Hindawi
Mathematical Problems in Engineering
Volume 2018, Article ID 9253643, 15 pages
https://doi.org/10.1155/2018/9253643

Research Article

The Application of Fuzzy VIKOR for the Design Scheme Selection in Lean Management

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Received 28 February 2018; Accepted 15 August 2018; Published 10 September 2018

Academic Editor: Ibrahim Zeid

Given that using the same evaluation criteria in group decision making (GDM) may cause solution bias, this research proposes the decision making model using improved fuzzy VIKOR and takes the lean management design scheme selection process in a real estate company as an example to study the way of decision making. Research results are as follows: (1) improved fuzzy VIKOR allows different decision makers to evaluate all schemes with respect to different evaluation criteria systems and, based on this, this research proposes a decision making model which can effectively avoid making decision using the same criteria system; (2) this decision making model is very scientific, as it is not sensitive to the coefficient of selection mechanism, the weight of decision maker, and the weight of evaluation criterion, so the decision results are very stable; (3) the decision making model proposed in this research can effectively obtain the optimal result and avoid suboptimal solution.

1. Introduction

Lean management originates from lean production, the prototype of lean production is Toyota production system (TPS). Lean production theory can work as the guideline of enterprise strategic management [1]. The concept of lean idea proposed by Womack is the basis of lean management, which means to manage various enterprise activities using lean idea [2]. After that, led by manufacturing, multiple industries and sectors bring in lean management around the world. Existing theories and practices have verified that lean management can work in multiple industries to improve production efficiency, reduce production cost, bring enterprise considerable economic income, and improve management innovation ability. The outstanding successes achieved by applying lean management show that lean management is scientific and advanced [3]. During the past decades, lean management has changed the development track of enterprises and provided a new management mode [4].

Lean management is playing a more and more significant role in enterprise management. Multiple enterprises begin to learn lean management and regard lean management as a key way to improve enterprise efficiency. When applying lean management, enterprises should design concrete lean management schemes first. At present, enterprises mainly use the following three methods to design and select lean management schemes: (1) lean management experts design schemes and submit them to managers for decision; (2) lean management experts and managers design schemes jointly; (3) lean management experts guide managers to design schemes. Multiple enterprise managers lack lean management knowledge, so totally depending on managers to design lean management design schemes is quite unusual for enterprises in China. Actually, lean management experts play main roles in lean management scheme design. When designing lean management schemes, lean management experts usually design several lean management schemes and submit them to managers for decision, or they present only one scheme and then seek for opinions of managers to revise the scheme time again. In scheme selection process, it takes a long time to reach a consensus because different managers may apply different criteria to evaluate schemes. Sometimes, scheme will be repeatedly revised in order to weigh the opinions of all managers, which often leads to a suboptimal selection, bringing great discount to the effect of lean management promotion. Therefore, researching on the design scheme selection method in lean management is the basis of improving the effect of lean management promotion.

Lacking scientific method of lean management design scheme selection is the main reason that leads to suboptimal solution. Currently, decision makers mainly select lean management design scheme through discussion, which means subjective judgment is predominant. Selecting lean management design scheme is a typical group decision making problem, which has three main features: (1) different schemes have different advantages, and they cannot be evaluated using the same evaluation criteria system; (2) different decision makers may have different evaluation criteria systems; (3) selecting lean management design scheme is a fuzzy process. Scientifically selecting lean management design scheme must take the above three features into consideration.

In order to solve the problems in selecting lean management design scheme, this research applies fuzzy VIKOR to make a selection from a quantitative perspective and constructs a design scheme selection model in lean management. Main contributions of this research include the following: (1) the design scheme selection model constructed in this research will save time in selecting scheme for enterprise, improve the accuracy of lean management design scheme selection, and provide a way of effectively avoiding suboptimal scheme; (2) this research expands the application range of fuzzy VIKOR method; (3) this research creates a model of design scheme selection in lean management, providing basis for enterprises to select design scheme scientifically in lean management practices.

2. Literature Review

Designing schemes is the beginning of all management activities and the quality of management schemes reflects the management strategy of the enterprise. Designing lean management schemes is the basis of implementing lean management. Whether the schemes are splendid or not will affect the result of lean management implementation. Therefore, scientifically selecting lean management design scheme is the basis of implementing lean management; at the same time, the method of scheme selection is the basis of scientifically selecting lean management design scheme. Existing researches have proposed the following six main methods of scheme selection.

(1) Analytic Hierarchy Process (AHP). Since AHP was proposed by American scholar Saaty in 1970s [5], it has been applied in multiple sectors to solve decision making problems. For example, Yu et al. [6] research on product life cycle schemes selection applying AHP and establish hierarchical structure relation to select optimal design scheme; optimal scheme is obtained through pairwise comparison and comprehensive evaluation. Wang and Chin [7] propose the new data envelopment analysis (DEA) method for priority determination in AHP, helping decision makers choose optimal scheme. Zhu and Xu [8] apply AHP in hesitant group decision making (GDM) process to help with decision making, taking the water conservancy in China as an example, which means to apply AHP in GDM process that has hesitant judgments. When applying AHP, different decision makers hold different opinions on the importance of various elements, so the order of schemes obtained is also different. Therefore, Xie [9] combines covariance matrix and AHP to create a Cov-AHP method; this method can construct judgment matrix using covariance matrix and obtain the only order of scheme through calculation.

(2) Multicriteria decision making (MCDM). MCDM includes multiobjective decision making (MODM) and multiattribute decision making (MADM). MCDM plays an important role in many fields. For example, Medjoudj et al. [10] apply MCDM to help decision makers improve profit and custom satisfaction in electric power company. Given that the risk of credit guarantee products is complex, He and Weng [11] use indeterminate language to describe the weight and attribute value of indexes in product risk evaluation index system, creating the group decision making model of indeterminate language for credit guarantee products. Chou and Ding [12] construct MCDM model to evaluate the service quality and the location choice of transshipment ports. Khasanah et al. [13] apply fuzzy MADM method in major selection at senior high school; research results show that this method can accommodate the presence of uncertainty in decision making, and the accuracy that decision making results are in accordance with the reality is as much as 90%. Büyüközkan et al. [14] apply MCDM method including intuitionistic fuzzy analytic network process, intuitionistic fuzzy decision making trial, and evaluation laboratory; this method can more effectively choose suitable business partner. With the development of Internet technology, many scholars construct web based on intelligence framework to help with decision making. For example, combining case-based reasoning system and MCDM technique to construct the web based on intelligence framework can improve the speed and accuracy of decision making [15]; constructing a web including all MCDM tools can help decision makers to select schemes more quickly and reliably [16].

(3) Case-based decision theory (CBDT). The main idea of CBDT is using previous method to solve current similar decision making problems. CBDT can avoid repetitive decision making, reducing time and cost. Through collecting similar previous cases and calculating the similarity between the target case and previous case, the utility value of the effect brought by previous case implementation can be calculated, and then integrated utility value of every scheme can be calculated [17]. Guilfoos and Pape [18] use CBDT to analyze the cooperative dynamics in prisoner's dilemma, proving that CBDT model is more suitable when it comes to selecting schemes using cooperative dynamic analysis. Studying the relationship between CBDT and ideal point model can reveal previous dependence point or provide reference point, which helps enterprise in product designing and product positioning, providing support for marketing decision [19].

(4) IF-TOPSIS. Intuitionistic fuzzy sets (IFS) are mainly applied to deal with the indeterminacy in decision making process. Technique for order performance by similarity to ideal solution (TOPSIS) can rank evaluation objects through testing the distance between evaluation objects and optimal solution or worst solution; an evaluation object will be the best solution if it is closest to optimal solution and farthest to worst solution. IF-TOPSIS can be used to solve

complex decision making problems with high indeterminacy. In complex decision making problem, IF-TOPSIS can eliminate indeterminacy, making the solution closer to the preference of decision makers [20]. Based on IF-TOPSIS, You et al. [21] study evaluation information combining accurate numbers and languages to help with decision making through simulation study.

(5) Prospect theory (PT). At the beginning, PT is mainly applied in analyzing the decision making under risks [22]. Hu et al. [23] apply value function and decision weighting function to calculate the prospect value of scheme and obtain the order of schemes according to prospect value. Given that the coefficient of evaluation criterion in gray random MCDM is not completely determined, Wang and Zhou [24] propose a decision making method through analyzing examples. Through comprehensively considering the risk preference of decision makers, Hao et al. [25] put forward the multistage random decision making method based on PT. Li et al. [26] combine IFS, PT, and gray correlation degree to solve random decision making problems.

(6) VIKOR. The process of decision making is always faced with problems such as lacking previous experience, lacking specific context of the organization, and having limited quantitative information of alternatives; while VIKOR is able to help decision maker to select an alternative closest to the ideal, assuming compromising is acceptable [27]. Awasthi and Kannan [28] combine fuzzy theory, nominal group technique, and VIKOR and propose the decision making method based on fuzzy NGT-VIKOR. Aghajani et al. [29] propose a method combining TOPSIS and VIKOR to help decision makers prioritize and select optimal alternative.

Above all, combining fuzzy VIKOR and other methods to make decision is the most commonly used. In previous study of fuzzy VIKOR application, the process of rating with respect to evaluation criteria is based on the condition that all experts are using the same evaluation criteria system to evaluate all schemes. However, in realistic process of decision making, various experts may hold different opinions on criteria selection; some criteria are considered to be important by all decision makers, but others are only partially favored. In other words, every decision maker tends to adopt different criteria systems to evaluate all schemes. Consequently, in order to make fuzzy VIKOR better adapted to realistic decision making process, this research proposes the decision making model using improved fuzzy VIKOR, in which different decision makers adopt different criteria systems to evaluate all schemes. At the fifth section of this research, sensitivity analysis is carried out to testify whether the decision making model is stable and scientific.

3. Research Idea and Theoretical Basis

3.1. Research Idea. When applying fuzzy VIKOR in scheme selection, every decision maker is supposed to evaluate all alternatives with the same evaluation criteria system. However, decision makers incline to evaluate schemes with different evaluation criteria systems, due to the differences in professional background among them. This research proposes a scheme selection model using improved fuzzy VIKOR, which allows different decision makers to apply different evaluation criteria systems in scheme selection process. The research idea is shown in Figure 1.

3.2. Scheme Selection Model Using Fuzzy VIKOR

3.2.1. Evaluation Criteria Selection. Before formulating the evaluation criteria system, the objectives of decision making should be made clear first. A comprehensive system of evaluation criterion should referee previous experience and consider the features of objectives at the same time.

3.2.2. Linguistic Variables and Corresponding Fuzzy Number. In scheme selection, the understanding, judgment, intuition, and preference of decision makers are fuzzy, which is difficult to be measured and represented with precise numerical value. Thus, it would be more accurate to represent these linguistic variables with fuzzy numbers. This paper applies the fuzzy VIKOR method based on trapezoidal fuzzy numbers.

When applying fuzzy VIKOR, the weight of evaluation criteria and the weight of alternatives with respect to each criterion are described using linguistic variables firstly. In this research, linguistic variables are divided into 7 levels, which are very low (VL), low (L), fairly low (FL), medium (M), fairly high (FH), high (H), and very high (VH) [30]. The trapezoidal fuzzy number corresponding to linguistic variables is $\widetilde{A}$, which can be defined as $\{(n_1, n_2, n_3, n_4) \mid n_1, n_2, n_3, n_4 \in R; n_1 \le n_2 \le n_3 \le n_4\}$, where n_1 denotes the possible minimum that each linguistic variable corresponds with, n_4 denotes the possible maximum, and n_2, n_3 denote the possible values between n_1 and n_4. The membership function is defined using (1) [30].

$$\mu_{\widetilde{A}}(x) = \begin{cases} \dfrac{x - n_1}{n_2 - n_1}, & x \in [n_1, n_2], \\ 1, & x \in [n_2, n_3], \\ \dfrac{n_4 - x}{n_4 - n_3}, & x \in [n_3, n_4], \\ 0 & \text{Otherwise.} \end{cases} \tag{1}$$

The details and values of n_1, n_2, n_3, n_4 are shown in Figures 2 and 3. The linguistic variables and corresponding trapezoidal fuzzy numbers are shown in Table 1 [30].

3.2.3. Data Collection. Invite relevant experts or managers from internal decision unit to rate the selected criteria using linguistic variables. Then, linguistic variables are transformed into corresponding fuzzy set. Let the fuzzy rating of scheme A_i with respect to criteria Z_j by decision maker D_k be R_{ijk}, where $R_{ijk} = \{R_{ijk1}; R_{ijk2}; R_{ijk3}; R_{ijk4}\}$, and importance weight of evaluation criteria Z_j by decision maker D_k be W_{jk}, $W_{jk} = \{W_{jk1}; W_{jk2}; W_{jk3}; W_{jk4}\}$.

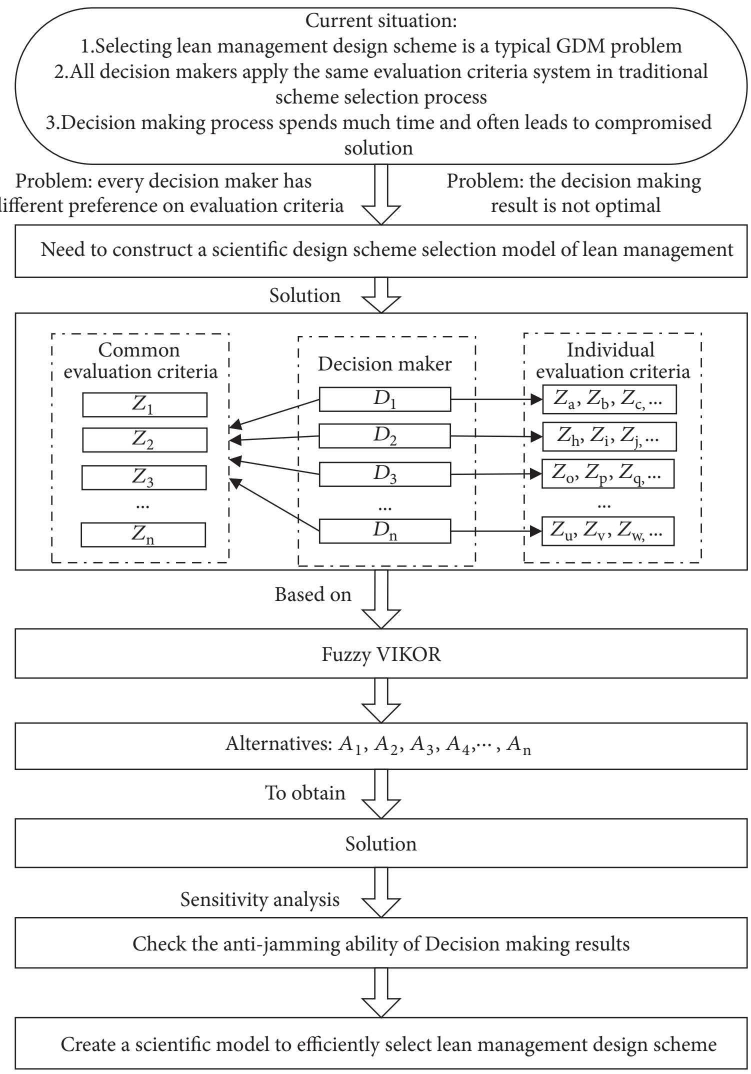

FIGURE 1: Research idea.

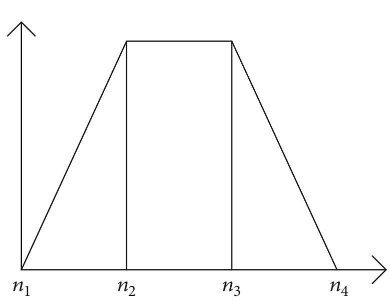

FIGURE 2: Trapezoidal fuzzy numbers $\widetilde{A}$.

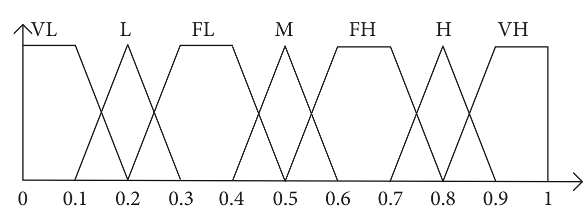

FIGURE 3: Corresponding trapezoidal fuzzy numbers.

3.2.4. Data Processing: Aggregation, Normalization, and Defuzzification

(1) Aggregation. The aggregated fuzzy weight of each criterion is calculated in (2)–(6) [30, 31].

$$W_j = \{W_{j1}; W_{j2}; W_{j3}; W_{j4}\} \quad (2)$$

where

$$W_{j1} = \min \{W_{jk1}\} \quad (3)$$

$$W_{j2} = \frac{1}{k} \sum W_{jk2} \quad (4)$$

$$W_{j3} = \frac{1}{k} \sum W_{jk3} \quad (5)$$

$$W_{j4} = \max \{W_{jk4}\} \quad (6)$$

Table 1: Linguistic variables and corresponding fuzzy numbers.

Linguistic variable	Fuzzy number
Very low (VL)	(0.0,0.0,0.1,0.2)
Low (L)	(0.1,0.2,0.2,0.3)
Fairly low (FL)	(0.2,0.3,0.4,0.5)
Medium (M)	(0.4,0.5,0.5,0.6)
Fairly high (FH)	(0.5,0.6,0.7,0.8)
High (H)	(0.7,0.8,0.8,0.9)
Very high (VH)	(0.8,0.9,1.0,1.0)

The aggregated fuzzy ratings of alternatives with respect to criterion are obtained using (7)–(11) [30, 32].

$$R_{ij} = \left\{R_{ij1}; R_{ij2}; R_{ij3}; R_{ij4}\right\} \tag{7}$$

where

$$R_{ij1} = \min\left\{R_{ijk1}\right\} \tag{8}$$

$$R_{ij2} = \frac{1}{k}\sum R_{ijk2} \tag{9}$$

$$R_{ij3} = \frac{1}{k}\sum R_{ijk3} \tag{10}$$

$$R_{ij4} = \max\left\{R_{ijk4}\right\} \tag{11}$$

(2) Normalization. In order to remove the dimensions of all criteria, linear normalization is applied to the fuzzy weight of criteria and weight of alternatives with respect to criteria. The criterion whose higher value is desirable is called beneficial criterion (B), and its value should be divided by the maximum value of the decision matrix; the criterion whose lower value is desirable is called cost criterion (C), and its value should be divided by the minimum value of decision matrix. The method is shown in (12)–(14) [30, 33].

$$R'_{ij} = \begin{cases} \left(\dfrac{R_{ij1}}{R^+_{ij4}}, \dfrac{R_{ij2}}{R^+_{ij4}}, \dfrac{R_{ij3}}{R^+_{ij4}}, \dfrac{R_{ij4}}{R^+_{ij4}}\right), & Z_j \in B \\ \left(\dfrac{R_{ij1}}{R^-_{ij1}}, \dfrac{R_{ij2}}{R^-_{ij1}}, \dfrac{R_{ij3}}{R^-_{ij1}}, \dfrac{R_{ij4}}{R^-_{ij1}}\right), & Z_j \in C \end{cases} \tag{12}$$

Here,

$$R^+_{ij4} = \max_{i\{decision\ matrix\}}, \quad Z_j \in B \tag{13}$$

$$R^-_{ij1} = \min_{i\{decision\ matrix\}}, \quad Z_j \in C. \tag{14}$$

(3) Defuzzification. The fuzzy weights of criteria and alternatives with respect to criteria are defuzzified through taking the average of the normalized trapezoidal fuzzy numbers, as is shown in (15) [30].

$$f_{ij} = Deffuz\left(R'_{ij}\right) = \left(\frac{R'_{ij1} + R'_{ij2} + R'_{ij3} + R'_{ij4}}{4}\right) \tag{15}$$

3.2.5. Calculation of Utility, Regret, and VIKOR Index. Utility (S_i), regret (G_i), and VIKOR index (Q_i) are calculated using (16)–(18) [30, 32, 34, 35].

$$S_i = \sum_{j=1}^{n} \frac{W_j^0\left(f^* - f_{ij}\right)}{f^* - f^-} \tag{16}$$

$$G_i = \max_i\left(\frac{W_j^0\left(f^* - f_{ij}\right)}{f^* - f^-}\right) \tag{17}$$

$$Q_i = \frac{v\left(S_i - S^*\right)}{S^- - S^*} + \frac{(1-v)\left(G_i - G^*\right)}{G^- - G^*} \tag{18}$$

where S_i, G_i, and Q_i, respectively, represent the utility, regret, and VIKOR index of the alternative A_i ($i = 1, 2, \cdots, m$), f^* and f^- indicate the best and worst value of f_{ij}, and W_j^0 indicates the weight of criterion Z_j. Here v is the coefficient of decision making mechanism (weight of group utility), and $1 - v$ is the weight of individual regret. $S^* = \min_i S_i, S^- = \max_i S_i; G^* = \min_i G_i, G^- = \max_i G_i$.

Rank all alternatives according to the values of S_i, G_i, and Q_i in increasing order; the alternative which has the least value of Q_i is quite likely to be the best solution. However, it still needs further refining; the detailed method for judging the best solution is shown in the following part of this research.

3.2.6. Proposing Compromise Solution. If the alternative $A^{(1)}$ ($A^{(1)}$ is the first position in the alternatives ranked by Q) satisfies the following two conditions, then it is the best solution [30].

Condition 1. $Q(A^{(2)}) - Q(A^{(1)}) \geq 1/(m-1)$, $A^{(2)}$ is the second position in the alternatives ranked by Q.

Condition 2. Alternative $A^{(1)}$ must also be at the first position when ranked by S or/and R.

If condition 1 is not satisfied, then we could only get a set of compromise solutions [30]. The compromise solutions are composed of $A^{(1)}, A^{(2)}, \cdots, A^{(x)}$, where $A^{(x)}$ is obtained according to $Q(A^{(x)}) - Q(A^{(1)}) < 1/(m-1)$ for maximum x.

4. Case Study

This research brings several improvements to fuzzy VIKOR method and proposes the lean management design scheme selection model based on previous research. In order to more clearly introduce the application of the design scheme selection model, this research takes the decision making process in W real estate development group Co. Ltd. (WGC) as a case.

4.1. Case Situation. WGC is an integrated enterprise group in China, which is based on real estate development and involves building constriction, commercial logistics, catering services,

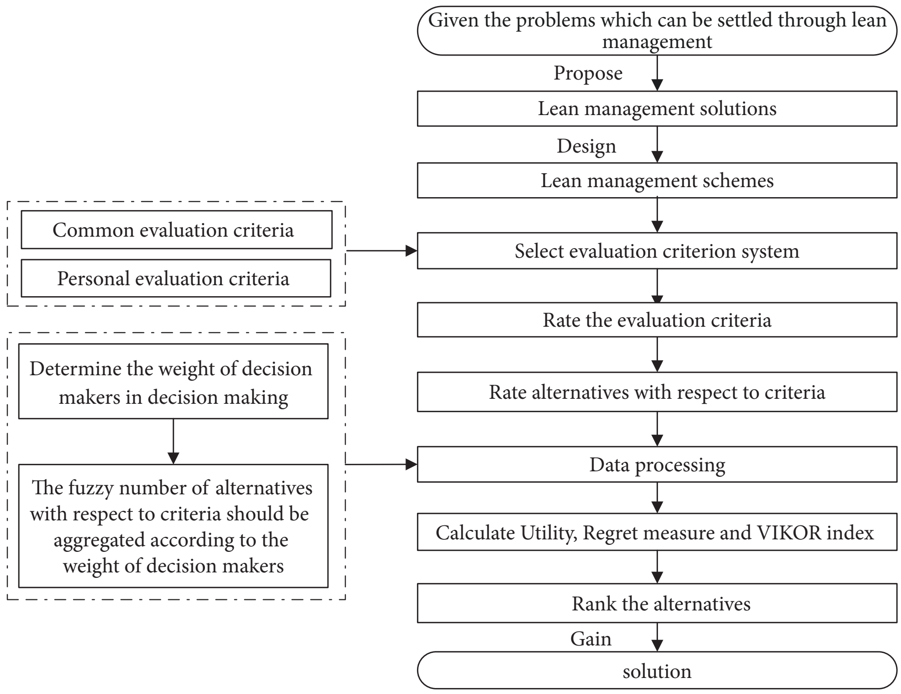

Figure 4: Lean management design scheme selection model using improved fuzzy VIKOR.

and culture media. WGC has been rapidly developing since its establishment, while at the same time, some hidden management problems also show up with the scale expansion. Existing management problems are mainly in the following aspects:

(1) The responsibility and authority are divided unclearly, and performance appraisal system and stimulation measures are incomplete.

(2) The management is extensive, lacking standard management processes, reasonable management systems, and scientific management methods, and the operation costs are high.

(3) The management layer is aging badly, and talent echelon construction is quite lagging.

In order to improve management, managers in WGP decide to bring in lean management and invite an experienced lean management team. Given the existing problems, lean management team summarizes several improvement measures:

(1) Management by objective (MBO) includes job and staff design, objective design, objective performance appraisal, and performance reward system.

(2) Profit center management (PCM) includes profit center design and performance appraisal for executives.

(3) Cost management (CM) includes designing budgeting and cost evaluation mechanism and setting research projects of cost reduction.

(4) Talents echelon building (TEB) includes lean idea popularization and talents echelon bank construction.

Based on these, lean management experts and senior managers design five lean management schemes, as is shown in Table 2.

In order to select optimal lean management design scheme, chairman of the board (D_4), CFO (D_5), and three lean management experts (D_1, D_2, D_3) form a decision making team. The next part of this research will specifically explain how to use the lean management design scheme selection model to reach the optimal solution.

4.2. Scheme Selection Model Using Improved Fuzzy VIKOR. The model of design scheme selection in lean management using improved fuzzy VIKOR is shown in Figure 4.

4.2.1. Evaluation Criteria and Alternatives Description. The criteria considered in this research are shown in Table 3.

The criteria considered in this research can be divided into common evaluation criteria and personal evaluation criteria. Common evaluation criteria include capital investment (Z_1), expected output (Z_2), the reasonability of scheme (Z_3), and long-term development of company (Z_4). Personal evaluation criteria include waste minimization (Z_5), continuous improvement (Z_6), all staff participation (Z_7), complexity of scheme (Z_8), difficulty of implementation (Z_9), and value maximization (Z_{10}).

Capital investment is directly linked with the cost, expected output indicates the outcome of a scheme, the reasonability of scheme is related to the coordination between all improvement plans in the scheme, and the long-term development of company depends on whether the scheme can exert favorable and lasting influence on the development of enterprise. Waste minimization is closely related to the utilization of various resources and materials, continuous improvement is required to ensure the perpetual optimization of the company, and all staff participation means all staffs

Table 2: Lean management design schemes.

Schemes	Contents	Costs(¥)	Objectives
A_1	MBO	400000	MBO 100% done
A_2	MBO, PCM	550000	MBO 100% done; profits improve by 30%
A_3	MBO, CM	500000	MBO 100% done; costs reduce by 10%
A_4	MBO, CM, TEB	600000	MBO 100% done; costs reduce by 10%; TEB 100% done.
A_5	MBO, PCM, CM, TEB	680000	MBO 100% done; profits improve by 30%; costs reduce by 10%; TEB 100% done.

Table 3: Evaluation criteria system.

Common evaluation criteria	Capital investment (Z_1)				
	Expected output (Z_2)				
	Reasonability of scheme (Z_3)				
	Long-term development of company (Z_4)				
	D_1	D_2	D_3	D_4	D_5
Personal evaluation criteria	Waste minimization (Z_5)	Continuous improvement (Z_6)	Waste minimization (Z_5)	Continuous improvement (Z_6)	Waste minimization (Z_5)
	Continuous improvement (Z_6)	Complexity of scheme (Z_8)	All staff participation (Z_7)	Difficulty of implementation (Z_9)	All staff participation (Z_7)
	All staff participation (Z_7)	Difficulty of implementation (Z_9)	Complexity of scheme (Z_8)	Value maximization (Z_{10})	Value maximization (Z_{10})

are involved in the scheme implementation. The complexity of scheme includes the number of plans and the workload of each plan, the difficulty of implementation considers the response of staff and the enthusiasm of managers, and value maximization means to bring the company optimal improvement under present condition.

4.2.2. Data Collection. Firstly, this research invites five decision makers to rate the weight of criteria using linguistic variables; the rating results are shown in Table 4 and the corresponding fuzzy numbers are shown in Table 5.

Then, this research invites five decision makers to rate each alternative with respect to criteria using linguistic variables; the rating results are shown in Table 6 and corresponding fuzzy numbers are shown in Table 7.

4.2.3. Data Processing

(1) Aggregation. Firstly, weight of criterion is aggregated using (2)–(6). Taking the fuzzy ratings of Z_1 as an example, the ratings are (0.7,0.8,0.8,0.9), (0.7,0.8,0.8,0.9), (0.7,0.8,0.8,0.9), (0.8,0.9,1.0,1.0), (0.8,0.9,1.0,1.0).

$$\begin{aligned} W_{11} &= \min\{W_{1k1}\} = 0.7 \\ W_{12} &= \sum \theta_k \bullet W_{1k2} \\ &= \frac{1}{5} \times (0.8 + 0.8 + 0.8 + 0.9 + 0.9) = 0.84 \\ W_{13} &= \sum \theta_k \bullet W_{1k3} \\ &= \frac{1}{5} \times (0.8 + 0.8 + 0.8 + 1.0 + 1.0) = 0.87 \\ W_{14} &= \max\{W_{1k4}\} = 1.0 \end{aligned} \tag{19}$$

Therefore, the aggregated fuzzy rating of Z_1 is (0.7, 0.84, 0.87, 1.0).

Then, the weight of alternative with respect to criteria is aggregated. In this research, five decision makers apply different evaluation criteria systems to rate every alternative; while for decision makers, the influence of their decision making is different. Hence, this research applies AHP method to determine the weights of decision makers in decision making (shown in Table 8).

The weight of decision maker is calculated using the root method (20).

$$\overline{\theta}_i = \left(\prod_{j=1}^{n} a_{ij}\right)^{1/n} \tag{20}$$

Taking the calculation of $\overline{\theta}_1$ as an example, $\overline{\theta}_1 = (\prod_{j=1}^{n} a_{ij})^{1/n} = (1 \times 2 \times 4 \times 2 \times 3)^{1/5} = 2.17$

The results are shown in Table 9.

The rating of alternatives with respect to criterion assessed by different decision makers needs to be linearly normalized; the normalization results are shown in Table 10.

Table 4: Weight of criteria assessed by decision makers (linguistic variable).

	D_1	D_2	D_3	D_4	D_5
Z_1	H	H	H	VH	VH
Z_2	VH	VH	VH	VH	VH
Z_3	VH	VH	VH	H	H
Z_4	H	H	H	VH	H
Z_5	H	FH	H	M	VH
Z_6	H	H	M	H	FH
Z_7	VH	M	VH	FH	H
Z_8	FH	VH	H	M	M
Z_9	M	H	M	H	M
Z_{10}	FH	M	FH	VH	VH

Table 5: Weight of criteria assessed by decision makers (fuzzy set).

	D_1	D_2	D_3	D_4	D_5
Z_1	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)
Z_2	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)
Z_3	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
Z_4	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)
Z_5	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.8,0.9,1.0,1.0)
Z_6	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)
Z_7	(0.8,0.9,1.0,1.0)	(0.4,0.5,0.5,0.6)	(0.8,0.9,1.0,1.0)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
Z_8	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)
Z_9	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)
Z_{10}	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)

Table 6: Rating results (linguistic variables).

				D_1				D_2						
	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_1	Z_2	Z_3	Z_4	Z_6	Z_8	Z_9
A_1	VH	H	VH	M	M	H	H	H	M	H	FH	M	FH	VH
A_2	FH	VH	FH	M	H	M	H	FH	H	M	H	M	VH	H
A_3	H	VH	H	H	H	H	VH	H	VH	H	M	FH	H	H
A_4	FH	FH	VH	VH	FH	VH	VH	VH	H	VH	H	H	FH	H
A_5	M	H	VH	VH	VH	VH	VH	M	VH	VH	VH	VH	M	FH
				D_3							D_4			
	Z_1	Z_2	Z_3	Z_4	Z_5	Z_7	Z_8	Z_1	Z_2	Z_3	Z_4	Z_6	Z_9	Z_{10}
A_1	FH	M	FH	H	M	FH	H	VH	M	FH	H	M	VH	M
A_2	H	H	M	FH	FH	FH	H	H	FH	H	H	H	M	FH
A_3	H	FH	H	FH	H	H	H	H	VH	H	FH	VH	H	H
A_4	M	FH	VH	VH	FH	VH	FH	FH	FH	VH	FH	VH	FH	FH
A_5	VH	VH	VH	VH	VH	VH	M	M	H	H	VH	H	M	H
				D_5										
	Z_1	Z_2	Z_3	Z_4	Z_5	Z_7	Z_{10}							
A_1	H	M	VH	FH	M	M	M							
A_2	VH	H	H	H	FH	FH	FH							
A_3	H	H	FH	VH	VH	H	H							
A_4	FH	FH	H	FH	FH	H	FH							
A_5	FH	VH	VH	H	FH	VH	VH							

Table 7: Rating results (fuzzy set).

		A_1	A_2	A_3	A_4	A_5
D_1	Z_1	(0.8,0.9,1.0,1.0)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
	Z_2	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
	Z_3	(0.8,0.9,1.0,1.0)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)
	Z_4	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)
	Z_5	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)
	Z_6	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)
	Z_7	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)
D_2	Z_1	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.4,0.5,0.5,0.6)
	Z_2	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)
	Z_3	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)
	Z_4	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)
	Z_6	(0.4,0.5,0.5,0.6)	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)
	Z_8	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)
	Z_9	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)
D_3	Z_1	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.4,0.5,0.5,0.6)	(0.8,0.9,1.0,1.0)
	Z_2	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)
	Z_3	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)
	Z_4	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)
	Z_5	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)
	Z_7	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)
	Z_8	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)
D_4	Z_1	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)
	Z_2	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
	Z_3	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)
	Z_4	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)
	Z_6	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)
	Z_9	(0.8,0.9,1.0,1.0)	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.4,0.5,0.5,0.6)
	Z_{10}	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
D_5	Z_1	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
	Z_2	(0.4,0.5,0.5,0.6)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)
	Z_3	(0.8,0.9,1.0,1.0)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)
	Z_4	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)
	Z_5	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
	Z_7	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.8,0.9,1.0,1.0)
	Z_{10}	(0.4,0.5,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.7,0.8,0.8,0.9)	(0.5,0.6,0.7,0.8)	(0.8,0.9,1.0,1.0)

Table 8: The judgment results using a scale of 1-9.

	D_1	D_2	D_3	D_4	D_5
D_1	1	2	4	2	3
D_2	0.5	1	3	1	2
D_3	0.25	0.33	1	0.33	0.5
D_4	0.5	1	3	1	2
D_5	0.33	0.5	2	0.5	1

Table 9: Weight results of decision makers.

	D_1	D_2	D_3	D_4	D_5
$\bar{\theta}_1$	2.17	1.25	0.42	1.25	0.70

Take the rating of A_1 with respect to Z_1 as an example; the ratings are (0.8,0.9,1.0,1.0), (0.7,0.8,0.8,0.9), (0.5,0.6,0.7,0.8), (0.8,0.9,1.0,1.0), (0.7,0.8,0.8,0.9).

$$R_{111} = \min\left\{R_{11k1}\right\} = 0.5 \tag{21}$$

$$\begin{aligned} R_{112} &= \sum \theta_k R_{11k2} \\ &= 0.37 \times 0.9 + 0.22 \times 0.8 + 0.06 \times 0.6 + 0.22 \\ &\quad \times 0.9 + 0.13 \times 0.8 = 0.85 \end{aligned} \tag{22}$$

$$\begin{aligned} R_{113} &= \sum \theta_k R_{11k3} \\ &= 0.37 \times 1.0 + 0.22 \times 0.8 + 0.06 \times 0.7 + 0.22 \\ &\quad \times 1.0 + 0.13 \times 0.8 = 0.91 \end{aligned} \tag{23}$$

Table 10: Weight of decision makers (normalized).

	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}
D_1	0.37	0.37	0.37	0.37	0.66	0.46	0.66			
D_2	0.22	0.22	0.22	0.22		0.27		0.79	0.5	
D_3	0.06	0.06	0.06	0.06	0.11		0.11	0.21		
D_4	0.22	0.22	0.22	0.22		0.27			0.5	0.63
D_5	0.13	0.13	0.13	0.13	0.23		0.23			0.37

Table 11: Summary sheet of collected data.

	Z_1	Z_2	Z_3	Z_4	Z_5
W_j	(0.7,0.84,0.87,1.0)	(0.8,0.9,1.0,1.0)	(0.7,0.86,0.92,1.0)	(0.7,0.82,0.84,1.0)	(0.4,0.72,0.76,1.0)
A_1	(0.5,0.85,0.91,1.0)	(0.4,0.61,0.61,0.9)	(0.5,0.79,0.87,1.0)	(0.4,0.62,0.65,0.9)	(0.4,0.5,0.5,0.6)
A_2	(0.5,0.70,0.77,1.0)	(0.5,0.80,0.85,1.0)	(0.4,0.64,0.70,0.9)	(0.4,0.70,0.71,0.9)	(0.5,0.73,0.77,0.9)
A_3	(0.7,0.8,0.8,0.9)	(0.5,0.87,0.96,1.0)	(0.7,0.8,0.8,0.9)	(0.4,0.8,0.8,1.0)	(0.7,0.80,0.82,1.0)
A_4	(0.4,0.66,0.75,1.0)	(0.5,0.6,0.65,0.9)	(0.7,0.89,0.97,1.0)	(0.5,0.77,0.85,1.0)	(0.5,0.6,0.7,0.8)
A_5	(0.4,0.54,0.63,0.8)	(0.7,0.84,0.88,1.0)	(0.7,0.88,0.96,1.0)	(0.7,0.89,0.97,1.0)	(0.5,0.84,0.93,1.0)
	Z_6	Z_7	Z_8	Z_9	Z_{10}
W_j	(0.7,0.84,0.9,1.0)	(0.8,0.9,1.0,1.0)	(0.7,0.86,0.92,1.0)	(0.7,0.82,0.84,1.0)	(0.4,0.72,0.76,1.0)
A_1	(0.4,0.64,0.64,0.9)	(0.4,0.71,0.72,0.9)	(0.5,0.64,0.72,0.9)	(0.8,0.9,1.0,1.0)	(0.4,0.5,0.5,0.6)
A_2	(0.4,0.58,0.58,0.9)	(0.5,0.73,0.74,0.9)	(0.7,0.88,0.96,1.0)	(0.4,0.65,0.65,0.9)	(0.5,0.6,0.7,0.8)
A_3	(0.7,0.83,0.85,1.0)	(0.7,0.87,0.97,1.0)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
A_4	(0.7,0.87,0.89,1.0)	(0.7,0.88,0.95,1.0)	(0.5,0.6,0.7,0.8)	(0.5,0.7,0.75,0.9)	(0.5,0.6,0.7,0.8)
A_5	(0.7,0.88,0.95,1.0)	(0.8,0.9,0.9,1.0)	(0.4,0.5,0.5,0.6)	(0.4,0.55,0.6,0.8)	(0.7,0.84,0.87,1.0)

$$R_{114} = \max\left\{R_{11k4}\right\} = 1.0 \quad (24)$$

Accordingly, the aggregated fuzzy rating of A_1 with respect to Z_1 is (0.5, 0.85, 0.91, 1.0). The aggregation results are shown in Table 11.

Secondly, using (12) to normalize the criterion weights and alternative ratings with respect to criterion assessed by decision makers, in this research, Z_1, Z_5, and Z_7 are cost criteria, and their values should be divided by the minimum value of decision matrix; other criteria are benefit criteria, and their values should be divided by the maximum value of the decision matrix. The normalization results are shown in Table 12.

(2) Defuzzification. The defuzzification of the data in Table 12 is achieved using (15); the results of defuzzification are shown in Table 13.

Take the defuzzification of the rating of A_1 with respect to Z_1 as an example; the fuzzy rating is (1.25, 2.13, 2.28, 2.5).

$$\begin{aligned} \text{Deffuz}\left(r_{11}\right) &= \left(\frac{r_{111} + r_{112} + r_{113} + r_{114}}{4}\right) \\ &= \frac{1.25 + 2.13 + 2.28 + 2.5}{4} = 2.04 \end{aligned} \quad (25)$$

4.2.4. Arrangement and Analysis of Results

(1) Calculate the Best and Worst Values. f^* and f^- indicate the best and worst values of alternative rating with respect to the same criterion; the best values (f^*) and worst values (f^-) are shown in Table 14.

(2) Calculation of Utility, Regret, and VIKOR Index. Utility (S_i), regret (G_i), and VIKOR index (Q_i) are calculated using (16)–(18); take the calculation of S_1, G_1, and Q_1 as an example.

$$\begin{aligned} S_1 &= \sum_{j=1}^{n} \frac{W_j^0\left(f^* - f_{1j}\right)}{f^* - f^-} \\ &= \frac{2.15 \times (1.43 - 2.04)}{1.43 - 2.04} + \frac{0.93 \times (0.63 - 0.63)}{0.63 - 0.86} \\ &\quad + \frac{0.87 \times (0.66 - 0.82)}{0.66 - 0.89} + \frac{0.84 \times (0.64 - 0.66)}{0.64 - 0.88} \\ &\quad + \frac{1.80 \times (1.25 - 1.25)}{1.25 - 2.11} + \frac{0.86 \times (0.62 - 0.64)}{0.62 - 0.88} \\ &\quad + \frac{0.93 \times (0.68 - 0.68)}{0.68 - 0.93} + \frac{2.18 \times (1.25 - 1.73)}{1.25 - 2.21} \\ &\quad + \frac{0.84 \times (0.58 - 0.93)}{0.58 - 0.93} + \frac{0.72 \times (0.5 - 0.5)}{0.5 - 0.86} \\ &= 4.76 \end{aligned}$$

$$\begin{aligned} G_1 &= \max_i \left(\frac{W_j^0\left(f^* - f_{ij}\right)}{f^* - f^-}\right) = \frac{2.15 \times (1.43 - 2.04)}{1.43 - 2.04} \\ &= 2.15 \end{aligned}$$

Table 12: Normalization results.

	Z_1	Z_2	Z_3	Z_4
W_j	(1.75,2.10,2.25,2.50)	(0.80,0.90,1.00,1.00)	(0.70,0.86,0.92,1.00)	(0.70,0.82,0.84,1.00)
A_1	(1.25,2.13,2.28,2.50)	(0.40,0.61,0.61,0.90)	(0.50,0.79,0.87,1.00)	(0.40,0.62,0.65,0.90)
A_2	(1.25,1.75,1.93,2.50)	(0.50,0.80,0.85,1.00)	(0.40,0.64,0.70,0.90)	(0.40,0.70,0.71,0.90)
A_3	(1.75,2.00,2.00,2.25)	(0.50,0.87,0.96,1.00)	(0.70,0.80,0.80,0.90)	(0.40,0.80,0.80,1.00)
A_4	(1.00,1.65,2.13,2.50)	(0.50,0.60,0.65,0.90)	(0.70,0.89,0.97,1.00)	(0.50,0.77,0.85,1.00)
A_5	(1.00,1.35,1.58,2.00)	(0.70,0.84,0.88,1.00)	(0.70,0.88,0.96,1.00)	(0.70,0.89,0.97,1.00)
	Z_5	Z_6	Z_7	Z_8
W_j	(1.00,1.80,1.90,2.50)	(0.70,0.84,0.90,1.00)	(0.80,0.90,1.00,1.00)	(1.75,2.15,2.30,2.50)
A_1	(1.00,1.25,1.25,1.50)	(0.40,0.64,0.64,0.90)	(0.40,0.71,0.72,0.90)	(1.25,1.60,1.80,2.25)
A_2	(1.25,1.83,1.93,2.25)	(0.40,0.58,0.58,0.90)	(0.50,0.73,0.74,0.90)	(1.75,2.20,2.40,2.50)
A_3	(1.75,2.00,2.10,2.50)	(0.70,0.83,0.85,1.00)	(0.70,0.87,0.97,1.00)	(1.75,2.00,2.00,2.25)
A_4	(1.00,1.20,1.40,1.60)	(0.70,0.87,0.89,1.00)	(0.70,0.88,0.95,1.00)	(1.25,1.50,1.75,2.00)
A_5	(1.25,2.10,2.33,2.50)	(0.70,0.88,0.95,1.00)	(0.80,0.90,0.90,1.00)	(1.00,1.25,1.25,1.50)
	Z_9	Z_{10}		
W_j	(0.70,0.82,0.84,1.00)	(0.40,0.72,0.76,1.00)		
A_1	(0.80,0.90,1.00,1.00)	(0.40,0.50,0.50,0.60)		
A_2	(0.40,0.65,0.65,0.90)	(0.50,0.60,0.70,0.80)		
A_3	(0.70,0.80,0.80,0.90)	(0.70,0.80,0.80,0.90)		
A_4	(0.50,0.70,0.75,0.90)	(0.50,0.60,0.70,0.80)		
A_5	(0.40,0.55,0.60,0.80)	(0.70,0.84,0.87,1.00)		

Table 13: Defuzzification results.

	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}
Weight	2.15	0.93	0.87	0.84	1.80	0.86	0.93	2.18	0.84	0.72
A_1	2.04	0.63	0.83	0.64	1.25	0.64	0.68	1.73	0.93	0.50
A_2	1.85	0.79	0.66	0.67	1.81	0.62	0.72	2.21	0.65	0.65
A_3	2.00	0.83	0.79	0.71	2.11	0.83	0.87	2.15	0.80	0.80
A_4	1.76	0.69	0.89	0.78	1.30	0.88	0.88	1.63	0.71	0.65
A_5	1.43	0.86	0.88	0.89	2.04	0.88	0.93	1.25	0.59	0.85

$$
\begin{aligned}
Q_1 &= \frac{\nu\left(S_1 - S^*\right)}{S^- - S^*} + \frac{(1-\nu)\left(G_1 - G^*\right)}{G^- - G^*} \\
&= \frac{0.5 \times (4.80 - 4.80)}{4.80 - 9.94} + \frac{0.5 \times (1.15 - 2.15)}{1.15 - 2.18} \\
&= 0.49
\end{aligned} \tag{26}
$$

The results are shown in Table 15.

In this research, A_4 is best ranked by Q and G, but it is not best ranked by S; at the same time $Q(A_5) - Q(A_4) = 0.44 - 0.21 < 1/(5-1) = 0.25$. These facts mean that A_4 does not satisfy condition 1; in other words, according to the judgment standard of traditional fuzzy VIKOR, A_4 is not the best solution, and A_4 and A_5 are components of compromise solutions. However, applying improved fuzzy VIKOR introduced in this research can effectively guarantee A_4 to be the best solution. In order to prove that A_4 is the optimal solution, this research proposes sensitivity analysis.

5. Sensitivity Analysis

In order to prove the lean management design scheme selection model using improved fuzzy VIKOR to be scientific, the antijamming ability of this model needs to be checked. Existing research has indicated that, through testing whether the change in weights of various relevant factors will cause great deviation to decision making, result can prove the decision making model to be scientific [36]. Given this, sensitivity analysis is approached from three aspects to analyze the variation of decision making result: the weight of decision maker θ, the weight of evaluation criteria ω, and the weight of mechanism coefficient ν.

5.1. Analysis on the Coefficient of Decision Making Mechanism. Let the coefficient of decision making mechanism ν change in the interval [0.1, 0.9], with a range of 0.1 each time; the results are shown in Figure 5.

Figure 5 shows that, with the decision making mechanism coefficient changing from 0.1 to about 0.75, A_1 takes the

TABLE 14: The best and worst values.

	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}
f^*	1.43	0.63	0.66	0.65	1.25	0.62	0.68	1.25	0.59	0.5
f^-	2.04	0.86	0.89	0.89	2.11	0.88	0.93	2.21	0.93	0.85

TABLE 15: Utility, regret, and VIKOR index and their ranking.

	A_1	ranking	A_2	ranking	A_3	ranking	A_4	ranking	A_5	ranking
S	4.76	1	6.20	2	9.94	5	6.90	4	6.78	3
G	2.15	4	2.18	5	2.03	3	1.17	1	1.66	5
$Q(\nu = 0.5)$	0.49	3	0.64	4	0.93	5	0.21	1	0.44	2

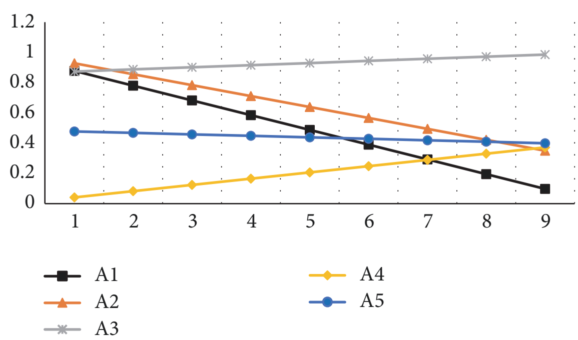

FIGURE 5: Sensitivity analysis on decision making mechanism coefficient ν.

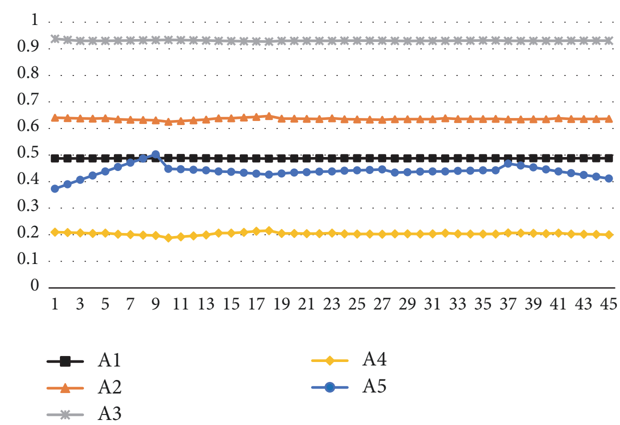

FIGURE 6: Sensitivity analysis on the weight of decision maker θ.

optimized position; when the coefficient changes from about 0.75 to 0.9, A_1 comes to be the best solution.

5.2. Analysis on the Weight of Decision Maker. In this research, perturbation method [36] is applied to analysis the sensitivity about the weight of decision maker. Let the perturbation parameter be ξ; then $\theta_k' = \xi \bullet \theta_k$.

For the five decision makers involved in this research, their weights are normalized, which means

$$\sum_{k=1}^{5} \theta_k = 1, \quad (27)$$

$$\theta' + \sum_{m=1, m\neq k}^{5} \theta_m' = 1 \quad (28)$$

$$\xi \bullet \theta_k + \lambda \sum_{m=1, m\neq k}^{5} \theta_m = 1. \quad (29)$$

Combining (27) with (29), we can obtain that $\lambda = (1 - \xi \bullet \theta_k)/(1 - \theta_k)$, which means that when the weight of D_k changes with a coefficient of ξ, then the weight of other decision makers will change with a coefficient of λ. The sensitivity analysis is taken making ξ change within the interval [0.8, 1.2], with a range of 0.5 each time; the results are shown in Figure 6.

Figure 6 shows that, in the 45 times experiments, all schemes are not so sensitive to the change in the weight of decision makers, and the priority order of schemes remains still except the 9th experiment. The research results further certify that A_4 is the best solution.

5.3. Analysis on the Weight of Evaluation Criteria. To test the sensitivity of decision making results affected by weight of evaluation criteria, this experiment brings in a series of random disturbances; the method is as follows: 200 sets of random coefficients $[\alpha_{a1}, \alpha_{a2}, \cdots, \alpha_{a10}]$ $(a = 1, 2, \cdots, 200)$ that satisfy Gaussian distribution with mean 0 and variance 0.6666 are provided using MATLAB. According to the feature of Gaussian distribution, the probability that values of these random coefficients are involved in the interval [0.1, 0.9] is 99.74%. Partial random coefficients are shown in Table 16, the weight of evaluation criteria changed from W_j^0 to $\alpha_{aj} W_j^0$, and this change will further affect VIKOR index Q (shown in Figure 7).

Figure 7 shows that A_5 is very sensitive to the disturbance and fluctuates severely. However, A_4 is quite stable that disturbance exerts a negligible effect on A_4. Also, A_4 takes the position of optimal solution all the time (the VIKOR index value of A_4 is always the lowest). With no doubt, A_4 is the optimal solution.

6. Conclusions

Currently, fuzzy VIKOR is a widely used decision making method. In decision making model using fuzzy VIKOR, all

Table 16: Random coefficients that satisfy Gaussian distribution (partial).

Random coefficients that satisfy Gaussian distribution (partial)									
1.08	1.04	1.10	0.91	1.06	1.07	1.04	1.11	1.02	0.98
1.06	1.06	1.06	1.06	0.86	1.00	0.95	1.02	0.98	0.95
0.97	0.92	1.08	1.04	1.04	0.99	1.02	0.97	1.10	1.08
0.96	0.96	1.09	0.95	0.89	0.93	0.95	1.02	1.00	1.05
1.09	1.09	0.83	0.93	0.99	1.01	0.91	1.02	0.98	1.06
0.98	1.04	1.03	0.98	0.91	1.04	0.95	1.08	0.96	1.01
1.01	1.14	1.00	0.99	1.02	1.08	0.97	1.06	0.97	0.88
1.08	0.98	1.00	1.00	0.96	0.95	1.05	1.07	0.99	1.14
1.00	0.99	0.95	1.10	0.97	1.03	0.93	1.01	0.86	0.95
0.94	0.99	0.89	1.10	1.12	1.05	1.04	1.02	1.06	1.04
0.98	0.99	0.94	0.95	0.93	1.07	0.94	1.07	0.99	1.11
1.08	1.08	1.02	1.05	1.06	0.99	1.07	1.01	1.11	1.01
0.95	1.07	1.00	1.06	0.95	0.93	1.01	0.90	1.08	0.99
1.08	1.27	1.04	1.06	0.97	0.97	0.99	1.01	0.92	1.05
0.99	1.09	1.05	1.04	1.08	0.95	0.92	0.94	1.04	0.98
0.94	0.86	0.93	1.03	1.03	1.00	0.92	0.99	0.93	0.95
0.94	0.96	1.00	0.98	1.03	0.89	0.99	0.97	0.93	0.85
1.06	1.02	1.03	0.96	1.08	0.96	1.08	0.95	0.98	0.99
1.02	0.95	0.94	1.02	0.96	0.96	1.00	1.08	0.90	1.01
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

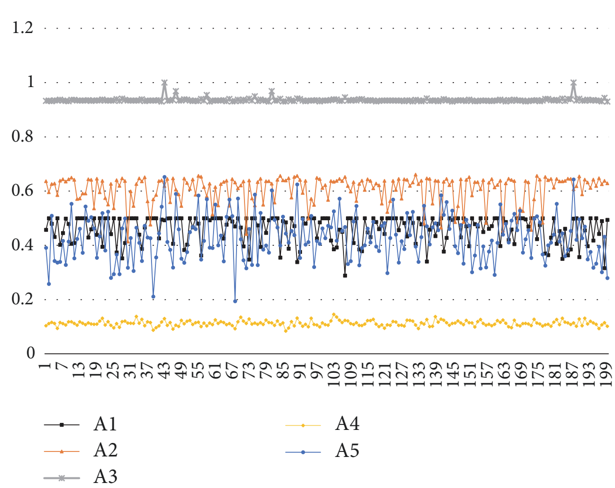

Figure 7: Sensitivity analysis on the weight of evaluation criteria ω.

decision makers apply the same evaluation criteria to evaluate all schemes. However, in realistic decision making process, different decision makers may hold different opinions on evaluation criteria. Under this situation, applying the same evaluation criteria to evaluate all schemes will spend much time in decision making and cannot always obtain optimal solution. In order to weigh the opinions of all decision makers and to obtain optimal solution in shorter time, this research proposes the decision making model using improved fuzzy VIKOR and implies this model in real lean management design scheme model selection case. This research also carries out sensitivity analysis to test whether the solution is optimal; the analysis results confirm that this model is scientific. This research proposes the lean management design scheme selection model using improved fuzzy VIKOR. This model has three advantages: (1) the model can weigh the opinions of all decision makers because the model allows different decision makers to evaluate all schemes with different evaluation criteria systems; it is more applicable to realistic decision making process in enterprise; (2) solution obtained using this model has been tested to be quite stable, so this model is scientific and can effectively avoid suboptimal solution. In conclusion, the model is quite scientific and stable, and it can be widely applied in lean management design scheme selection process to obtain optimal solution.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Acknowledgments

This research work is supported by the Program for the Philosophy and Social Sciences Research of Higher Learning Institutions of Shanxi No. 2016 (39), No. 2017326; the National Natural Science Foundation of China under Grant No.

71071107; and the Program for the Outstanding Innovative Teams of Higher Learning Institutions of Shanxi No. 2016 (3).

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