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Investigation of the Level of Adoption of the Lean Philosophy in Small and Medium Enterprises Using integrated Fuzzy Assessment Model Based on Fuzzy DEMATEL / Fuzzy TOPSIS

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Zainab Al-baldawi*, AllaEldin H. Kassam, Sawsan Sabeeh A. Al-Zubaidi

Production Engineering and Metallurgy Dept., University of Technology-Iraq, Alsina'a street, 10066 Baghdad, Iraq.
*Corresponding author Email: Zainab.A.Albaldawi@uotechnology.edu.iq

HIGHLIGHTS

- The adoption of lean philosophy in SMEs, which is important for economies yet under-explored, was assessed
- FMCDM methods were used to efficiently assess SMEs' lean level
- A fuzzy assessment model integrating FDEMATEL and FTOPSIS was used to investigate SMEs' lean adoption
- A cause-effect diagram depicted and distinguished lean dimension types
- Radar maps visually illustrated SMEs' lean level

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ABSTRACT

Lean Production is a continuous improvement philosophy derived from the Toyota Production System (TPS) aimed at improving the operational efficiency and performance of companies. Although the Lean philosophy has been widely applied in large enterprises, its implementation and adoption in small and medium-sized enterprises (SMEs) has remained relatively underexplored. In this paper, a fuzzy assessment model has been proposed that integrates Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (Fuzzy TOPSIS) to aim to investigate the level of implementation and adoption of the lean philosophy in SMEs through five lean dimensions, namely, management, process, supplier, customer, and employee. Fuzzy DEMATEL is used to identify the weight of influence of each lean dimension on SMEs leanness and identify the cause and effect lean dimensions, while Fuzzy TOPSIS is used to investigate and assess the level of adoption of lean philosophy related to these five dimensions in SMEs. The main contribution of this research lies in providing a comprehensive framework for; assessing the level of influence of lean dimensions on SMEs leanness which is an important issue in the improvement process and identifying the level of adoption of lean philosophy in SMEs. The proposed model has been applied in five Iraqi SMEs for producing healthy water and juice. The results show that although the management, employee, and process have the highest weights of influence on SMEs leanness, management, and employee are cause lean dimensions that have a high influence on improving the effect dimensions, process, and customer. The level of adoption of lean philosophy of the assessed SMEs related to the five lean dimensions is in the mid-level so this refers to acceptable implementation of lean philosophy.

1. Introduction

SMEs are considered an engine of sustainable economic development in both developed and developing world [1] and are considered vital contributors to economic growth, employment generation, and innovation. They contribute about 46 % of the global Gross Domestic Product (GDP) and provide between 50% - 60% of the total employment opportunities [2]. It is characterized as independent and non-subsidiary enterprises with a simple organizational structure, limited resources, and employee numbers [2].

In today's complex and dynamic business environment, SMEs face many challenges related to quality improvement, cost, operational efficiency, and competitiveness. SMEs continuously pursue improving their performance to overcome these challenges to ensure staying in competitive markets with their rivals through adopting an efficient manufacturing system like lean production (LP). Lean production is a philosophy for continuous improvement that focuses on involving all enterprise levels in the improvement process to eliminate the eight types of waste (the eight non-added value activities) [3].

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Leanness can be defined as a relative metric that determines whether a company has adopted the lean philosophy or not. It describes the level of adoption of the lean philosophy. Although lean production is a philosophy aimed at reducing or eliminating waste, it involves using fewer resources and generating benefits such as reduced scrap, lower costs of storing, and shorter lead times. In spite leanness can be measured, an ideal indicator for measuring leanness has not developed yet. Nowadays, Many techniques are used to measure leanness as an indicator, like a comparison with some worse or ideal case, a questionnaire to collect qualitative data related to the system from responsible people, and quantitative methods using objective data about the system [3].

Fuzzy Multi-Criteria Decision Making Methods (FMCDM) have been widely used for decision-making and problem-solving. Fuzzy Decision-making Trial and Evaluation Laboratory (FDEMANTEL) and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS) are efficient FMCDM methods that are extensively applied in the field of lean production. FDEMATEL was introduced by Geneva in 1973, and it has been widely applied in decision-making methods to illustrate the relationships among the criteria and distinguish them into effect criteria and cause criteria. It decreases the number of evaluation criteria by emphasizing cause criteria over effect criteria, which is highly beneficial for organizations in performance improvement [4]. In reality, crisp values are not effective because human judgments are largely difficult and indistinct to assess by exact crisp values, due to the imperfection of some evaluation criteria and even uncertain factors thus fuzzy DEMATEL has developed for overcoming this type of MCDM problem [5,6]. The FDEMATEL has been used in different aspects related to lean production. Zhu et al. [7] used the FDEMATEL method for calculating the level of influence, and the centrality and causes for the brittleness factors for the lean–green and analysis of the causal relationships between these factors in the Manufacturing System. Kilic et al. [8] developed a methodology based on neutrosophic DEMATEL to assess the importance weight of five lean dimensions which include process, supplier, performance, human resources management, and inventory. Kang et al. [9] used DEMATEL to identify the importance level and interactions of eight key factors that Increase free cash flow for manufacturers utilizing lean production. These factors include strategic planning, strategic deployment, new product planning, leadership, quality first, quality built into the process, PD matrix management, and goal orientation. Tayaksi et al. [10] developed a comprehensive framework for assessing leanness based on fuzzy DEMATEL for identifying the weight of importance and causal relationships between lean practices in the plastics industry of Turkey that related; manufacturing activities, supplier issues, JIT, cost and financial management, marketing, employees, management responsibility and quality management. Sharma et al. [11] applied DEMATEL for assessing the causal relationships among seventeen lean practices in XYZ machine tool manufacturing companies such; as VSM, JIT, Information technology, Visual control, SMED, Poka-yoke, CIM, ERP, Job scheduling, 5S, Standardized work, Fixed position layout, Cellular Manufacturing, Training, Smart process and automation, TQM and Concurrent engineering. Azadeh et al. [12] Proposed evaluating model based on data envelopment analysis (DEA), fuzzy DEA (FDEA), fuzzy cognitive map (FCM), Decision Making Trial and Evaluation Laboratory (DEMATEL), and Analytic Hierarchy Process (AHP) for evaluating and optimizing the leanness degree of organizations based on twenty leanness factors which include management nature, structure of organization, adaptation of customer reaction, business processes, Changing technical and, JIT flow, Supplier Development, Cellular manufacturing, Streamlining procedures, Worker status ,Worker involvement, Manufacturing setups, Product Service ,Integrated product design, In-house technology, Production procedure, Manufacturing Planning, Quality status , Productivity status ,Cost management and Management of time. FTOPSIS has proposed by Yoon and Hwang where it is based on chosen the alternative that have the shortest distance to Positive Ideal Solution (PIS) and the farthest distance to Negative Ideal Solution (NIS). Fuzzy logic has used into TOPSIS to develop FTOPSIS to deal with situations of ambiguity and uncertainty due to its ability for overcoming the probable shortcomings while dealing with unclear and vagueness in decision making. It can deal with both quantitative and qualitative information [13,14]. Yanfeng Li et al. [15] proposed an assessment model based on TOPSIS for evaluating the lean level of three production lines ABC. Weights of criteria have been calculated by entropy method, Fuzzy CRITIC method, and TOPSIS and then determining the final ranking of the lean level of these production lines as B-C-A or C-B-A. Devnath et al. [16] developed an integrated model based on Quality Function Deployment (QFD) and TOPSIS for evaluating and prioritizing the lean practices and policies for finding and ranking the major wastes on a production floor. House of Quality (HOQ) was used for identifying the major waste by identifying significant waste signs through interviews and then converting those signs into seven major wastes, whereas TOPSIS was used for prioritizing the suitable lean practices and policies. Results illustrated that inventory waste is the crucial one on the shop floor then over production and motion waste. Kanban or pull system, is the best tool for eliminating waste. Mirnoori [17]. Proposed model for evaluating and ranking twenty Lean practices using three MCDM methods; TOPSIS, VIKOR and SAW. Results illustrated that these methods showed approximately the same ranking in evaluation the lean practices. Rajpurohit et al., [18]. Proposed an assessment model using fuzzy TOPSIS for assessing the lean level of three SMEs A, B, C and experts have directly identified criteria weights and rating the firms' performance against lean criteria. The lean performance levels of these SMEs are firm C (0.48) is leaner than firm B (0.46), firm B is leaner than firm A (0.45). Kumar et al., [19] developed a framework for evaluating of lean performance of three firms where experts assessed weights of criteria and rating the firms' performance against lean criteria. Sensitivity analysis has applied for verifying the robustness of the proposed methodology where results show the overall performance of firm 3 > firm 1 > firm 2. Akram et al. [20] used fuzzy TOPSIS to develop an innovative approach for assessing the lean level of Partizan Sanat company using eleven criteria .criteria weights have identified by experts. The company lean level is at the mediocre level of leanness (0.52). Hojjati et al., [21] developed assessment model based on integrating SAW and TOPSIS for evaluating lean practices and policies and ranking them based on their efficacy under four criteria: cost, lead time, value, and defects. The results show that the obtained level of tool scores varies for the four criteria, where the highest score for decreasing lead time, cost, belong to: Continuous flow; Pull system meanwhile highest score for reducing defects belongs to Poka yoke. The surveyed papers have been focused on studying influence of various lean dimensions or activities on enterprise leanness or studying level of adoption lean philosophy in organizations without considering the lean adoption in SMEs with identifying the most influence dimensions on the improvement process. Lack of available of mechanism to assess the level of influence of lean dimensions and the level of adoption lean philosophy in SMEs in case of vague data is the problem that paper address. This paper provides a comprehensive framework aimed at determining the most influence lean dimensions on SMEs leanness and assessing the level of adoption of lean philosophy in these enterprises.

This paper investigated the level of lean adoption in SMEs by proposing an integrated fuzzy assessment model using fuzzy DEMATEL and fuzzy TOPSIS to comprehensively assess the level of influence of the five lean dimensions, namely process, management, supplier, customer, and employee, on SMEs leanness and assess the level of leanness of SMEs related to these dimensions. FDEMATEL was used to identify the weight and level of influence of the five lean dimensions, in addition to categorizing it into cause and effect dimensions by the cause–effect diagram to identify the most influencing one, while FTOPSIS was used to assess the level of SMEs leanness related to these five lean dimensions.

2. Fuzzy Assessment Model

The proposed fuzzy assessment model involves three main stages as shown in Figure 1 and each stage includes many steps as follows:

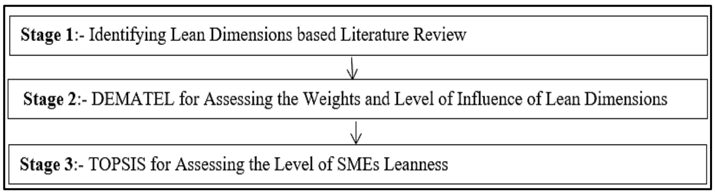

Figure 1: Structure of the Proposed Fuzzy Assessment Model

2.1 Stage 1: Identifying Lean Dimensions through Literature Review

Five lean dimensions have been identified through survey papers from 2016–2021, using keywords lean philosophy, SMEs, and lean dimensions, using Google and Research Gate to identify the weight and level of influence of these lean dimensions on SMEs leanness, as shown in Table 1. Each lean dimension involves various lean activities that lead to improved performance of this dimension as illustrated in Table 2.

Table 1: Lean Dimensions

Management	Process	Supplier	Customer	Employee	Lean Dimensions Ref.
●	●	●	●	●	[22]
●		●	●	●	[23]
	●	●	●	●	[24]
●	●				[25]
●	●	●		●	[10]
●	●	●	●	●	[26]
●	●		●	●	[27]
		●	●	●	[28]
●	●	●	●	●	[29]
	●	●	●		[30]
●		●	●	●	[31]
●	●			●	[32]

Table 2: Description of Lean Dimensions

Lean Dimensions	Description
Management	This dimension Involves many lean practices and policies related to the management dimension such; as management having a close relationship with all employees and motivating, supporting, empowering, and Involving employees in the decision-making process improving company performance also sharing information related to the company with all levels of the company.
Process	This dimension involves lean practices related to shop floor that are applied to improve the performance of the production process and work environment; workplace organization, visual management system, pull approach (Kanban), lot size reduction, preventive maintenance, Poka Yoke, standardization and simplification work, Kazien Team
Supplier	This dimension involves the lean practices and policies related to supplier relationships, evaluation of suppliers' performance based on quality, and cost suppliers development through training them on the needed quality of items and in-time deliveries of the needed items.
Customer	This dimension involves various lean practices and policies that lead to customer satisfaction such; as handling and solving customer complaints by an efficient complaints team in addition to incorporation and execution of customer suggestions, feedback, and requirements in product development.
Employee	This dimension involves lean practices and policies related to employee training, employment of multiskill employees, and encouraging teamwork and job rotation between employees.

2.2 Stage 2: DEMATEL for Assessing the Weights and Level of Influence of Lean Dimensions

Stage Two involves sequential steps to calculate the weights and level of influence of lean dimensions as shown in Figure 2:

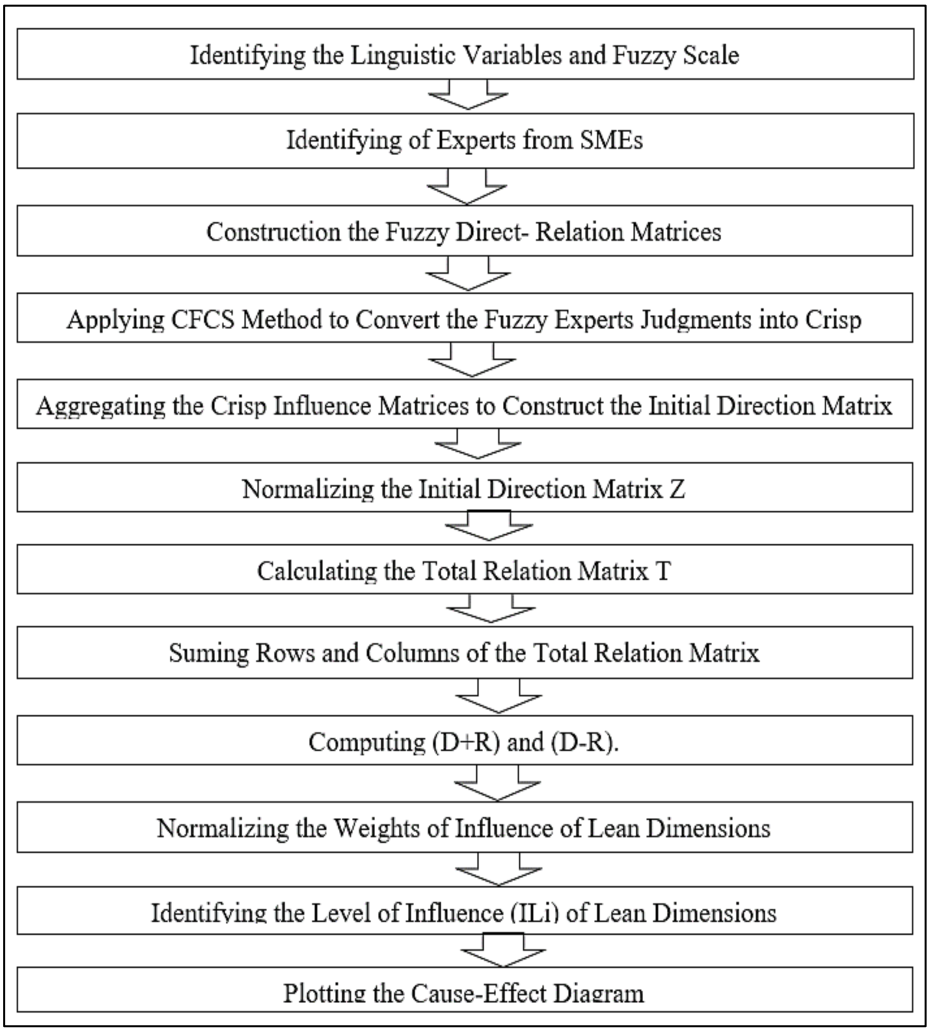

Figure 2: Structure of the Stage Two

2.2.1 Identifying the Linguistic Variables and Fuzzy Scale

The linguistic variables and the fuzzy scale of TFNs have been identified as shown in Table 3

Table 3: Linguistic Variables and Fuzzy Scale of Influence for TFNs [33,34]

Linguistic Variables	Symbol	TFNs	Description
No Influence	NI	(0,0, 0.25)	The two evaluation criteria are not related to each other
Low influence	LI	(0, 0.25, 0.5)	Low correlation between the two evaluation criteria
Medium influence	MI	(0.25,0.5,0.75)	A moderate correlation between the two evaluation criteria
High Influence	HI	(0.5,0.75,1)	A high degree of correlation between the two evaluation criteria
Very High Influence	VHI	(0.75,1,1)	A very high degree of correlation between the two evaluation criteria

2.2.2 Identifying of Experts from SMEs

Five experts were identified to obtain their judgments through a questionnaire about the influence of each lean dimension on SMEs leanness. The experts have been asked to evaluate and identify their opinion about the influence of each lean dimension on the other by pairwise comparison using linguistic variables, Table 3.

2.2.3 Construction of the Fuzzy Direct-Relation Matrices

The fuzzy direct–relation matrices have been constructed to identify the influences of lean dimensions on each other based on the results of the questionnaire, where (0,0,0.25) fuzzy scale was used to refer to the diagonal of a matrix to refer to the comparison of the same dimension as shown in Table 4.

Let, $z_{ij}^{k} = (l_{ij}^{k}, m_{ij}^{k}, u_{ij}^{k})$ is the fuzzy score based on the judgment of the K experts based on Table 3 ,where k=1,2,…..,p.

Then, the expert's judgments have transformed into fuzzy triangular fuzzy numbers (TFNs) as illustrated in Figure 3.

Table 4: The Fuzzy Direct- Relation Matrix

Lean Dimensions	Management	Process	Supplier	Customer	Employee
Management	No Influence				
Processes		No Influence			
Supplier			No Influence		
Customer				No Influence	
Employees					No Influence

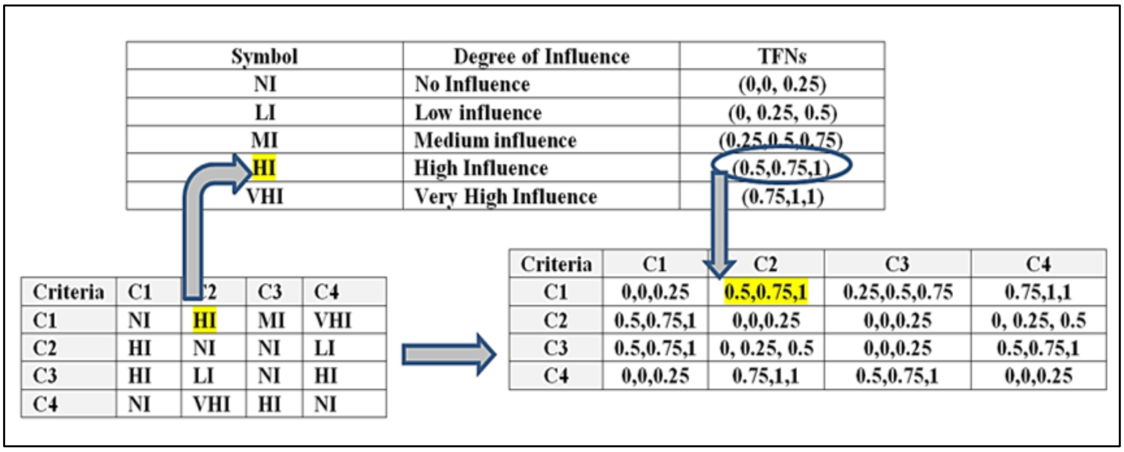

Figure 3: Example of transferring the linguistic variables, Adopted by authors

2.2.4 Applying the CFCS Method to Convert the Fuzzy Experts Judgments into Crisp Values

Converting Fuzzy data into Crisp Scores (CFCS) defuzzification method has been applied for Converting the fuzzy experts judgments Into Crisp value as follow [35,6]:

2.2.4.1 .Normalization of the fuzzy judgments of experts by Equations 1,2,3, and 4, as follows

$$xl_{ij}^{k} = (l_{ij}^{k} - min\ l_{ij}^{k})/\Delta_{min}^{max} \tag{1}$$

$$x\,m_{ij}^{k} = (m_{ij}^{k} - min\ l_{ij}^{k})/\Delta_{min}^{max} \tag{2}$$

$$xu_{ij}^{k} = (u_{ij}^{k} - min\ l_{ij}^{k})/\Delta_{min}^{max} \tag{3}$$

$$\Delta_{min}^{max} = max.\ u_{ij}^{k} - min\ l_{ij}^{k} \tag{4}$$

where xu_{ij}^{k} :- Normalized value of the upper fuzzy score, $x\,m_{ij}^{k}$:- Normalized value of the middle fuzzy score, xl_{ij}^{k} :- Normalized value of the lower fuzzy score, $min\ l_{ij}^{k}$:- Min. value of the lower fuzzy score, Δ_{min}^{max} :- Max. fuzzy score value of u_{ij}^{k} (the upper limit of TFN) of lean dimension minus Min, fuzzy score value of l_{ij}^{k} (the lower limit of TFN) for the same dimension

2.2.4.2 Identifying the right (us) and the left (ls) normalized values using Equations 5, and 6 as follows

$$xls_{ij}^{k} = xm_{ij}^{k}/(1 + xm_{ij}^{k} - xl_{ij}^{k} \tag{5}$$

$$xus_{ij}^{k} = xu_{ij}^{k}/(1 + xu_{ij}^{k} - xm_{ij}^{k} \tag{6}$$

2.2.4.3 Calculating the total normalized crisp value by Equation7 as follows

$$x_{ij}^{k} = [xls_{ij}^{k}(1 - xls_{ij}^{k}) + xus_{ij}^{k} \times xus_{ij}^{k}]/[1 - xls_{ij}^{k} + xus_{ij}^{k}] \tag{7}$$

The crisp values can be computed by Equation 8 as follows:-

$$Z_{ij}^{k} = min.\,l_{ij}^{k} + x_{ij}^{k} \times \Delta_{min}^{max} \tag{8}$$

$where: -\ x_{ij}^{k}$: - the total normalized value of dimension calculated by Equation 7, $min\ l_{ij}^{k}$: - Min. value of the lower limit of TFN of dimension, Δ_{min}^{max} : - Value calculated by Equation 4.

2.2.5 Aggregating the Crisp Influence Matrices to Construct the Initial Direction Matrix

Aggregating the crisp influence matrices to construct the Initial Direction Matrix using Equation 9: Integrating the crisp value by aggregating the opinion of all experts in one opinion using arithmetic mean to construct the initial direction matrix $Z = [z_{ij}]_{n\times n}$. that identifies the influences of the five lean dimensions as follows:

$$Z_{ij} = \frac{1}{p}\sum_{k=1}^{p} z_{ij}^{k} \quad (9)$$

where, Z_{ij} represents the crisp value of the influence of lean dimensions with each other

2.2.6 Normalizing the Initial Direction Matrix Z

The initial direction matrix has normalized to identify the normalized direct relation matrix X where$X = [x_{ij}]_{n\times n}$ and $0 \leq x_{ij} \leq 1$,as follow [36]:

$$\text{X}= \text{r. Z} \quad (90)$$

$$r = \frac{1}{\underset{1\leq i\leq n}{max}} \sum_{j=1}^{n} \text{zij} \quad (101)$$

where: - i, j=1, 2,...., n

2.2.7 Calculating the Total Relation Matrix T

The total relation matrix T has been identified by Equation 12 and Threshold of the matrix (α) by Equation 13 [36]:

$$\text{T=X(I-X)-1} \quad (112)$$

where I is the identity matrix

$$\alpha = (\sum_{i=1}^{5}\sum_{j=1}^{5} X_{ij})/\text{n} \quad (123)$$

2.2.8 Summing Rows and Columns of Total Relation Matrix

Rows and columns of Total Relation Matrix T have been separately summed using Equation 15 and Equation 16 [36]:

$$\text{T}=[t_{ij}]_{n\times n} \quad (134)$$

$$\text{D}=\sum_{j=1}^{n} t_{ij} \quad (145)$$

$$\text{R}=\sum_{i=1}^{n} t_{ij} \quad (156)$$

R:- the sum of columns cells for the total relation matrix T.
D:- the sum of rows cells for the total relation matrix T.

2.2.9 Computing the Influence Weight of Criteria (**IW_i**)and Degree of Relation of Criteria (**IR_i**)

The influence weight of the five lean dimensions (IW_i)was computer by Equation 17 while the degree of relation of lean dimensions (IR_i) was calculated by Equation 18.

$$\text{IW}_\text{i} = \text{D}_i + \text{R}_i \quad (17)$$

$$\text{IR}_\text{i} = \text{D}_i - \text{R}_i \quad (18)$$

where:-IW_i: - the weight of influence of the five lean dimensions, IR_i :- degree of the relation of the five lean dimensions.

2.2.10 Normalizing the Weights of Influence of Lean Dimensions

The Weights of Influence of Lean Dimensions have been normalized by Equation 19.

$$IW_i = IW_i/(\sum_{m}^{i-1} IW_i) \quad (19)$$

2.2.11 Identifying the Level of Influence (ILi) of Lean Dimensions

Of SMEs Lean dimensions have been identified by Equation 18.

$$IL_i = IW_i \times 100 \quad (20)$$

2.2.12 Plotting the Cause-Effect Diagram

The Cause-effect Diagram has been developed to identify the cause lean dimensions that drive the improvement process and the effect lean dimensions that are influenced directly by the cause dimensions and improve with improving the cause dimensions.

2.3 Stage 3: TOPSIS for Assessing the Level of SMEs Leanness

FTOPSIS has been used for identifying the level of SMEs Leannes, where the leanness level is [0-1]. The optimum level of leanness is 1, while 0 refers to the worst level which means lean philosophy is not applied in processes or activities of SMEs. The level of SMEs Leanness concerning the five lean dimensions has been computed through the following sequential steps as illustrated in Figure 4.

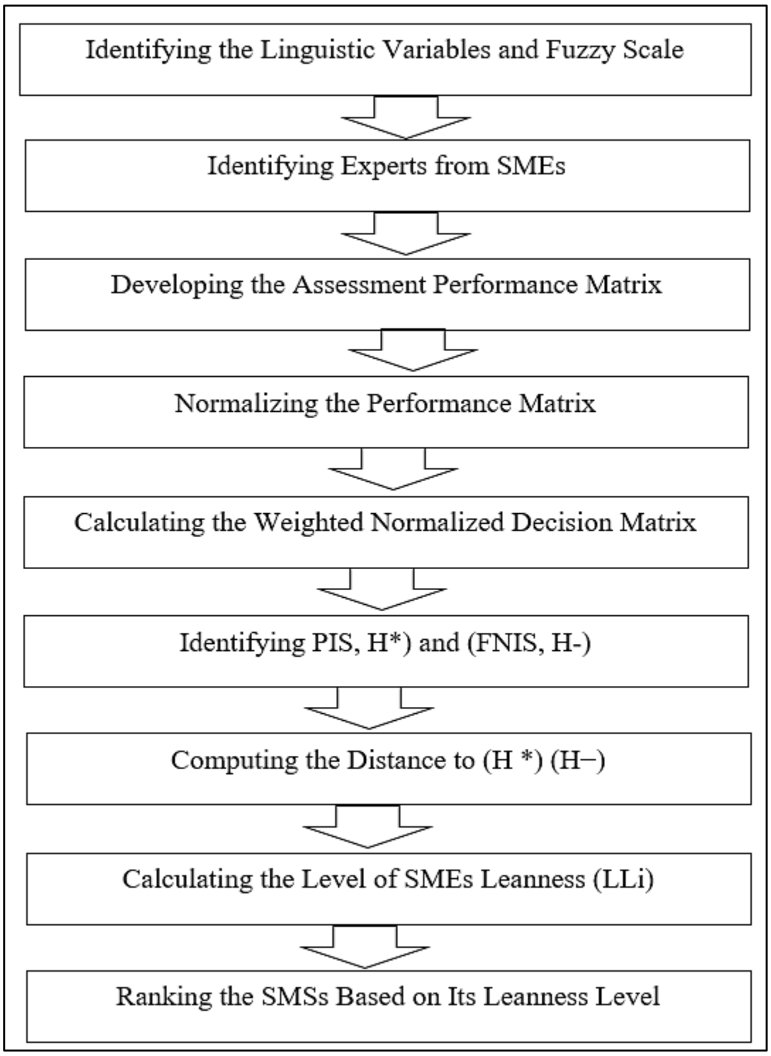

Figure 4: Structure of Stage Three

2.3.1 Identifying the Linguistic Variables and Fuzzy Scale

Linguistic variables and the fuzzy scale of TFN were identified, as shown in Table 5, for rating the performance of SMEs related to the five lean dimensions.

2.3.2 Identifying Experts from SMEs

Five experts have been asked in each company to rate the performance of the five lean dimensions using linguistic variables and fuzzy scales, Table 5.

Table 5: Linguistic Variables of TFN for Performance Rating [20]

Linguistic Variables	Symbol	Lower Limit	Medium Limit	Upper Limit
Very Low	VL	0.00	0.00	0.10
Low	L	0.00	0.10	0.25
Medium Low	ML	0.15	0.30	0.45
Medium	M	0.35	0.50	0.65
Medium High	MH	0.55	0.75	0.85
High	H	0.80	0.90	1.00
Very High	VH	0.90	1.00	1.00

2.3.3 Developing the Assessment Performance Matrix

The assessment performance matrix has been constructed that involves weights of importance of lean activities W_i that computed previously by FAHP and rate of performance of lean activities of enterprise by Linguistic Variables of Performance Rating, as shown in Table 6 [37,38].

where:- k = Expert No. , k= 1, 2, ... p, W_j= weights of influence of lean dimensions obtained by FDEMATEL, j=1, 2,..., m

Table 6: Lean Performance Rating Matrix using TFN

Weight W_j	SMEs Lean Dimensions	A1	A2	....	A_m
W_{jc1}	C1	$x^{\sim}_{C1\,A1}$	$x^{\sim}_{C1A2}$	....	$x^{\sim}_{C1Am}$
W_{jc2}	C2	$x^{\sim}_{C2A1}$	$x^{\sim}_{C2A2}$	....	$x^{\sim}_{C2Am}$
	….	…	…	....	…
W_{jc5}	C_n	$x^{\sim}\ C_{nA1}$	$x^{\sim}_{nA2}$	....	$x^{\sim}\ C_{n\,Am}$

$x^{\sim}$ Ci Aj is the fuzzy performance rating of lean dimensions for each SMEs.

Am are the number of SMEs, j = 1, 2...., m

Cn are number of lean dimension, i =1, 2,....., n

Experts judgments have been aggregated in one aggregated judgment matrix using the Arithmetic Mean method using Equation 21:-

$$\boldsymbol{x_{\tilde{ij}} = \frac{\sum_{k=1}^{p} x_{ij}^{\tilde{k}}}{p}} \quad (21)$$

$x_{\tilde{ij}} = (l_{ij}, m_{ij}, u_{ij})$, l_{ij} , m_{ij} , $u_{ij}$are the lower, peak and upper limits of is the lower limit of TFN.

2.3.4 Normalizing the Performance Matrix

Linear scale transformation has been applied to normalize the aggregated performance matrix for obtaining the normalized fuzzy decision matrix $R^{\sim}$.The normalized decision matrix has been identified by Equation 22 and Equation 23 [37,38]:

$$R^{\sim} = \left[r_{\tilde{ij}}\right] m \times n \quad (22)$$

$r_{\tilde{ij}}$ for beneficial subjective lean dimensions.

$$r_{\tilde{ij}} = \frac{x_{\tilde{ij}}}{u_j^*} = \left(\frac{l_{ij}}{u_j^*}, \frac{m_{ij}}{u_j^*}, \frac{u}{u_j^*}\right) \quad (163)$$

$r_{\tilde{ij}}$ for cost-lean activities

$$r_{\tilde{ij}} = \left(\frac{l_{\tilde{j}}}{u_{ij}}, \frac{l_{\tilde{j}}}{m_{ij}}, \frac{l_{\tilde{j}}}{l_{ij}}\right) \quad (174)$$

u_j^* is the max upper limit of TFN of the beneficial subjective lean dimensions (the non-financial dimension) that is calculated by identifying the max upper limit of TFN for the assessed SMEs for each non-financial lean dimension and then selecting the max value from them, where u_j^*= $\max_i u_{ij}$.

2.3.5 Calculating the Weighted Normalized Decision Matrix

Linear scale transformation has been used to maintain the property to which the ranges of normalized triangular fuzzy numbers belong [0, 1]. The weighted normalized decision matrix V~ has been formed as follows using Equation 25 and Equation 26 [37,38]:

$$V^{\sim} = [v_{ij}^{\sim}]_{m\times n} \quad (185)$$

$$v_{ij}^{\sim} = r_{ij}^{\sim} \times w_j \quad (196)$$

where:- $r_{ij}^{\sim}$ = normalize fuzzy value obtained by step 2, W_j = weight of influence of lean dimensions obtained by FDEMATEL.

2.3.6 Identifying (FPIS, H*) and (FNIS, H-)

The fuzzy positive ideal solution (FPIS) that is denoted by aspiration H* by Equation 27 and the fuzzy negative ideal solution (FNIS) that is denoted by the worst levels H- by Equation 28 [37,38]:

$$H^{*} = (V_1^{\sim *}, V_2^{\sim *}, V_j^{\sim *}, \dots \dots V_n^{\sim *},) \quad (207)$$

where, $v_j^{\sim *} = max_i v_{ij}^{\sim} = max u_{ij}^{\sim}$ and $max u_{ij}^{\sim} = (u_1^{\sim}, u_2^{\sim}, \dots., u_m^{\sim})$

$$H^{-} = (V_1^{\sim -}, V_2^{\sim -}, V_j^{\sim -}, \dots \dots V_n^{\sim -}) \quad (218)$$

where, $v_j^{\sim -} = min_i v_{ij}^{\sim} = min l_{ij}^{\sim}$ and $min l_{ij}^{\sim} = (l_1^{\sim}, l_2^{\sim}, \dots., l_m^{\sim})$

2.3.7 Computing the Distance to (H*) (H-)

The distance d_i^* of i_{th} alternatives to positive ideal solutions H^* has been calculated using Equation 29 while The distance d_i^- of i_{th} alternatives from negative ideal solutions H^- has been calculated using Equation 30 [37,38].

$$d_i^* = \sum_{j=1}^{n} (v_{ij}^{\sim}, v_j^*) \, \forall_i = 1,2,3, \dots.., m \quad (229)$$

$$d_i^- = \sum_{j=1}^{n} (v_{ij}^{\sim}, v_j^-) \, \forall_i = 1,2,3, \dots.., m \quad (30)$$

2.3.8 Calculating the Level of SMEs Leanness (LL_i)

LL_i has been identified as related to the five lean dimensions using Equation 29 where the level of SMEs leanness belongs to the closed interval [0, 1] [37,38]:

$$LL_i = {d_i^-}\Big/{(d_i^- + d_i^*)} \; ; \text{ where } 0 \le LL_i \le 1 \quad (31)$$

2.3.9 Ranking the SMSs Based on Its Leanness Level

SMEs have been ranked based on their Leanness LLi from the highest level to the lowest one.

3. The Practical Application in Iraqi SMEs

The proposed fuzzy assessment model has been applied in five Iraqi SMEs for producing soft drinks and healthy water in Baghdad to investigate the level of adoption of lean philosophy in these SMEs related to the five lean dimensions and identify which dimensions have the most influence on Iraqi SMEs leanness. The proposed model has been developed using Microsoft Excel, and all calculations have been done using FDEMATEL and FTOPSIS.

4. Results and Discussion

Five experts were asked to obtain their opinions about the influence of each lean dimension on others by questionnaire using linguistic variables and a fuzzy scale Table 4 as shown in Table 7. The five fuzzy expert's judgments matrices have been converted into crisp matrices using Equations 1-8. The crisp matrices have aggregated using Equation 9 to establish the crisp aggregated initial direct relation matrix as shown in Table 8.

Table 7: Expert's judgments

Experts No.	Experts Judgments					
Expert 1	**Lean Dimensions**	**Management**	**Process**	**Supplier**	**Customer**	**Employees**
	Management	0,0,0.25 NI	0.75,1,1 VHI	0.50,0.75,1 HI	0,0.25,0.50 LI	0.75,1,1 VHI
	Process	0,0.25,0.50 LI	0,0,0.25 NI	0,0,0.25 NI	0.50,0.75,1 HI	0,0.25,0.50 LI
	Suppliers	0,0,0.25 NI	0.50,0.75,1 HI	0,0,0.25 NI	0,0.25,0.50 LI	0.25,0.50,0.75 MI
	Customers	0.50,0.75,1 HI	0,0,0.25 NI	0,0,0.25 NI	0,0,0.25 NI	0,0,0.25 NI
	Employees	0.25,0.50,0.75 MI	0.75,1,1 VHI	0,0,0.25 NI	0,0,0.25 NI	0,0,0.25 NI
Expert 2	**Lean Dimensions**	**Management**	**Process**	**Supplier**	**Customer**	**Employees**
	Management	0,0,0.25 NI	0.75,1,1 VHI	0.50,0.75,1 HI	0,0.25,0.50 LI	0.75,1,1 VHI
	Process	0,0,0.25 NI	0,0,0.25 NI	0,0.25,0.50 LI	0,0.25,0.50 LI	0.25,0.50,0.75 MI
	Suppliers	0,0.25,0.50 LI	0,0.25,0.50 LI	0,0,0.25 NI	0,0,0.25 NI	0,0,0.25 NI
	Customers	0.50,0.75,1 HI	0,0,0.25 NI	0,0.25,0.50 LI	0,0,0.25 NI	0,0.25,0.50 LI
	Employees	0.50,0.75,1 HI	0.75,1,1 VHI	0,0,0.25 NI	0,0.25,0.50 LI	0,0,0.25 NI
Expert 3	**Lean Dimensions**	**Management**	**Process**	**Supplier**	**Customer**	**Employees**
	Management	0,0,0.25 NI	0.75, 1,1 VHI	0.50,0.75,1 VHI	0.25,0.50,0.75 HI	0.75,1,1 VHI
	Process	0.25,0.50,0.75 HI	0,0,0.25 NI	0,0.25,0.50 LI	0,0.25,0.50 LI	0.50,0.75,1 HI
	Suppliers	0,0.25,0.50 LI	0,0,0.25 NI	0,0,0.25 NI	0,0,0.25 NI	0,0,0.25 NI
	Customers	0.75,1,1 VHI	0.25,0.50,0.75 HI	0.25,0.50,0.75 MI	0,0,0.25 NI	0,0,0.25 NI
	Employees	0.50,0.75,1 HI	0.75,1,1 VHI	0,0,0.25 NI	0,0.25,0.50 LI	0,0,0.25 NI
Expert 4	**Lean Dimensions**	**Management**	**Process**	**Supplier**	**Customer**	**Employees**
	Management	0,0,0.25 NI	0.50,0.75,1 HI	0.75,1,1 VHI	0.25,0.50,0.75 MI	0.25,0.50,0.75 MI
	Process	0.25,0.50,0.75 MI	0,0,0.25 NI	0,0.25,0.50 LI	0,0,0.25 NI	0,0.25,0.50 LI
	Suppliers	0.25,0.50,0.75 MI	0,0.25,0.50 LI	0,0,0.25 NI	0,0,0.25 NI	0,0,0.25 NI
	Customers	0.25,0.50,0.75 MI	0,0.25,0.50 LI	0,0.25,0.50 LI	0,0,0.25 NI	0,0.25,0.50 LI
	Employees	0.25,0.50,0.75 MI	0.75,1,1 VHI	0,0,0.25 NI	0,0,0.25 NI	0,0,0.25 NI
Expert 5	**Lean Dimensions**	**Management**	**Process**	**Supplier**	**Customer**	**Employees**
	Management	0,0,0.25 NI	0.75,1,1 VHI	0.50, 0.75,1 HI	0.25,0.50,0.75 MI	0.50, 0.75,1 HI
	Process	0.75,1,1 VHI	0,0,0.25 NI	0,0.25,0.50 LI	0,0.25,0.50 LI	0.25,0.50,0.75 MI
	Suppliers	0.50,0.75,1 HI	0,0,0.25 NI	0,0,0.25 NI	0,0,0.25 NI	0,0,0.25 NI
	Customers	0.50,0.75,1 HI	0,0,0.25 NI	0,0,0.25 NI	0,0,0.25 NI	0,0,0.25 NI
	Employees	0.75,1,1 VHI	0.50,0.75,1 HI	0,0,0.25 NI	0,0,0.25 NI	0,0,0.25 NI

Table 8: The Crisp Aggregated Initial Direct Relation Matrix

Lean Dimensions	Management	Process	Supplier	Customer	Employee
Management	0.10	0.73	0.58	0.58	0.70
Process	0.34	0.10	0.10	0.33	0.34
Supplier	0.35	0.20	0.10	0.14	0.18
Customer	0.62	0.18	0.10	0.10	0.18
Employee	0.58	0.70	0.10	0.21	0.10

The aggregated matrix was normalized using Equations 10 and 11. Values of the Total Relation Matrix have been calculated by Equation 12 and, the threshold value (α) has been computed by average of all values of the Total Relation Matrix using Equation 13 as shown in Table 9.

Table 9: The Total Relation Matrix and Thresholder (α)

Lean Dimensions	Management	Process	Supplier	Customer	Employee	
Management	<u>0.35</u>	<u>0.58</u>	<u>0.36</u>	<u>0.44</u>	<u>0.51</u>	
Process	0.22	0.20	0.11	0.23	<u>0.28</u>	
Supplier	0.25	0.22	0.12	0.16	0.19	
Customer	<u>0.38</u>	0.26	0.15	0.18	0.24	**Threshold**
Employee	<u>0.40</u>	<u>0.48</u>	0.17	0.26	0.26	**0.28**

Values of D that represent the sum of values of rows of the Total Relation Matrix have been computed by Equation 15, while values of R that represent the sum of columns of the Total Relation Matrix have been identified using Equation 16. The weight of Influence (IW) has been calculated by Equation 17 and normalized by Equation 19, while the degree of influence (D-R) that categorize lean dimensions into cause and effect dimensions has been computed using Equation 18. The positive values of D-R represent the cause dimensions, whereas the negative values of D-R represent the effect dimensions, as shown in Table 10. The level of influence of the five lean dimensions has been identified by Equation 20 as shown in Table 10. Lean dimensions have been ranked based on their weight of influence.

Table 10: Weight, Level of influence level, and Degree of Relation of the Five Lean Dimensions

Lean Dimensions	D	R	Influence Weight (D+R)	Normalized Weights	Level of influence	Ranking	Degree of Relation D-R	Relation Type
Management	2.234	1.587	3.822	0. 2737	27.37%	1	0.646	Cause
Processes	1.035	1.740	2.776	0.1988	19.88%	3	-0.705	Effect
Suppliers	0.935	0.907	1.843	0.1320	13.20%	5	0.027	Cause
Customer	1.208	1.268	2.477	0.1774	17.74%	4	-0.060	Effect
Employees	1.566	1.474	3.040	0.2178	21.78%	2	0.092	Cause

The management dimension has the highest influence on SMEs leanness as illustrated in Table 10, with a weight of influence equal to 0.2737 and a level of influence equal to 27.37%. It is the influence cause dimension that the company focuses on improving due to its influence directly and automatically on the effect dimensions. Employee and supplier are also cause dimensions but with less influence. Process and customer both are effect dimensions that are influenced by improvement in the management, employee, and supplier dimensions.

Cause- Effect Diagram has been developed to categorize and distinguish the five lean dimensions into influencing dimensions that represent the cause dimensions and influenced dimensions that represent the effect dimensions as shown in Figure 5.

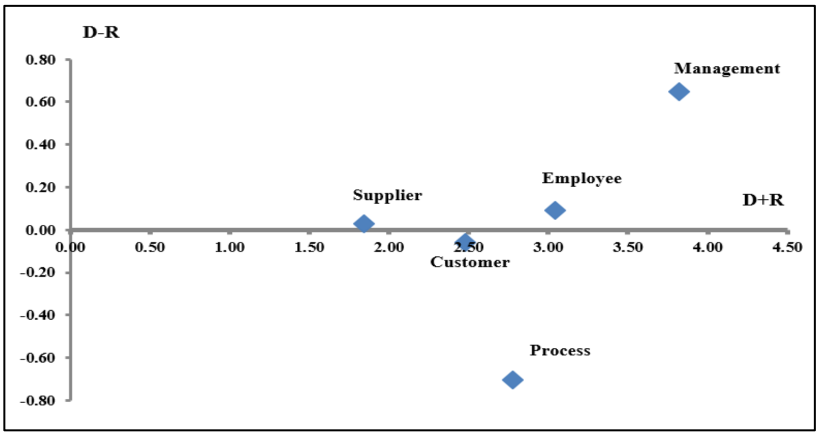

Figure 5: Cause –Effect Diagram

The X-axis represents the weight of influence, while the y-axis represents the relation degree for the five lean dimensions. The cause dimensions are located above the x-axis, while the effect dimensions are located below the x-axis. Management is identified as the leading cause dimension due to its location in the upper right corner of the diagram. The supplier dimension is another cause dimension, but with less influence on the effect dimensions, as depicted in Figure 3.

FTOPSIS was used to identify the level of leanness of the five SMEs (A1, A2, A3, A4 and A5). Five experts from these SMEs have been asked to rate the performance of the five lean dimensions using linguistic variables and fuzzy scales that are represented in Table 5 as shown in Table 11. Judgments of the five experts of each enterprise have been aggregated by Equations 21 for constructing the aggregated fuzzy performance matrix as illustrated in Table 12. The fuzzy performance matrix involves both the weight of influence calculated by FDEMATEL and the aggregated experts judgments in Table 12 as shown in Table 13.

Table 11: Rating the Performance of the Five Lean Dimensions for the Five SMEs

SMEs	The Five Expert Judgments															
A1	**Lean Dimensions**	**Expert 1**			**Expert 2**			**Expert 3**			**Expert 4**			**Expert 5**		
	Process	0.50	0.75	1.00	0.25	0.50	0.75	0.50	0.75	1.00	0.50	0.75	1.00	0.25	0.50	0.75
	Management	0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.75	1.00	1.00	0.25	0.50	0.75
	Supplier	0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.25	0.50	0.75	0.75	1.00	1.00
	Customer	0.25	0.50	0.75	0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.25	0.50	0.75
	Employee	0.75	1.00	1.00	0.50	0.75	1.00	0.75	1.00	1.00	0.75	1.00	1.00	0.50	0.75	1.00
A2	**Lean Dimensions**	**Expert 1**			**Expert 2**			**Expert 3**			**Expert 4**			**Expert 5**		
	Process	0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.25	0.50	0.75
	Management	0.75	1.00	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.75	1.00	1.00	0.50	0.75	1.00
	Supplier	0.50	0.75	1.00	0.25	0.50	0.75	0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00
	Customer	0.50	0.75	1.00	0.50	0.75	1.00	0.25	0.50	1.00	0.25	0.50	1.00	0.50	0.75	1.00
	Employee	0.50	0.75	1.00	0.50	0.75	1.00	0.25	0.50	1.00	0.25	0.50	1.00	0.50	0.75	1.00
A3	**Lean Dimensions**	**Expert 1**			**Expert 2**			**Expert 3**			**Expert 4**			**Expert 5**		
	Process	0.25	0.50	0.75	0.50	0.75	1.00	0.25	0.50	0.75	0.50	0.75	1.00	0.50	0.75	1.00
	Management	0.75	1.00	1.00	0.50	0.75	1.00	0.75	1.00	1.00	0.75	1.00	1.00	0.75	1.00	1.00
	Supplier	0.25	0.50	0.75	0.25	0.50	0.75	0.25	0.50	0.75	0.00	0.25	0.50	0.50	0.75	1.00
	Customer	0.25	0.50	0.75	0.50	0.75	1.00	0.50	0.75	1.00	0.25	0.50	0.75	0.25	0.50	0.75
	Employee	0.75	1.00	1.00	0.75	1.00	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00
A4	**Lean Dimensions**	**Expert 1**			**Expert 2**			**Expert 3**			**Expert 4**			**Expert 5**		
	Process	0.25	0.50	0.75	0.25	0.50	0.75	0.25	0.50	0.75	0.50	0.75	1.00	0.50	0.75	1.00
	Management	0.75	1.00	1.00	0.75	1.00	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00
	Supplier	0.00	0.25	0.50	0.25	0.50	0.75	0.25	0.50	0.75	0.50	0.75	1.00	0.50	0.75	1.00
	Customer	0.25	0.50	0.75	0.25	0.50	0.75	0.25	0.50	0.75	0.50	0.75	1.00	0.50	0.75	1.00
	Employee	0.75	1.00	1.00	0.75	1.00	1.00	0.75	1.00	1.00	0.50	0.75	1.00	0.50	0.75	1.00
A5	**Lean Dimensions**	**Expert 1**			**Expert 2**			**Expert 3**			**Expert 4**			**Expert 5**		
	Process	0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.25	0.50	0.75
	Management	0.75	1.00	1.00	0.50	0.75	1.00	0.50	0.75	1.00	0.75	1.00	1.00	0.75	1.00	1.00
	Supplier	0.25	0.50	0.75	0.50	0.75	1.00	0.50	0.75	1.00	0.25	0.50	0.75	0.25	0.50	0.75
	Customer	0.00	0.25	0.50	0.25	0.50	0.75	0.00	0.25	0.50	0.25	0.50	0.75	0.25	0.50	0.75
	Employee	0.50	0.75	1.00	0.75	1.00	1.00	0.75	1.00	1.00	0.50	0.75	1.00	0.50	0.75	1.00

Table 12: The Aggregated Fuzzy Performance Matrix

Lean Dimensions	A1			A2			A3			A4			A5		
Process	0.40	0.65	0.90	0.45	0.70	0.95	0.40	0.65	0.90	0.35	0.60	0.85	0.45	0.70	0.95
Management	0.50	0.75	0.95	0.60	0.85	1.00	0.70	0.95	1.00	0.60	0.85	1.00	0.65	0.90	1.00
Supplier	0.50	0.75	0.95	0.45	0.70	0.95	0.25	0.50	0.75	0.30	0.55	0.80	0.35	0.60	0.85
Customer	0.40	0.65	0.90	0.40	0.65	1.00	0.35	0.60	0.85	0.35	0.60	0.85	0.15	0.40	0.65
Employee	0.65	0.90	1.00	0.40	0.65	1.00	0.60	0.85	1.00	0.65	0.90	1.00	0.60	0.85	1.00

Table 13: The fuzzy performance matrix

Weight	Lean Dimensions	A1			A2			A3			A4			A5		
0.20	Process	0.40	0.65	0.90	0.45	0.70	0.95	0.40	0.65	0.90	0.35	0.60	0.85	0.45	0.70	0.95
0.27	Management	0.50	0.75	0.95	0.60	0.85	1.00	0.70	0.95	1.00	0.60	0.85	1.00	0.65	0.90	1.00
0.13	Supplier	0.50	0.75	0.95	0.45	0.70	0.95	0.25	0.50	0.75	0.30	0.55	0.80	0.35	0.60	0.85
0.18	Customer	0.40	0.65	0.90	0.40	0.65	1.00	0.35	0.60	0.85	0.35	0.60	0.85	0.15	0.40	0.65
0.22	Employee	0.65	0.90	1.00	0.40	0.65	1.00	0.60	0.85	1.00	0.65	0.90	1.00	0.60	0.85	1.00

Equations 22-30 have been used to calculate the distance of each enterprise to FPIS as shown in Table 14 and the distance from FNIS as shown in Table 15.

The leanness level of the five SMEs has been calculated by Equation 31 based on Total d* Table 14 and Total d- Table 15. SMEs leanness level is ranked based on lean level from the highest level to the lowest as shown in Table 16. The five SMEs are in the mid-score of leanness level as shown in Table 16 which indicates that these SMEs have adopted and implemented lean philosophy in their process and activities in an acceptable way. The level of Leanness of the studying SMEs can be improved by focusing on the improvement of the cause dimensions, particularly on the management dimension which is considered the leading driving lean dimension. Improvement of the management dimension will directly influence the improvement of the other lean dimensions specialty the effect dimensions, process, and customer dimensions.

Table 14: Distance of SMEs to FPIS

Lean Dimensions	A1	A2	A3	A4	A5
Process	0.092	0.080	0.092	0.105	0.080
Management	0.105	0.075	0.049	0.075	0.062
Supplier	0.046	0.053	0.089	0.079	0.070
Customer	0.089	0.087	0.101	0.101	0.151
Employee	0.049	0.107	0.060	0.049	0.060
Total d*	0.381	0.403	0.391	0.410	0.422

Table 15: Distance of SMEs to FNIS

Lean Dimensions	A1	A2	A3	A4	A5
Process	0.131	0.146	0.131	0.117	0.146
Management	0.141	0.168	0.187	0.168	0.177
Supplier	0.121	0.117	0.078	0.087	0.097
Customer	0.162	0.177	0.149	0.149	0.099
Employee	0.173	0.142	0.165	0.173	0.165
Total d-	0.728	0.749	0.710	0.694	0.684

Table 16: Level of Leanness of the Five SMEs

SMEs	Total d*	Total d-	Level of Leanness	Ranking
A1	0.381	0.728	0.656	1
A2	0.403	0.749	0.650	2
A3	0.391	0.710	0.645	3
A4	0.410	0.694	0.629	4
A5	0.422	0.684	0.618	5

The rader map was used as a visual way to illustrate the current leanness level of the five Iraqi SMEs. It involves a multi-level that starts with 0 in the center and ends with 1 at the periphery. The best performance values are located the nearest to the periphery and gradually decrease with moving towards the center, where performance closest to the center represents poor performance. A value of 0 represents the worst level of lean which means the SMEs have not adopted lean philosophy in their processes and activities. Value 1 refers to the optimum implementation of lean philosophy. Leanness levels of the five Iraqi SMEs are depicted as being in the middle as shown in Figure 4 with a bold black line. A1 has the highest level of leanness, equal to 0.656 which indicates it has adopted lean philosophy in most processes and activities followed by A2, A3, A4, and A5 respectively.

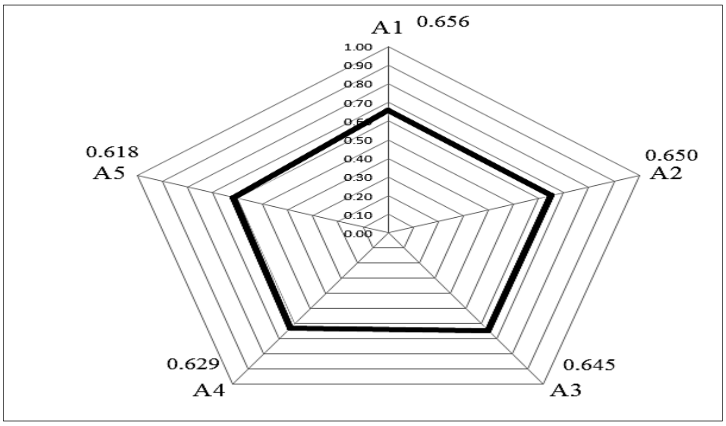

Figure 6: Radar Map of SMEs Leannes Level

5. Conclusion

SMEs have an important role in countries' economies by contributing to GDP and creating employment opportunities. SMEs pursue to improve their performance to stay competitive in global markets by adopting an efficient production system like lean Production (LP). LP is a continuous improvement philosophy for continuous improvement of lean performance by eliminating waste through lean activities. A fuzzy assessment model has been proposed that integrates the Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (Fuzzy TOPSIS) to investigate the level of adoption of the lean philosophy in SMEs through five lean dimensions, namely, management, process, supplier, customer, and employee. Fuzzy DEMATEL was used to identify the weight of the influence of the lean dimension on SMEs leanness, while Fuzzy TOPSIS was used to assess the level of adoption of lean philosophy in SMEs. The practical side of research has been applied in five Iraqi SMEs for producing healthy water and juice. The results reveal that the management dimension is the most influential lean dimension and has the highest impact on improvement compared to the other lean dimensions. The five Iraqi SMEs have been located at a midlevel of leanness that indicates an acceptable implementation of the lean philosophy in these SMEs. Improving the lean level of these SMEs can be done by focusing on the management dimension to drive the improvement process for increasing the level of leanness of these SMEs. The findings of this research can contribute to the development of strategies aimed at facilitating the implementation of lean philosophy in SMEs to improve their competitiveness and sustainability in the current changing business environment.

Author contributions

Conceptualization, Z. Al-baldawi, A. Kassam and S. Al-Zubaidi; investigation, Z. Al-baldawi, A. Kassam and S. Al-Zubaidi; writing—original draft preparation, Z. Al-baldawi, A. Kassam and S. Al-Zubaidi; writing—review and editing, Z. Al-baldawi, A. Kassam and S. Al-Zubaidi.; visualization, Z. Al-baldawi, A. Kassam and S. Al-Zubaidi; supervision, A. Kassam and S. Al-Zubaidi. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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