positive distance (PD) and negative distance (ND).**

| | $PD_1$ | $ND_1$ | $PD_2$ | $ND_2$ | $PD_3$ | $ND_3$ | $PD_4$ | $ND_4$ | $PD_5$ | $ND_5$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $A_1$ | 0.17 | 0.00 | 0.00 | 0.22 | 0.11 | 0.00 | 0.18 | 0.00 | 0.00 | 0.52 |
| $A_2$ | 0.50 | 0.00 | 0.00 | 0.57 | 0.56 | 0.00 | 0.00 | 0.76 | 0.12 | 0.00 |
| $A_3$ | 0.00 | 0.17 | 0.13 | 0.00 | 0.00 | 0.33 | 0.00 | 0.29 | 0.00 | 0.20 |
| $A_4$ | 0.17 | 0.00 | 0.48 | 0.00 | 0.11 | 0.00 | 0.18 | 0.00 | 0.00 | 0.52 |
| $A_5$ | 0.00 | 0.50 | 0.48 | 0.00 | 0.00 | 0.33 | 0.18 | 0.00 | 0.12 | 0.00 |
| $A_6$ | 0.00 | 0.17 | 0.00 | 0.22 | 0.11 | 0.00 | 0.00 | 0.29 | 0.44 | 0.00 |
| $A_7$ | 0.5 | 0.00 | 0.13 | 0.00 | 0.00 | 0.33 | 1.12 | 0.00 | 0.12 | 0.00 |
| $A_8$ | 0.00 | 0.50 | 0.00 | 0.22 | 0.11 | 0.00 | 0.00 | 0.29 | 0.44 | 0.00 |

Second, the initial weights of the SSE indexes are adjusted by using Eq. (4). After determining the Kano type of each SSE index, the adjustment coefficients corresponding to each type are selected to determine the final weight $\omega_j^{ad}$ of each SSE index. The comparison of the adjusted weight and the initial weight of SSE indexes are described in Figure 5.

#### 4) CALCULATE THE AVERAGE VALUE $AV_j$ OF SSE INDEXES

Calculate the average value $AV_j$ according to Eq. (6), as shown in Table 7.

#### 5) CALCULATE THE POSITIVE AND NEGATIVE DISTANCE AVERAGE SOLUTION

According to the operation effect of PW-PSS, the supply demand of general parts ($C_1$) and the leasing demand of non-general parts ($C_2$) are the cost-oriented evaluation indexes. cooperation time demand ($C_3$), dynamic storage space demand ($C_4$), distribution timeliness demand ($C_5$) are the profit-oriented evaluation indexes.

Eqs. (7) ∼ (10) are used to calculate the positive distance and negative distance of an SSE index from the average solution. The results are given in Table 8.

#### 6) NORMALIZE THE SP AND SN FOR ALL ALTERNATIVES

Use Eqs. (13) ∼ (14) to normalize the SP and SN values for all alternatives, which are described in Table 9.

**TABLE 9.** Values of $SP_i$, $SN_i$, $NSP_i$, $NSN_i$, $AS_i$, and solution ranking considering customer preferences.

| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ | $A_8$ |
|---|---|---|---|---|---|---|---|---|
| $SP_i$ | 0.0826 | 0.2634 | 0.0233 | 0.1685 | 0.1398 | 0.1406 | 0.2956 | 0.1406 |
| $SN_i$ | 0.1751 | 0.1970 | 0.2000 | 0.1357 | 0.1782 | 0.1100 | 0.0772 | 0.1766 |
| $NSP_i$ | 0.2794 | 0.8910 | 0.0787 | 0.5700 | 0.4727 | 0.4756 | 1.0000 | 0.4908 |
| $NSN_i$ | 0.1245 | 0.0149 | 0.0000 | 0.3214 | 0.1059 | 0.4502 | 0.6139 | 0.1168 |
| $AS_i$ | 0.2019 | 0.4529 | 0.0394 | 0.4457 | 0.2893 | 0.4629 | 0.8070 | 0.3038 |
| Ranking | 7 | 3 | 8 | 4 | 6 | 2 | 1 | 5 |

**TABLE 10.** Values of $SP_i'$, $SN_i'$, $NSP_i'$, $NSN_i'$, $AS_i'$, and solution ranking without considering customer preferences.

| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ | $A_8$ |
|---|---|---|---|---|---|---|---|---|
| $SP_i'$ | 0.0718 | 0.1538 | 0.0363 | 0.2057 | 0.1934 | 0.0993 | 0.3575 | 0.0993 |
| $SN_i'$ | 0.1669 | 0.3072 | 0.1539 | 0.1056 | 0.1085 | 0.1446 | 0.0300 | 0.1964 |
| $NSP_i'$ | 0.2008 | 0.4302 | 0.1014 | 0.5754 | 0.5409 | 0.2778 | 1.0000 | 0.2778 |
| $NSN_i'$ | 0.4566 | 0.0000 | 0.4992 | 0.6564 | 0.6467 | 0.5293 | 0.9023 | 0.3606 |
| $AS_i'$ | 0.3287 | 0.2151 | 0.3003 | 0.6159 | 0.5938 | 0.4036 | 0.9511 | 0.3192 |
| Ranking | 5 | 8 | 7 | 2 | 3 | 4 | 1 | 6 |

#### 7) CALCULATE THE EVALUATION VALUE OF ALL ALTERNATIVES

Using Eq. (15), the final evaluation value $AS$ of the eight alternatives provided by PW-PSS provider is obtained ($0 \leq AS_i \leq 1$), and the results are given in Table 9.

From the above results, it can be concluded that 8 alternatives are ranked as $A_7 > A_6 > A_2 > A_4 > A_8 > A_5 > A_1 > A_3$. Therefore, considering the customer preferences, the warehousing solution $A_7$ is suggested as the best solution.

## V. DISCUSSIONS

We compare the results considering customer preferences with that without considering customer preferences to verify our proposed method is reasonable and reliable. Without considering customer preferences, the initial weight instead of the adjusted weight of SSE indexes are used to evaluate the service satisfaction of PW-PSS. The initial weights of the SSE indexes are shown in Table 5 and Figure 5. The distance average solution method is also used to evaluate the 8 warehousing solutions ($A_1 \sim A_8$) provided by the third-party PW-PSS provider. In the calculation processes, the values of $SP_i'$, $SN_i'$, $NSP_i'$, $NSN_i'$, and $AS_i'$ are described in Table 10, taking the initial weight of SSE indexes as input parameters. On that basis, the ranked alternatives result is achieved as $A_7 > A_4 > A_5 > A_6 > A_1 > A_8 > A_3 > A_2$.

It can be seen from the results that the solutions ranking without considering customer preferences differs from that considering customer preferences. To compare which will win more customer satisfaction, we invite SMEs in the IP to implement the provided 8 solutions in different time periods (i.e. 10 days for each solution), keeping other experiment conditions the same, and we investigate the SMEs to score the service satisfaction degree of each solution in a questionnaire. Through weighted average value calculation, we find the final scores are highly in accordance with the solutions ranking result considering customer preferences in Table 9. Only the sequence of $A_2$ and $A_6$ is reversed. It can be explained because the SSE value of $A_2$ ($AS_2 = 0.4529$) and $A_6$ ($AS_6 = 0.4629$) are very approximate, the ranking sequence of them may be influenced by dynamic fluctuation and inaccuracy when evaluating the actually implemented service satisfaction.

Therefore, it can indirectly verify the reasonability and reliability of the proposed model and method considering customer preferences. However, this kind of comparative evaluation seems a little subjective because it relies on expert experience and SMEs questionnaire. We will find effective methods in our future work to further verify the proposed model and method more objectively.

## VI. CONCLUSION AND FUTURE WORK

In the context of SOM, we introduced a new warehousing service model called PW-PSS for manufacturing enterprises, especially for the SMEs in an IP. In this paper, PW-PSS is defined as an integrated solution of public warehouses and related warehousing services. PW-PSS model is helpful for cutting down investment and operation costs of non-core warehousing businesses, improving the flexibility and efficiency of warehouse management, and ensuring the continuous and smooth production for SMEs.

In the PW-PSS, the most important thing is to evaluate the service satisfaction of SMEs on the PW-PSS warehousing solutions provided by third-party PW-PSS providers. Based on the analysis of customer preferences, this paper proposed a service satisfaction evaluation (SSE) method in detail and studied an industrial case to verify the proposed method. The main conclusions are drawn as follows:

1) The SSE procedures to evaluate PW-PSS warehousing solutions was constructed. Standard impact loss method was used to determine the initial weights of SSE indexes, and Kano model was used to adjust the above weights to cater to SMEs preferences, which can reduce the subjectivity of the SSE index weights.

2) The positive and negative distances were calculated based on a distance average solution method to evaluate the service satisfaction degree of the provided PW-PSS warehousing solutions. By integrating the SSE indexes with adjusted weights into the PW-PSS warehousing solutions, it can make the SSE process more reasonable and reliable.

Our future work will include: (1) study the corresponding resource scheduling and strategies for the transportation and distribution of raw materials/WIP/products/tools in the IP to reduce logistics cost, and (2) study the service matching and composition method to design the warehousing service packages. Besides, more efficient algorithms should be tried to solve the SSE problem to improve the efficiency of our proposed method.

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