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Developing a sustainable operational management system using hybrid Shapley value and Multimoora method: case study petrochemical supply chain

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Abstract

In this research, a new method to determine the supply chain performance based on its sustainable strategies is proposed. This method consists of a balanced scorecard, path analysis, and hybrid Shapley value and Multimoora method. The main contribution of this research is to design an intelligent performance evaluation system for different supply chains. In this intelligent performance evaluation method, first, a set of strategies are determined through the balanced scorecard, next, by applying the path analysis method, the best strategic paths are specified, and then the Shapely value of the listed paths is calculated. Among these, five with the highest Shapley value are selected through the hybrid Dematel-based analytical network process and Multimoora method. This method is implemented in the petrochemical supply chain in Iran, and the results are analyzed. This application revealed that the best policy in organizational–operational management optimization is subject to applying this up-to-date technological apparatus at its best. In this approach, the production and delivery time cycle would be reduced. This intelligent system reduces production costs as well. The findings here can be applied in any industry of concern as to improve operations.

Keywords Operational management system · Sustainable strategy · Petrochemical supply chain · Shapley value · Multimoora method

1 Introduction

Accurate perception of an organization's operation, which would lead to appropriate programming, is the most contributive aspect therein. Assessing and managing together with clarifying the existing situation can determine the sustainable strategic progress of an organization (Fahimnia et al., 2017).

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Every organization has to orient its workforce toward its objectives. Organizations must have their own performance measurement (PM) system to assess and evaluate their resource utilization, the outcome of which would contribute to strategic management and accomplishing objectives therein in a controlled manner (Ganga et al., 2011).

According to Cai et al., (2009), if the organizational performance is appropriate, it would lead to better supply chain performance. The PM is a rotating process with a core named the mission, vision, and strategy, Fig. 1, where the tagged stages follow a clockwise path.

Accordingly, the main question of this research can be summarized as how to find an intelligent methodology for evaluating the performance of complex supply chains, especially in the petrochemical industry.

The innovation of this study is in combining the balanced scorecard (BSC), path analysis (PA), and Shapley value (SV). Moreover, a hybrid method based on decision-making trial and evaluation laboratory method (DEMATEL), analytical network process (ANP), and Multimoora methods is proposed. This novel proposed intelligent model which is implemented in the petrochemical industry of Iran, and the obtained results are reported.

This article is organized as follows: The literature is reviewed in Sec. 2; the method is introduced in Sec. 3; the numerical results and discussion are presented in Sec. 4 and Sec. 5, respectively; and the article is concluded in Sec. 6.

2 Literature review

Multi-criteria decision-making (MCDM) techniques are one of the most widely used methods in the literature. In these methods, using collective opinions and numerical calculations, the best solutions are determined. MDCM methods have also been widely used in

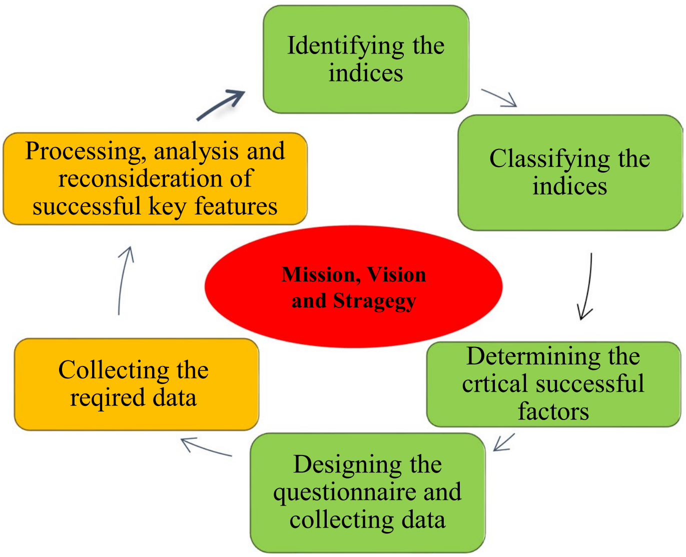

Fig. 1 Rotating process of PM

performance appraisal. To have a background of what has been assessed and found in this context, the following studies are of concern.

Gunasekaran et al. (2004) introduced important criteria that are applied in many studies to come. Bhagwat & Sharma (2007) ran a review article on PM and introduced criteria and matrices for balanced performance at all aspects. Min et al., (2009) determined the performance measurement criteria at strategic, tactical, and performance levels and determined weights through AHP by applying preemptive goal programming (PGP) with three objective functions to improve operations.

Cai et al. (2009) devised a framework in a systematic approach to analyzing the operation of repeatable key indices, where the correlation between key process indices are analyzed in their qualitative sense. Sarkis et al., (2010) assessed the management operational branches at the executive management level of the organization, and the comparisons therein implemented the outcome in the BSC aspects.

Ganga et al. (2011) assessed the indices and the key factors influencing the supply chain concerning the given environment concept and introduced a framework thereof. El-Baz (2011) assessed the PM indices with respect to uncertainty by introducing a new approach, where the Fuzzy logic is applied in assessing the relations between the SCOR made levels. They first determined some indices regarding the sustainable supply chain, next, weighted this through fuzzy entropy, and then evaluated the supply chain PM based on the indices therein through fuzzy multi-attribute utility theory (FMAUT). Cho et al. (2012) combined the BSC and the evolutionary game theory to introduce the best-combined strategies regarding the assessment of a supply chain. Uysal (2012) determined the sustainable performance indices through Dematel and measured their effect on each other, then compared it. Van Horenbeek & Pintelon (2014) evaluated PM of producing companies based on their repair and maintenance activities, where the ANP method is applied. Liu et al. (2015) introduced a double-section conceptual model in evaluating the state-private sector cooperation based on the available findings in this context. One section is involved with the variables at the state and the other in the private sectors. The statistical approach is applied in analyzing this proposed model. Chomchaiya & Esichaikul (2016) introduced a hybrid framework to evaluate companies that procure state organizations. In that study, the shareholders constitute the essential pillar as to PM of the procuring comparing. Sainaghi et al. (2017) evaluated the PM of the companies in the Tourism Industry for the 1996–2014 period, and developed a framework to improve PM. They applied the search and found that appropriate programming and scheduling are the best components to compare the PM in this industry. Sangwa & Sangwan (2018) developed an evaluation framework for lean organizations, where a set of key performance indicator (KPI) is introduced to yield a perceptual model. Petrillo et al., (2019) assessed the PM of production at the global scale and introduced a perceptual model therein, by assigning production indices at the global scale, the relations of which are analyzed through the analytic hierarchy process (AHP). Gupta & Tripathi (2020) assessed the small producers PM in the developing countries, that is, Ethiopia, he collected information from 198 such outfits and ran statistical analysis and found that the manpower abilities and having access to appropriate financial resources are the most influential parameters therein. Kazancoglu et al., (2021) evaluated a reverse logistics of food supply chain in a circular economy. In this regard, a system dynamics model is concluded that the environmental impacts of production and distribution activities should be closely examined from a managerial perspective. In Table 1, the most important researches are compared.

In general, the comparison of the related findings with that of this newly proposed design are briefed as:

Table 1 Summarized literature review

Researches	Decision		Organization				Method and approach					
	Fuzzy	Certain	Production	Services	Environmental	Dependency analysis	Fuzzy logic	Statistical test	Game theory	MCDM	BSC	Literature Review
Gunasekaran et al. (2004)		*	*									*
Hervani et al. (2005)		*			*							*
Bhagwat & Sharma (2007)		*	*								*	*
Cai et al. (2009)		*	*			*				*	*	*
Min et al. (2009)		*	*								*	*
Amaratunga et al. (2010)		*	*					*			*	*
Sarkis et al. (2010)				*							*	
Ganga et al. (2011)	*		*				*					
Erol et al. (2011)	*		*			*		*		*		
El-Baz (2011)	*		*			*		*		*		
Cho et al. (2012)	*			*		*				*		*
Uysal (2012)		*	*			*		*		*		
Van Horenbeek & Pintelon (2014)		*	*			*		*		*		
Liu et al. (2015)		*		*								*
Chomchaiya & Esichaikul (2016)		*		*		*		*				
Sainaghi et al.(2017)	*			*			*					*
Sangwa & Sangwan (2018)		*	*	*		*		*				
Petrillo et al. (2019)	*		*			*				*		
Gupta & Tripathi (2020)		*	*				*					
Kazancoglu et al. (2021)		*	*		*			*				
This study		*	*			*			*	*	*	

- Among most of the available studies, the combined BSC, game theories, and multi-criteria decision-making process are not addressed in PM, while here it is of major concern, thus, the innovation.
- As to applying the multi-criteria decision-making process if any, the DANP and Multi-moora method are not applied in one. Applying this method and its implementation is another innovation here.
- The magnitude of the petrochemical supply chain makes it a very complex supply chain to evaluate its different factors and indices must be of concern. There exists no study run on this major subject. This subject is assessed in this study, thus, another innovation.

3 Method

The attempt is made in this study to introduce a new method in assessing PM and analyze the most appropriate combined sustainable strategy in a petrochemical supply chain. The flowchart for conducting this research is shown in Fig. 2.

In the first step, by reviewing the thematic performance evaluation literature, performance evaluation indicators in the petrochemical supply chain are identified and analyzed, and then, using balanced scorecard criteria, strategies related to each of the scorecard criteria are identified. In the following, the strategic plan is designed, and the existing strategic routes between different strategies are determined. This method, as strategic path analysis, will reveal to us the different strategic combinations in the organization, where different strategic paths are determined through a method named Shapley value in the field of participatory game theory. This will be actualized with the participation of firm experts, followed by selecting appropriate routes. The weight of each of the indicators is ranked by the DANP method, which allows the Multimoora method to be implemented in ranking the selected appropriate routes.

The four stages of this method are detailed as follows.

3.1 Identification of the related strategies in the subject organization

In this context, the strategies should be determined in the format of the four criteria of BSC financial customers, internal process, and learning and growth format. By applying the available findings, the performance evaluation of the subject supply chain as to each criterion some strategies are pursued.

To measure consistency, the Cronbach coefficient is applied through Eq. (1):

$$\alpha = \frac{k}{k-1}(1 - \frac{\sum_{i=1}^{k} p_i q_i}{s^2} \tag{1}$$

where k is the question count, p is the correct answer count, q is the wrong answer count, and S^2 is the simultaneous variance of all questions. If the questions are of value state, like the ones in this questionnaire, the questionnaire α Cronbach coefficient rate is obtained through Eq. (2):

$$\alpha = \frac{k}{k-1}(1 - \frac{\sum_{i=1}^{k} s_i^2}{s^2}) \tag{2}$$

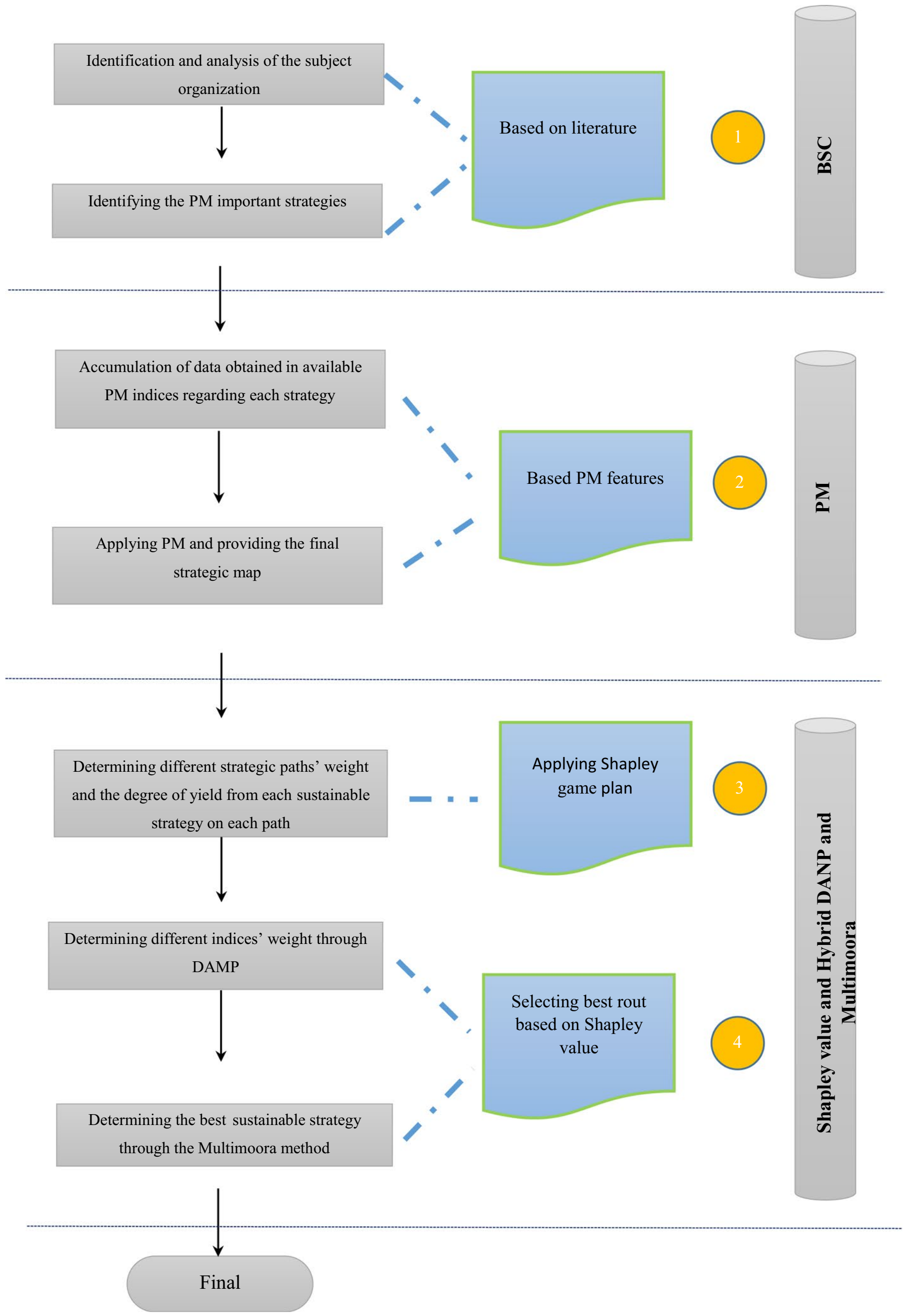

Fig. 2 Flowchart of the proposed intelligent performance analysis system

where S_i^2 is every question's variance. It is held that at α Cronbach coefficient rate$^{>}$0.7, the questionnaire is appropriately consistent.

3.2 Determining the relations among the strategies through path analysis

The cause and effect relations among the strategies are determined here. There is a direct relationship between one strategic state and the other. In each one of the BSC criteria, at least one sustainable strategy can be selected; thus, the relations among the strategies in each criterion are not considered in one package, and consequently, the initial path analysis model is charted as shown in Fig. 3.

In Fig. 3, L1, L2, and L3 represent the three strategies defined in the learning and growth criterion. In the same pattern, the I_1, I_2, $I_{3,}$ and C_1, C_2, $C_{3,}$ and F_1, F_2, and F_3 represent the three strategies selected in stage one for the internal process, customers, and financial criteria, respectively.

As observed, the cause and effect relations among the strategies, at one level, must be assessed through a sustainable strategy at three levels higher, provided that the measurable data for each strategy is available to determine the measuring indices for each strategy which would lead to determining the relations among the strategies cause and effect.

To analyze the different paths, the t test is applied. Assume that the two X and Y variables are available for determining the existence or non-existence of correlations therein, then the assumption test $H_0 : \rho = 0$, where ρ symbolizes the correlation coefficient between these variables which must be assessed.

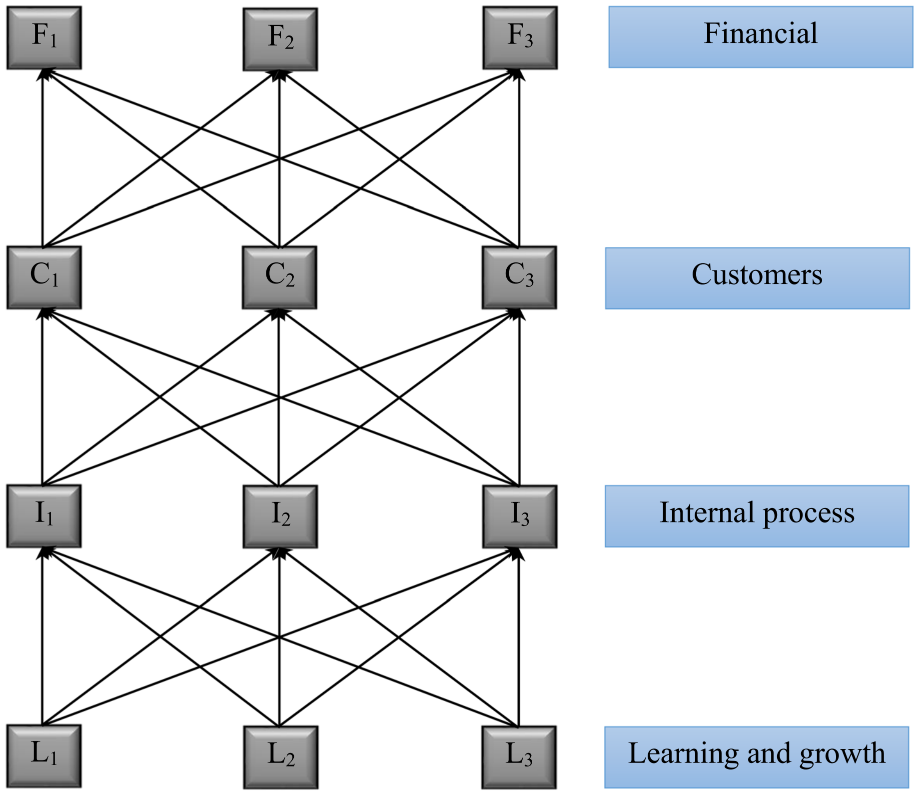

Fig. 3 Initial path analysis model

As shown in Fig. 3, if this step is not followed, a total of 81, that is, 3^4 general states can be considered among the variables, where most of the paths have no contribution in improving one another, thus eliminating the senseless correlations on the path.

3.3 Determining the sustainable strategy paths weights by applying the Shapley value

To accomplish this, the volumes ΔF (s_1, s_2, s_3, s_4) of the evolutionary game theory (EGT) are applied, accompanied by the Shapley value, one of the solutions in EGT.

In this method, a limited count of players (n), expressed as $N(1, 2, 3, \dots, n)$ are of concern. Each one of the $K, L \subseteq N$ subsets is named one coalition, that is, subsets contain players from set N not available in coalition K.

Assume that a coalition with K players is able to obtain the maximum guaranteed points at $V(K)$ volume, then $V(K)$ is named a feature function determined subject to $K \subseteq N$ conditions, which is accomplish by Eq. (3).

$$V(K \cup L) \geq V(K) + V(L) \quad \forall K \geq L \neq \emptyset, K, L \subseteq N \tag{3}$$

Equation (3) indicates that the value of one coalition consists of the sum of two elements of at least equal value. Here, first, the volumes of $V(s_i)$ related to each strategy that indicates the feature function therein must be determined. The $V(s_i)$ represents the strategy value of i^{th} organization, which is obtained by applying the fuzzy AHP for selecting 12 strategies through the experts of the organizations.

The fuzzy AHP method is a simple and practical decision-making method in which the weight of each criteria is obtained by using pairwise comparison. In this research, each of the strategies is used as a criterion in the fuzzy AHP method, and by performing the steps of this method, their weight is obtained.

Following this, the $V(k)$ volume, whole k is the coalition of players with their own specific strategy is calculated by observing the second property above. An example, provided in Eqs. (4–5).

$$V(I_1) = 0.047, \ V(L_1) = 0.035 \tag{4}$$

$$V(L_1 \cup I_1) \geq V(L_1) + V(I_1) = 0.047 + 0.035 = 0.082 \tag{5}$$

Now that all V volumes of coalitions 2 and 3 are obtained, the Shapley value of every different path member is obtained through Eq. (6).

$$\psi v_i = \sum_{j:j \notin i} \frac{j!(n-1-j)!}{n!} (V(j \cup \{i\}) - V(j)) \tag{6}$$

In this study, coalition values of four members are considered as 1, indicating the value of all paths is similar for the decision-maker.

3.4 Determining the best strategic path through DANP

3.4.1 The DANP technique

The steps of DANP are determined as follows.

Step 1 The direct relation matrix calculation:
Assessing the relation among the criteria (criterion interaction) is run under the experts' supervision by applying ranking spectrum within 0 (no effect), 1 (slight effect), 2 (moderate effect), 3 (high effect), and 4 (very high effect).
In this process, if they believe that criterion i affects criterion j, this phenomenon must be expressed as d_c^{ij}, thus at $D = \left[d_c^{ij}\right]$, there exists a direct relation.

$$D = \begin{bmatrix} d_c^{11} & \dots & d_c^{1j} & \dots & d_c^{1n} \\ \vdots & & \vdots & & \vdots \\ d_c^{i1} & \dots & d_c^{ij} & \dots & d_c^{in} \\ \vdots & & \vdots & & \vdots \\ d_c^{n1} & \dots & d_c^{nj} & \dots & d_c^{nn} \end{bmatrix} \tag{7}$$

Step 2 Direct relation matrix normalization.
Matrix D is normalized through Eq. (7), where matrix N is obtained:

$$N = VD; V = \min\{1/\max_i \sum_{j=1}^{n} d_{ij}, 1/\max_j \sum_{i=1}^{n} d_{ij}\}, i,j \in \{1, 2, \dots, n\} \tag{8}$$

Step 3 The total relation matrix calculation.
After matrix D is normalized and matrix N is yield, T, the total relation matrix is obtained through Eq. (9):

$$T = N + N^2 + \dots + N^h = N(I - N)^{-1}, \text{ when } h \to \infty \tag{9}$$

where I is an identity matrix, next, the T_C can be obtained through Eq. (10):

$$\boldsymbol{T}_c = \begin{array}{c c} & \begin{array}{ccccc} \boldsymbol{D}_1 & & \boldsymbol{D}_j & & \boldsymbol{D}_n \\ c_{11}\dots c_{1m_1} & \cdots & c_{j1}\ .c_{jm_j} & \cdots & c_{n1}\dots c_{nm_n} \end{array} \\ \begin{array}{cc} \boldsymbol{D}_1 & \begin{array}{c} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{array} \\ \vdots & \vdots \\ \boldsymbol{D}_i & \begin{array}{c} c_{i1} \\ c_{i2} \\ \vdots \\ c_{im_i} \end{array} \\ \vdots & \vdots \\ \boldsymbol{D}_n & \begin{array}{c} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{array} \end{array} & \begin{bmatrix} \boldsymbol{T}_c^{11} & \dots & \boldsymbol{T}_c^{1j} & \dots & \boldsymbol{T}_c^{1n} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{i1} & \dots & \boldsymbol{T}_c^{ij} & \dots & \boldsymbol{T}_c^{in} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{n1} & \dots & \boldsymbol{T}_c^{nj} & \dots & \boldsymbol{T}_c^{nn} \end{bmatrix} \end{array} \tag{10}$$

Step 4 Determining the effective criteria.
Here, the sum of the rows and columns of T_C matrix are calculated separately through Eqs. (11)-(12):

$$\boldsymbol{r} = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \tag{11}$$

$$\boldsymbol{c} = [c_j]_{1\times n} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n} \tag{12}$$

where r_i is the sum of *ith* row and c_j is that of the sum *jth* column of matrix T_c. The r_i+c_j index is the sum of *ith* row and *jth* column. At the general state when r_i-c_i is positive, the *ith* criterion is effective, otherwise affected.

Step 5 Total relation matrix dimensions ($T_D^{\propto}$) normalization.

The T_D matrix is obtained from T_c and is normalized through Eq. (13), in a sense that the sum of each row is calculated, and every element is divided into its own row sum.

$$T_D = \begin{bmatrix} t_{11}^{D_{11}} & \dots & t_{1j}^{D_{1j}} & \dots & t_{1m}^{D_{1m}} \\ \vdots & & \vdots & & \vdots \\ t_{i1}^{D_{i1}} & \dots & t_{ii}^{D_{ij}} & \dots & t_{im}^{D_{im}} \\ \vdots & & \vdots & & \vdots \\ t_{m1}^{D_{m1}} & \dots & t_{mj}^{D_{mj}} & \dots & t_{mm}^{D_{mm}} \end{bmatrix} \tag{13}$$

Step 6 Normalization of T_D ($T_D^{\propto}$) criteria is obtained through Eqs. (14–15):

$$d_{ci}^{11} = \sum_{j=1}^{m_1} t_{cij}^{11}, i = 1, 2, \dots, m_1 \tag{14}$$

$$\boldsymbol{T}_{\boldsymbol{C}}^{\propto 11} = \begin{bmatrix} t_{c11}^{11}/d_{c1}^{11} & \dots & t_{c1j}^{11}/d_{c1}^{11} & \dots & t_{c1m1}^{11}/d_{c1}^{11} \\ \vdots & & \vdots & & \vdots \\ t_{ci1}^{11}/d_{ci}^{11} & \dots & t_{cij}^{11}/d_{ci}^{11} & \dots & t_{cim1}^{11}/d_{ci}^{11} \\ \vdots & & \vdots & & \vdots \\ t_{cm11}^{11}/d_{cm1}^{11} & \dots & t_{cm1j}^{11}/d_{cm1}^{11} & \dots & t_{cm1m1}^{11}/d_{cm1}^{11} \end{bmatrix} == \begin{bmatrix} t_{c11}^{\propto 11} & \dots & t_{c1j}^{\propto 11} & \dots & t_{c1m1}^{\propto 11} \\ \vdots & & \vdots & & \vdots \\ t_{ci1}^{\propto 11} & \dots & t_{cij}^{\propto 11} & \dots & t_{cim1}^{\propto 11} \\ \vdots & & \vdots & & \vdots \\ t_{cm11}^{\propto 11} & \dots & t_{cm1j}^{\propto 11} & \dots & t_{cm1m1}^{\propto 11} \end{bmatrix} \tag{15}$$

Step 7 Supermatrix (W) formation.

Here, by transposing $T_C^{\propto}$ matrix the W matrix is yield via Eq. (16).

$$W = (T_C^{\propto}) = \begin{bmatrix} W^{11} & \dots & W^{i1} & \dots & W^{n1} \\ \vdots & & \vdots & & \vdots \\ W^{1j} & \dots & W^{ij} & \dots & W^{nj} \\ \vdots & & \vdots & & \vdots \\ W^{1n} & \dots & W^{in} & \dots & W^{nn} \end{bmatrix} \tag{16}$$

Step 8 Weighted supermatrix formation.

The $T_C^{\propto}$ is transposed and multiplied by the imbalanced matrix as Eq. (17):

$$\boldsymbol{W}^{\propto} = \boldsymbol{T}_{\boldsymbol{D}}^{\propto}\boldsymbol{W} = \begin{bmatrix} t_D^{\propto 11} \times W^{11} & \dots & t_D^{1i1} \times W^{i1} & \dots & t_D^{\propto n1} \times W^{n1} \\ \vdots & & \vdots & & \vdots \\ t_D^{\propto 1j} \times W^{1j} & \dots & t_D^{\propto ij} \times W^{ij} & \dots & t_D^{\propto nj} \times W^{nj} \\ \vdots & & \vdots & & \vdots \\ t_D^{\propto 1n} \times W^{1n} & \dots & t_D^{\propto in} \times W^{in} & \dots & t_D^{\propto nn} \times W^{nn} \end{bmatrix} \tag{17}$$

Step 9 Balanced supermatrix formation.

This matrix becomes restricted by inflating it into Z integer through powering to a point that it becomes converged with the supermatrix and reaches stability. The output of this essential step would be the DANP, expressed as Eq. (18).

$$\lim_{Z\to\infty} (W^{\propto})^{Z} \tag{18}$$

3.4.2 The multi-objective optimization on basics of ratio analysis (Multimoora)

Multi-objective optimization on the basics of ratio analysis is applied based on Pasaribu et al., (2018), where the two ratio system and reference point indexes are provided, and the same are applied here. The steps of Multimoora is as follows:

Step1 Decision-making matrix formation.

The formation of this matrix is based on criteria-alternative, where the criteria are presented in columns and the alternatives in rows.

Step2 Decision-making matrix normalization.

Equation (19) is applied for this purpose:

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^{2}}} i = 1,2,\dots,m \tag{19}$$

Step 3 Ranking the alternatives based on the ratio system index.

In order to rank the alternatives, Eq. (20) is applied.

$$y_j^{*} = \sum_{i=1}^{i=g} w_j x_{ij}^{*} - \sum_{i=g+1}^{i=m} w_j x_{ij}^{*} \tag{20}$$

where the first sum is related to the positive criteria, and the next is for negative ones.

Step 4 Ranking the criteria based on the reference point index.

Here, the reference point of each one of the criteria must be obtained, where the positive criteria equal the highest weighted value, and the opposite holds for the negative. The mathematical expressions are as Eqs. (21–22):

$$\mathrm{r_i} = \max_{\mathrm{j}}\{w_j \mathrm{x_j^{*}}\} \quad \text{for positive criteria} \tag{21}$$

$$\mathrm{r_i} = \min_{\mathrm{j}}\{w_j \mathrm{x_j^{*}}\} \quad \text{for negative criteria} \tag{22}$$

In this index, the ranking of the alternatives is performed through Eq. (23):

$$\min_j\{\max_i|w_j r_i - w_j x^*_{ij}| \tag{23}$$

where in each row, the highest weighted value of d_{ij} is selected, followed by selecting the lowest weighted value therein as the best criteria.

Step 4: Ranking the alternatives based on a complete multiplication index.

This complete multiplication index is obtained through Eq. (24) upon which the alternatives are ranked:

$$U_i = \frac{\prod_{j=1}^{g}\left(w_j x^*_{ij}\right)}{\prod_{j=g+1}^{n}\left(w_j x^*_{ij}\right)} \tag{24}$$

4 The numerical results

In this section, the numerical results obtained by applying the proposed method are presented. In this regard, the supply chain of petrochemical products in Iran has been studied. In this chain, due to the existence of different companies and a variety of products, designing a supply chain performance evaluation system is very important and key. The results are classified based on the explained steps of the proposed method.

4.1 Identification and analysis of the subject organization

In this study, according to the structure of the petrochemical supply chain in Iran, in the financial criterion, six strategies are extracted: (1) concentration on infraction transfer cost reduction, (2) budget fluctuation rate reduction, (3) p/hour production cost reduction, (4) improving capital return rate, (5) improving supplier operations status as to cost reduction and (6) increasing profits by improving the sales mechanism strategies are of concern.

As to the customer criterion, the seven sustainable strategies selected: (1) improving supply and distribution operations, (2) scheduling programs to improve order and distribution lead time, (3) introducing new products fit to customer demand, (4) allowing more flexibility in service provision to respond customer demand, (5) improving response system and sense of responsibility as to defected or returned products, (6) establishing appropriate collaboration with the customer through surveys and (7) improve customer satisfaction strategies are of concern.

To measure the supply chain in its internal process, the six sustainable strategies are obtained: (1) generating more effectiveness in the main production program, (2) reducing scheduling time, (3) reducing purchase time cycle, (4) improving the production techniques, (5) reducing general inventory cost and (6) expanding and improving order registration method strategies are analyzed. As to manpower job description in distribution and supply sections, applying more technical tools and increasing information sharing, and expanding new innovative ideas are of concern. By applying a two-way questionnaire, in each field, the three strategies with the highest scores are selected, as given in Table 2.

The subject questionnaire is distributed among 135 plant experts, professionals and managers, and customers in the food and drug outfits and standard office professionals, where only 120 responded within which, after statistical analysis on the results, three

Table 2 Sustainable strategies in the case study

Category	Factors and indices	Respondent count	Mean	SD	category	Factors and indices	Respondent count	Mean	SD
Financial	F_1: Budget fluctuations reduction level	120	5.850	0.7888	Customer	C_1: Planning for better order and distribution lead time	120	5.758	1.4937
	F_2: P/h production cost reduction	120	6.508	0.7041		C_2: Improving response and responsibility as to defected or returned goods	120	5.550	1.4422
	F_3: Improving sales level in relation to scheduling	120	6.358	0.9858		C_3:Improving custom satisfaction rate	120	5.783	1.3917
Internal process	I_1: Producing scheduling time cycle	120	6.275	1.3171	Learning and growth	L_1: Applying more advanced technological tools	120	4.367	1.1054
	I_2: Reducing purchasing time cycle	120	5.883	1.3059		L_2: Expanding the efficiency training as to employees job description in distribution and supply section	120	4.633	1.1276
	I_3: Reducing inventory cost	120	5.708	1.2557		L_3: Expanding new ideas for improvement	120	4.167	1.0705

strategies are selected for each field. To measure the questionnaire reliability rate, the α Cronbach coefficient is applied, which is 0.73% for the whole questionnaire, indicating appropriate reliability. The statistical analyses are run in SPSS software.

4.2 Determining the correlations among the strategies through path analysis

The measuring indices of each sustainable strategy must be determined to accumulate data, which are of 12 periods of 6 months each, as shown in Table 3. Following, these 27 hypotheses tests are expanded through these data, which are run in doublets among different elements according to the initial path analysis model, as shown in Fig. 4.

In the path analysis method, the statistical tests of the relation among the variables ignored in the hypothesis test are eliminated after implementing, which makes the final analysis as given in Table 4, and the final paths are shown in Fig. 4.

Now, the strategic paths are adjusted from 81 to 24 states and shown in Table 5.

As given in Table 5 and Fig. 4, out of all possible paths, 24 have been selected. These paths are identified using the test given in Table 4. In other words, in the path analysis method, the relationships between different factors can be analyzed, and the strongest relationships can be determined in the form of several selected paths. These factors are then ranked using the fuzzy AHP method.

4.3 Determining the weight of the strategic path through Shapley value

The $V(S_i)$ values which are calculated for each sustainable strategy through fuzzy AHP are shown in Table 6.

The $V(k)$ volumes, where k is a multi-coalition of the above strategies, are obtained from the experts and illustrated in Appendix Table 15. In Table 15, the volumes in bold show the highest V volume according to which the initial paths can be selected.

4.4 Determining the best strategic path through DANP and Multimoora combined method

Here, for $S1$, S2, $S3$, and S4, indices are subject to study as the main criteria, and each one of the triad indices is the sub-criteria. The five out of 24 paths are selected through the Multimoora method as the best for the decision-making process, as given in Table 7.

4.5 The obtained numerical results

The direct correlation matrix of the study factors is formed for evaluating their relations (the effect of one factor on the other) by considering the experts' ideas based on the 0–4 spectrum. In the DANP technique, when the model contains both the criteria and the sub-criteria, the direct correlation matrix is formed only for the latter to assess the factors through six experts who make the mean of their colleagues and illustrated in Appendix Table 16. By applying Eqs. (9–10), this direct correlation matrix is formed, which is shown in Appendix Table 17.

Table 3 Measuring indices data of each sustainable strategy

BSC	Symbol	sustainable Strategy	Measuring indices	1st 6 months, 2014	2nd 6 months, 2014	1rd 6 months, 2015	2nd 6 months 2015	1st 6 months, 2016	2nd 6 months, 2016	1st 6 months, 2017	2nd 6 months, 2017	1st 6 months, 2018	2nd 6 months, 2018	1st 6 months, 2019	2nd 6 months, 2019
Learning and growth	L_1	Applying more technological tools	The applied new facilities and technologies in relation to the old ones (p/percent)	24.00	24.00	26.00	37.00	37.00	37.00	41.15	44.30	44.30	44.30	53.80	53.80
	L_2	Expanding efficiency training as to employees job description distribution and supply	The time spent per capita training of each period	4.50	2.00	3.45	4.50	3.25	5.20	4.35	3.00	6.20	5.45	4.20	5.45
	L_3	Expanding new ideas for improvement	The studies run in R&D department in relation to the whole projects in each period (P/percent)	33.30	36.74	35.44	37.33	35.30	36.23	31.40	34.30	36.45	36.43	38.20	39.01

Table 3 (continued)

BSC	Symbol	sustainable Strategy	Measuring indices	1st 6 months, 2014	2nd 6 months, 2014	1rd 6 months, 2015	2nd 6 months 2015	1st 6 months, 2016	2nd 6 months, 2016	1st 6 months, 2017	2nd 6 months, 2017	1st 6 months, 2018	2nd 6 months, 2018	1st 6 months, 2019	2nd 6 months, 2019
Internal process	I_1	Reducing scheduling time cycle	Production planning time cycle mean (p/percent)	2.50	2.50	2.10	2.04	2.60	2.37	2.22	1.87	2.02	1.70	1.64	1.68
	I_2	Reducing ordering time cycle	Material order-purchase time cycle (p/day)	12.00	12.70	12.30	11.20	11.60	11.30	11.10	12.00	10.50	11.00	10.40	10.80
	I_3	Reducing inventory cost	Material and product inventory cost mean (p/h, p/Rls.)	783,450	754,460	836,220	844,490	838,460	836,330	840,070	823,400	873,330	864,500	900,340	923,040

Table 3 (continued)

BSC	Symbol	sustainable Strategy	Measuring indices	1^{st} 6 months, 2014	2^{nd} 6 months, 2014	1^{rd} 6 months, 2015	2^{nd} 6 months 2015	1^{st} 6 months, 2016	2^{nd} 6 months, 2016	1^{st} 6 months, 2017	2^{nd} 6 months, 2017	1^{st} 6 months, 2018	2^{nd} 6 months, 2018	1^{st} 6 months, 2019	2^{nd} 6 months, 2019
customers	C_1	Developing schedule to improve order and distribution lead time	Product order-delivery to customer time mean (p/day)	7.00	7.00	7.30	6.30	6.50	6.40	6.70	5.50	5.40	5.50	5.60	5.30
	C_2	Improving response and responsibility regarding defective and returned goods	Returned goods percentage	85.00	80.00	70.00	78.00	89.00	87.00	78.00	76.00	88.00	92.00	86.00	94.00
	C_3	Improving customer satisfaction rate	Customer satisfaction rating (p/survey)	65.00	63.00	63.50	63.00	71.00	73.00	69.00	65.00	69.00	70.00	73.00	70.00

Table 3 (continued)

BSC	Symbol	sustainable Strategy	Measuring indices	1st 6 months, 2014	2nd 6 months, 2014	1rd 6 months, 2015	2nd 6 months 2015	1st 6 months, 2016	2nd 6 months, 2016	1st 6 months, 2017	2nd 6 months, 2017	1st 6 months, 2018	2nd 6 months, 2018	1st 6 months, 2019	2nd 6 months, 2019
Financial	F_1	Reducing budget fluctuation rate	Budget level (p/Rls.)	4.20E+09	4.20E+09	4.20E+09	4.00E+09	3.85E+09	4.30E+09	4.85E+09	5.05E+09	4.85E+09	5.25E+09	5.00E+09	5.40E+09
	F_2	P/h production cost reduction	Overlap cost (p/Rls)	1,006,050	1,128,180	1,046,290	1,173,310	1,109,070	1,243,710	1,197,800	1,343,200	1,619,040	1,813,330	1,942,850	2,176,000
	F_3	Improving sales rate in relation to scheduling	Sell to predicted demand (Percent)	87.00	85.40	86.34	89.25	72.23	78.56	78.45	84.78	84.67	85.44	85.54	85.35

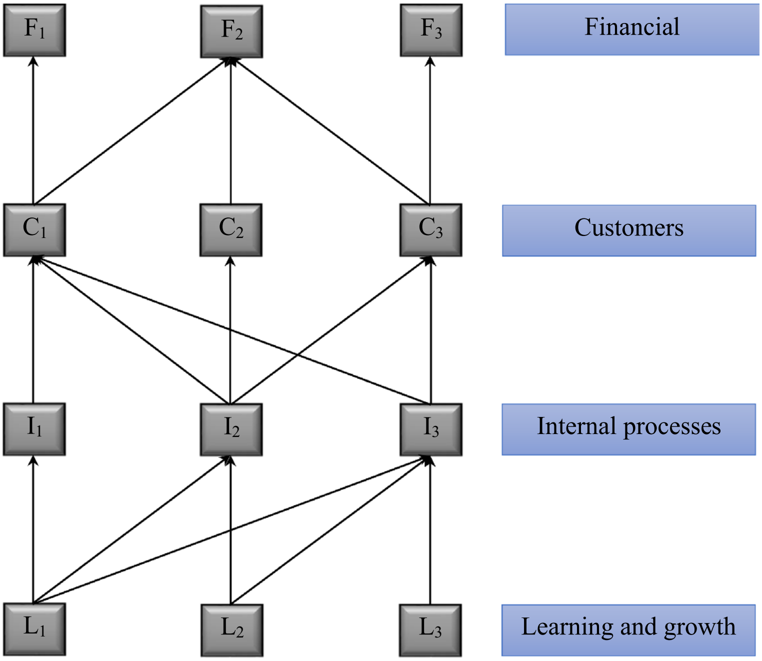

Fig. 4 Final model from path analysis

Here, to begin with, it is necessary to form casual correlations. The correlation matrix of all values for D and R are calculated through Eq. (11) and are tabulated in Table 8.

By applying Eq. (13), the ($T_D^{\propto}$) is obtained, which is normalized, where each cell is divided into the sum of its own row to form its transpose. The results are tabulated in Table 9.

The supermatrix formed by applying Eqs. (16–17) is presented in Table 10.

At this point, the criterion and sub-criteria final weighting are determined with respect to the super-threshold matrix, and the cells of which are the final weights of the study factors tabulated in Table 11.

The results here indicate that the two improvement responses are identified as the best indices in the petrochemical industry in Iran, and reveal the importance of high product return with respect to all criteria, thus, operational improvement.

4.6 The Multimoora results

Through this method, five ranking choices (five paths) are assessed, where, first decision-making matrix is formed, as given in Table 12.

After this matrix is weighted, the choices ranking is calculated based on three system relations, reference points, and complete multiplication approaches (Table 13).

The choice ranking is obtained by applying the dominant theory, as shown in Table 14 and Fig. 5.

As observed in this table, choice A2 has the first ranking followed by A1 and A5, that is, the best path is known as L_1 l_1 C_1 F_2. This intelligent system for petrochemical plants

Table 4 Analytic model statistic results

Test	Dependent agent	Independent agent	Effectiveness type	Hypothesis	Statistical volume	α	Test result
1	I1	L1	+	H1	3.96	0.01	√
2	I2	L1	+	H2	4.80	0.01	√
3	I3	L1	+	H3	5.78	0.01	√
4	I1	L2	+	H4	1.45	–	×
5	I2	L2	+	H5	4.04	0.01	√
6	I3	L2	+	H6	2.18	0.05	√
7	I1	L3	+	H7	1.75	–	×
8	I2	L3	+	H8	1.17	–	×
9	I3	L3	+	H9	1.88	0.10	√
10	C1	I1	+	H10	3.78	0.01	√
11	C2	I1	+	H11	0.60	–	×
12	C3	I1	+	H12	0.83	–	×
13	C1	I2	+	H13	3.27	0.01	√
14	C2	I2	+	H14	2.26	0.05	√
15	C3	I2	+	H15	3.01	0.05	√
16	C1	I3	+	H16	3.34	0.01	√
17	C2	I3	+	H17	1.72	–	×
18	C3	I3	+	H18	1.89	0.10	√
19	F1	C1	+	H19	3.91	0.01	√
20	F2	C1	+	H20	5.06	0.01	√
21	F3	C1	+	H21	0.85	–	×
22	F1	C2	+	H22	1.29	–	×
23	F2	C2	+	H23	2.65	0.05	√
24	F3	C2	+	H24	0.22	–	×
25	F1	C3	+	H25	1.68	–	×
26	F2	C3	+	H26	2.30	0.05	√
27	F3	C3	+	H27	2.12	0.10	√

Table 5 Selected strategic paths

1	L1→I1→C1→F1	9	L1→I3→C1→F2	17	L2→I3→C1→F1
2	L1→I1→C1→F2	10	L1→I3→C3→F2	18	L2→I3→C1→F2
3	L1→I2→C1→F1	11	L1→I3→C3→F3	19	L2→I3→C3→F2
4	L1→I2→C1→F2	12	L2→I2→C1→F1	20	L2→I3→C3→F3
5	L1→I2→C2→F2	13	L2→I2→C1→F2	21	L3→I3→C1→F1
6	L1→I2→C3→F2	14	L2→I2→C2→F2	22	L3→I3→C1→F2
7	L1→I2→C3→F3	15	L2→I2→C3→F2	23	L3→I3→C3→F2
8	L1→I3→C1→F1	16	L2→I2→C3→F3	24	L3→I3→C3→F3

indicates applying technological apparatus at their best, the organizational operation would improve, where the time cycle scheduling will reduce and an orderly order placing, and

Table 6 $V(Si)$ values obtained through fuzzy AHP

V	The value obtained by fuzzy AHP	V	The value obtained by fuzzy AHP
V(L1)	0.035	V(C1)	0.145
V(L2)	0.013	V(C2)	0.091
V(L3)	0.025	V(C3)	0.062
V(I1)	0.047	V(F1)	0.145
V(I2)	0.066	V(F2)	0.201
V(I3)	0.021	V(F3)	0.149

Table 7 Symbolizing the selected paths for ranking

The selected routs	Alternative symbol
L1 → I1 → C1 → F1	A1
L1 → I1 → C1 → F2	A2
L1 → I2 → C1 → F1	A3
L1 → I2 → C1 → F2	A4

Table 8 *D* and *R* indices

	F1	F2	F3	C1	C2	C3	I1	I2	I3	L1	L2	L3
F1	0.142	0.179	0.168	0.186	0.244	0.252	0.253	0.258	0.253	0.183	0.176	0.177
F2	0.179	0.143	0.175	0.176	0.247	0.249	0.257	0.250	0.247	0.187	0.187	0.177
F3	0.185	0.190	0.135	0.183	0.245	0.259	0.257	0.256	0.248	0.188	0.177	0.181
C1	0.177	0.181	0.184	0.139	0.246	0.253	0.256	0.255	0.247	0.187	0.184	0.195
C2	0.191	0.196	0.173	0.192	0.194	0.259	0.260	0.264	0.255	0.194	0.191	0.185
C3	0.193	0.186	0.175	0.178	0.250	0.193	0.257	0.253	0.242	0.184	0.177	0.188
I1	0.184	0.182	0.171	0.169	0.243	0.248	0.193	0.247	0.248	0.182	0.184	0.188
I2	0.171	0.189	0.171	0.168	0.235	0.242	0.246	0.186	0.237	0.175	0.170	0.182
I3	0.184	0.186	0.170	0.181	0.239	0.248	0.253	0.248	0.187	0.178	0.178	0.179
L1	0.195	0.195	0.180	0.180	0.250	0.265	0.258	0.260	0.252	0.149	0.191	0.190
L2	0.189	0.189	0.176	0.170	0.248	0.256	0.256	0.265	0.254	0.195	0.142	0.195
L3	0.187	0.199	0.186	0.189	0.254	0.261	0.261	0.259	0.254	0.192	0.189	0.150

Table 9 Normalized of transposed (T_D^{∞})

	S1	S2	S3	S4
S1	0.206	0.220	0.221	0.222
S2	0.286	0.270	0.285	0.284
S3	0.289	0.290	0.274	0.286
S4	0.219	0.220	0.220	0.208

Table 10 Super-threshold matrix

	F1	F2	F3	C1	C2	C3	I1	I2	I3	L1	L2	L3
F1	0.338	0.338	0.338	0.338	0.338	0.338	0.338	0.338	0.338	0.338	0.338	0.338
F2	0.342	0.342	0.342	0.342	0.342	0.342	0.342	0.342	0.342	0.342	0.342	0.342
F3	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320	0.320
C1	0.265	0.265	0.265	0.265	0.265	0.265	0.265	0.265	0.265	0.265	0.265	0.265
C2	0.363	0.363	0.363	0.363	0.363	0.363	0.363	0.363	0.363	0.363	0.363	0.363
C3	0.372	0.372	0.372	0.372	0.372	0.372	0.372	0.372	0.372	0.372	0.372	0.372
I1	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337
I2	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335	0.335
I3	0.328	0.328	0.328	0.328	0.328	0.328	0.328	0.328	0.328	0.328	0.328	0.328
L1	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337
L2	0.327	0.327	0.327	0.327	0.327	0.327	0.327	0.327	0.327	0.327	0.327	0.327
L3	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336	0.336

supply program is of concern. A reduction in production cost is evident in this sustainable strategy as well.

5 Discussion

The final result of implementing the proposed intelligent performance evaluation system can be analyzed from four aspects: financial, internal processes, customers, growth and learning. From a financial point of view, it has been found that reducing production costs has the greatest impact on the financial performance of the supply chain. Since production costs account for the bulk of total variable costs in the petrochemical industry, reducing these costs can help improve the financial performance of the supply chain. In terms of internal processes and growth and learning, production cycle scheduling and the use of new technologies, respectively, have the greatest impact on supply chain performance. It is noteworthy that according to the results of path analysis, factors related to customer discussion did not have a significant impact on improving supply chain performance. This is because the petrochemical industry is not a competitive one and the supply chains associated with it do not seek to create competition and increase market share. Accordingly, in this industry, with special attention to internal processes, growth and learning, as well as improving financial performance, the overall performance of the supply chain can be significantly improved.

6 Conclusion

To survive the supply chain, contemporary organizations, in a highly competitive market, must have a practical efficient evaluating system on their agenda. For this purpose, the intelligent operations evaluation system is gained momentum. Performance indexes indicate the proportional change of a state in a determined time frame or point. In defining any index, the objective of measuring that index should be clear as to what it should yield

Table 11 Final weights of the criterion and sub-criteria

Criterion name	Proportional weight	Final weight	Rank
Financial s1	0.218	0.218	2 (S1,S2,S3,S4)
Budget fluctuation rate reduction	0.337959	0.07354	2
Production cost reduction p/h	0.342228	0.074469	1
Sales rate improvement in relation to scheduling	0.319813	0.069591	3
Customer s2	0.281	0.281	3(S1,S2,S3,S4)
Developing a schedule to improve placing order and distribution lead time	0.264612	0.074382	3
Improving a sense of responsibility and response regarding the defected and returned goods	0.362952	0.102026	2
Improving customer satisfaction rate	0.372437	0.104692	1
Internal process S3	0.284	0.284	1(S1,S2,S3,S4)
Reducing scheduling time cycle	0.336501	0.095667	1
Reducing purchase-order time cycle	0.33536	0.095343	2
Reducing general inventory costs	0.328139	0.09329	3
Learning and growth S4	0.217	0.217	4(S1,S2,S3,S4)
Apply more technological apparatus	0.336741	0.073073	1
Expanding efficiency training and focusing on distribution and supply personnel job description	0.327173	0.070996	3
Encouraging the introduction of new ideas for improvement	0.336086	0.072931	2

Table 12 Multimoora decision-making matrix

	F1	F2	F3	C1	C2	C3	I1	I2	I3	L1	L2	L3
A1	4.467	2.933	3.467	2.967	2.967	2.900	3.500	2.833	3.000	2.533	2.400	2.867
A2	3.300	3.433	3.400	2.800	3.200	3.200	3.267	3.100	3.167	2.833	2.500	2.967
A3	3.200	3.467	3.433	3.533	3.233	2.967	3.800	3.033	3.433	3.200	2.467	3.133
A4	3.567	3.067	3.567	3.300	3.367	3.033	3.333	3.267	3.400	3.167	2.567	2.967
A5	3.367	3.167	3.200	3.000	3.138	2.667	3.333	2.933	3.067	2.900	2.467	2.800

Table 13 Alternative ranking

	System relation	Reference point	Complete multiplication
A1	0.263	0.0087	1.32*10–16
A2	0.303	0.0056	5.68*10–16
A3	0.318	0.0069	9.79*10–16
A4	0.306	0.0046	6.30*10–16
A5	0.286	0.0060	3.11*10–16

Table 14 Ranking the choices

	Proportion system	Resource point	Complete multi-plication	Final score
A1	2	1	2	2
A2	1	2	1	1
A3	5	3	5	5
A4	3	5	4	4
A5	4	4	3	3

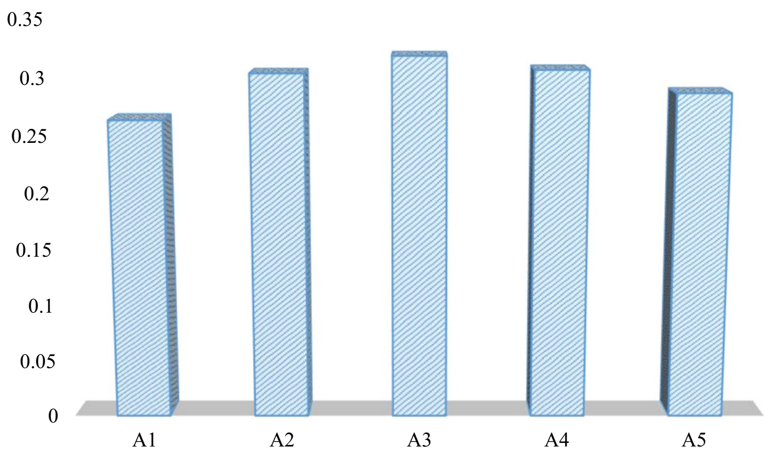

Fig. 5 Financial weights of the subject

of whether there exists the possibility of gathering for this purpose. To accomplish this, an intelligent operation evaluation system is designed by applying the BSC, path analysis, combined Shapley value model, DANP, and Multimoora approach.

This research has faced some limitations. The first limitation of this research is in the collection of input information. Access to more experts and collecting higher-quality information from them is one of the limitations of this research. The second limitation of the research is in evaluating decision-making methods. These methods, despite their high efficiency, were not comparable to their similar methods.

In order to develop this research, it is recommended to develop a multi-objective mathematical method, where better strategies would be identified, and the outcomes would be compared with the findings here. It is also suggested that a comparative evaluation be made between several different decision-making methods, including the best–worst method, TOPSIS, and VIKOR, with the techniques used in this study to demonstrate the superiority of each decision-making method.

Appendix

See Tables 15, 16, 17

Table 15 Coalition values of the model paths

L1→I1→C1→F1	V(L1)=0.035	V(I1)=0.047	V(C1)=0.145
	V(F1)=0.145	V(L1,I1)=0.116	V(L1,C1)=0.210
	V(L1,F1)=0.180	V(I1,C1)=0.272	V(I1,F1)=0.238
	V(C1,F1)=0.290	V(L1,I1,C1)=0.321	V(L1,I1,F1)=0.455
	V(L1,C1,F1)=0.475	V(I1,C1,F1)=0.606	V(L1,I1,C1,F1)=1
L1→I1→C1→F2	V(L1)=0.035	V(I1)=0.047	V(C1)=0.145
	V(F2)=0.201	V(L1,I1)=0.116	V(L1,C1)=0.210
	V(L1,F2)=0.311	V(I1,C1)=0.272	V(I1,F2)=0.350
	V(C1,F2)=0.378	V(L1,I1,C1)=0.321	V(L1,I1,F2)=0.566
	V(L1,C1,F2)=0.571	V(I1,C1,F2)=0.589	V(L1,I1,C1,F2)=1
L1→I2→C1→F1	V(L1)=0.035	V(I2)=0.066	V(C1)=0.145
	V(F1)=0.145	V(L1,I2)=0.121	V(L1,C1)=0.210
	V(L1,F1)=0.180	V(I2,C1)=0.232	V(I2,F1)=0.298
	V(C1,F1)=0.290	V(L1,I2,C1)=0.378	V(L1,I2,F1)=0.691
	V(L1,C1,F1)=0.475	V(I2,C1,F1)=0.534	V(L1,I2,C1,F1)=1
L1→I2→C1→F2	V(L1)=0.035	V(I2)=0.066	V(C1)=0.145
	V(F2)=0.201	V(L1,I2)=0.121	V(L1,C1)=0.210
	V(L1,F2)=0.311	V(I2,C1)=0.232	V(I2,F2)=0.277
	V(C1,F2)=0.378	V(L1,I2,C1)=0.378	V(L1,I2,F2)=0.603
	V(L1,C1,F2)=0.571	V(I2,C1,F2)=0.679	V(L1,I2,C1,F2)=1
L1→I2→C2→F2	V(L1)=0.035	V(I2)=0.066	V(C2)=0.091
	V(F2)=0.201	V(L1,I2)=0.121	V(L1,C2)=0.126
	V(L1,F2)=0.311	V(I2,C2)=0.157	V(I2,F2)=0.277
	V(C2,F2)=0.301	V(L1,I2,C2)=0.272	V(L1,I2,F2)=0.603
	V(L1,C2,F2)=0.462	V(I2,C2,F2)=0.501	V(L1,I2,C2,F2)=1
L1→I2→C3→F2	V(L1)=0.035	V(I2)=0.066	V(C3)=0.062
	V(F2)=0.201	V(L1,I2)=0.121	V(L1,C3)=0.097
	V(L1,F2)=0.311	V(I2,C3)=0.181	V(I2,F2)=0.277
	V(C3,F2)=0.275	V(L1,I2,C3)=0.266	V(L1,I2,F2)=0.603
	V(L1,C3,F2)=0.421	V(I2,C3,F2)=0.427	V(L1,I2,C3,F2)=1
L1→I2→C3→F3	V(L1)=0.035	V(I2)=0.066	V(C3)=0.062
	V(F3)=0.149	V(L1,I2)=0.121	V(L1,C3)=0.097
	V(L1,F3)=0.201	V(I2,C3)=0.181	V(I2,F3)=0.235
	V(C3,F3)=0.240	V(L1,I2,C3)=0.266	V(L1,I2,F3)=0.499
	V(L1,C3,F3)=0.369	V(I2,C3,F3)=0.360	V(L1,I2,C3,F3)=1
L1→I3→C1→F1	V(L1)=0.035	V(I3)=0.021	V(C1)=0.145
	V(F1)=0.145	V(L1,I3)=0.066	V(L1,C1)=0.210
	V(L1,F1)=0.180	V(I3,C1)=0.168	V(I3,F1)=0.175
	V(C1,F1)=0.290	V(L1,I3,C1)=0.301	V(L1,I3,F1)=0.346
	V(L1,C1,F1)=0.475	V(I3,C1,F1)=0.312	V(L1,I3,C1,F1)=1
L1→I3→C1→F2	V(L1)=0.035	V(I3)=0.021	V(C1)=0.145
	V(F2)=0.201	V(L1,I3)=0.066	V(L1,C1)=0.210
	V(L1,F2)=0.311	V(I3,C1)=0.168	V(I3,F2)=0.272
	V(C1,F2)=0.378	V(L1,I3,C1)=0.301	V(L1,I3,F2)=0.458
	V(L1,C1,F2)=0.571	V(I3,C1,F2)=0.513	V(L1,I3,C1,F2)=1

Table 15 (continued)

L1→I3→C3→F2	V(L1) = 0.035	V(I3) = 0.021	V(C3) = 0.062
	V(F2) = 0.201	V(L1,I3) = 0.066	V(L1,C3) = 0.097
	V(L1,F2) = 0.311	V(I3,C3) = 0.085	V(I3,F2) = 0.272
	V(C3,F2) = 0.275	V(L1,I3,C3) = 0.242	V(L1,I3,F2) = 0.458
	V(L1,C3,F2) = 0.421	V(I3,C3,F2) = 0.426	V(L1,I3,C3,F2) = 1
L1→I3→C3→F3	V(L1) = 0.035	V(I3) = 0.021	V(C3) = 0.062
	V(F3) = 0.149	V(L1,I3) = 0.066	V(L1,C3) = 0.097
	V(L1,F3) = 0.201	V(I3,C3) = 0.085	V(I3,F3) = 0.170
	V(C3,F3) = 0.240	V(L1,I3,C3) = 0.242	V(L1,I3,F3) = 0.354
	V(L1,C3,F3) = 0.369	V(I3,C3,F3) = 0.348	V(L1,I3,C3,F3) = 1
L2→I2→C1→F1	V(L2) = 0.013	V(I2) = 0.066	V(C1) = 0.145
	V(F1) = 0.145	V(L2,I2) = 0.080	V(L2,C1) = 0.223
	V(L2,F1) = 0.158	V(I2,C1) = 0.232	V(I2,F1) = 0.298
	V(C1,F1) = 0.290	V(L2,I2,C1) = 0.386	V(L2,I2,F1) = 0.403
	V(L2,C1,F1) = 0.428	V(I2,C1,F1) = 0.534	V(L2,I2,C1,F1) = 1
L2→I2→C1→F2	V(L2) = 0.013	V(I2) = 0.066	V(C1) = 0.145
	V(F2) = 0.201	V(L2,I2) = 0.080	V(L2,C1) = 0.223
	V(L2,F2) = 0.216	V(I2,C1) = 0.232	V(I2,F2) = 0.277
	V(C1,F2) = 0.378	V(L2,I2,C1) = 0.386	V(L2,I2,F2) = 0.503
	V(L2,C1,F2) = 0.538	V(I2,C1,F2) = 0.534	V(L2,I2,C1,F2) = 1
L2→I2→C2→F2	V(L2) = 0.013	V(I2) = 0.066	V(C2) = 0.091
	V(F2) = 0.201	V(L2,I2) = 0.080	V(L2,C2) = 0.138
	V(L2,F2) = 0.216	V(I2,C2) = 0.157	V(I2,F2) = 0.277
	V(C2,F2) = o.301	V(L2,I2,C2) = 0.340	V(L2,I2,F2) = 0.503
	V(L2,C2,F2) = 0.431	V(I2,C2,F2) = 0.501	V(L2,I2,C2,F2) = 1
L2→I2→C3→F2	V(L2) = 0.013	V(I2) = 0.066	V(C3) = 0.062
	V(F2) = 0.201	V(L2,I2) = 0.080	V(L2,C3) = 0.075
	V(L2,F2) = 0.216	V(I2,C3) = 0.181	V(I2,F2) = 0.277
	V(C3,F2) = 0.275	V(L2,I2,C3) = 0.211	V(L2,I2,F2) = 0.503
	V(L2,C3,F2) = 0.390	V(I2,C3,F2) = 0.427	V(L2,I2,C3,F2) = 1
L2→I2→C3→F3	V(L2) = 0.013	V(I2) = 0.066	V(C3) = 0.062
	V(F3) = 0.149	V(L2,I2) = 0.080	V(L2,C3) = 0.075
	V(L2,F3) = 0.185	V(I2,C3) = 0.181	V(I2,F3) = 0.235
	V(C3,F3) = 0.240	V(L2,I2,C3) = 0.211	V(L2,I2,F3) = 0.385
	V(L2,C3,F3) = 0.316	V(I2,C3,F3) = 0.360	V(L2,I2,C3,F3) = 1
L2→I3→C1→F1	V(L2) = 0.013	V(I3) = 0.021	V(C1) = 0.145
	V(F1) = 0.145	V(L2,I3) = 0.048	V(L2,C1) = 0.223
	V(L2,F1) = 0.158	V(I3,C1) = 0.168	V(I3,F1) = 0.175
	V(C1,F1) = 0.290	V(L2,I3,C1) = 0.358	V(L2,I3,F1) = 0.308
	V(L2,C1,F1) = 0.428	V(I3,C1,F1) = 0.312	V(L2,I3,C1,F1) = 1
L2→I3→C1→F2	V(L2) = 0.013	V(I3) = 0.021	V(C1) = 0.145
	V(F2) = 0.201	V(L2,I3) = 0.048	V(L2,C1) = 0.223
	V(L2,F2) = 0.216	V(I3,C1) = 0.168	V(I3,F2) = 0.272
	V(C1,F2) = 0.378	V(L2,I3,C1) = 0.358	V(L2,I3,F2) = 0.470
	V(L2,C1,F2) = 0.538	V(I3,C1,F2) = 0.513	V(L2,I3,C1,F2) = 1

Table 15 (continued)

L2→I3→C3→F2	V(L2)=0.013	V(I3)=0.021	V(C3)=0.062
	V(F2)=0.201	V(L2,I3)=0.048	V(L2,C3)=0.075
	V(L2,F2)=0.216	V(I3,C3)=0.085	V(I3,F2)=0.272
	V(C3,F2)=0.275	V(L2,I3,C3)=0.234	V(L2,I3,F2)=0.470
	V(L2,C3,F2)=0.390	V(I3,C3,F2)=0.426	V(L2,I3,C3,F2)=1
L2→I3→C3→F3	V(L2)=0.013	V(I3)=0.021	V(C3)=0.062
	V(F3)=0.149	V(L2,I3)=0.048	V(L2,C3)=0.075
	V(L2,F3)=0.185	V(I3,C3)=0.085	V(I3,F3)=0.170
	V(C3,F3)=0.240	V(L2,I3,C3)=0.234	V(L2,I3,F3)=0.289
	V(L2,C3,F3)=0.316	V(I3,C3,F3)=0.348	V(L2,I3,C3,F3)=1
L3→I3→C1→F1	V(L3)=0.025	V(I3)=0.021	V(C1)=0.145
	V(F1)=0.145	V(L3,I3)=0.046	V(L3,C1)=0.170
	V(L3,F1)=0.170	V(I3,C1)=0.168	V(I3,F1)=0.175
	V(C1,F1)=0.290	V(L3,I3,C1)=0.286	V(L3,I3,F1)=0.324
	V(L3,C1,F1)=0.473	V(I3,C1,F1)=0.312	V(L3,I3,C1,F1)=1
L3→I3→C1→F2	V(L3)=0.025	V(I3)=0.021	V(C1)=0.145
	V(F2)=0.201	V(L3,I3)=0.046	V(L3,C1)=0.170
	V(L3,F2)=0.225	V(I3,C1)=0.168	V(I3,F2)=0.272
	V(C1,F2)=0.378	V(L3,I3,C1)=0.286	V(L3,I3,F2)=0.419
	V(L3,C1,F2)=0.524	V(I3,C1,F2)=0.513	V(L3,I3,C1,F2)=1
L3→I3→C3→F2	V(L3)=0.025	V(I3)=0.021	V(C3)=0.062
	V(F2)=0.201	V(L3,I3)=0.046	V(L3,C3)=0.092
	V(L3,F2)=0.225	V(I3,C3)=0.085	V(I3,F2)=0.272
	V(C3,F2)=0.275	V(L3,I3,C3)=0.233	V(L3,I3,F2)=0.419
	V(L3,C3,F2)=0.407	V(I3,C3,F2)=0.426	V(L3,I3,C3,F2)=1
L3→I3→C3→F3	V(L3)=0.025	V(I3)=0.021	V(C3)=0.062
	V(F3)=0.149	V(L3,I3)=0.046	V(L3,C3)=0.092
	V(L3,F3)=0.175	V(I3,C3)=0.085	V(I3,F3)=0.170
	V(C3,F3)=0.240	V(L3,I3,C3)=0.233	V(L3,I3,F3)=0.331
	V(L3,C3,F3)=0.354	V(I3,C3,F3)=0.348	V(L3,I3,C3,F3)=1

Table 16 Direct correlation matrix

	F1	F2	F3	C1	C2	C3	I1	I2	I3	L1	L2	L3
F1	0.00	2.00	1.90	2.80	3.20	3.40	3.40	3.70	3.70	2.30	2.10	1.90
F2	2.20	0.00	2.40	2.30	3.50	3.30	3.70	3.30	3.40	2.60	2.80	2.00
F3	2.40	2.60	0.00	2.60	3.20	3.70	3.50	3.50	3.30	2.50	2.10	2.10
C1	1.90	2.00	2.80	0.00	3.20	3.30	3.40	3.40	3.20	2.40	2.50	2.90
C2	2.60	2.80	2.00	3.00	0.00	3.50	3.50	3.80	3.50	2.70	2.80	2.20
C3	3.00	2.50	2.40	2.40	3.70	0.00	3.70	3.50	3.10	2.40	2.20	2.70
I1	2.50	2.30	2.20	1.90	3.30	3.30	0.00	3.20	3.50	2.30	2.70	2.70
I2	2.00	3.00	2.50	2.10	3.20	3.30	3.50	0.00	3.20	2.20	2.10	2.60
I3	2.60	2.60	2.20	2.70	3.10	3.40	3.60	3.30	0.00	2.10	2.40	2.20
L1	2.80	2.70	2.40	2.20	3.20	3.80	3.30	3.40	3.20	0.00	2.70	2.40
L2	2.50	2.40	2.20	1.70	3.20	3.40	3.30	3.90	3.50	2.80	0.00	2.80
L3	2.20	2.80	2.60	2.60	3.30	3.40	3.30	3.20	3.20	2.40	2.50	0.00

Table 17 *Tc* direct correlation matrix

	F1	F2	F3	C1	C2	C3	I1	I2	I3	L1	L2	L3
F1	0.142	0.179	0.168	0.186	0.244	0.252	0.253	0.258	0.253	0.183	0.176	0.177
F2	0.179	0.143	0.175	0.176	0.247	0.249	0.257	0.250	0.247	0.187	0.187	0.177
F3	0.185	0.190	0.135	0.183	0.245	0.259	0.257	0.256	0.248	0.188	0.177	0.181
C1	0.177	0.181	0.184	0.139	0.246	0.253	0.256	0.255	0.247	0.187	0.184	0.195
C2	0.191	0.196	0.173	0.192	0.194	0.259	0.260	0.264	0.255	0.194	0.191	0.185
C3	0.193	0.186	0.175	0.178	0.250	0.193	0.257	0.253	0.242	0.184	0.177	0.188
I1	0.184	0.182	0.171	0.169	0.243	0.248	0.193	0.247	0.248	0.182	0.184	0.188
I2	0.171	0.189	0.171	0.168	0.235	0.242	0.246	0.186	0.237	0.175	0.170	0.182
I3	0.184	0.186	0.170	0.181	0.239	0.248	0.253	0.248	0.187	0.178	0.178	0.179
L1	0.195	0.195	0.180	0.180	0.250	0.265	0.258	0.260	0.252	0.149	0.191	0.190
L2	0.189	0.189	0.176	0.170	0.248	0.256	0.256	0.265	0.254	0.195	0.142	0.195
L3	0.187	0.199	0.186	0.189	0.254	0.261	0.261	0.259	0.254	0.192	0.189	0.150

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