**Management and Production Engineering Review**
Volume 15 • Number 1 • March 2024 • pp. 76–89
DOI: 10.24425/mper.2024.149991

# Assessment the Level of Importance of SME Lean Activities Using an Integrated Model Based on Fuzzy Logic

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Received: 06 September 2023
Accepted: 21 November 2023

**Abstract**
Small and Medium Enterprises SME play a crucial role in the global economy through their contribution in countries economy and creation of employment opportunities, and their success heavily relies on the implementation of efficient manufacturing systems like Lean Production(LP). LP is a continuous improvement philosophy based on various lean activities for improving enterprise lean performance. A fuzzy model that integration Fuzzy Consistency Algorithm (FCA) and Fuzzy Analytical Hierarchy Process (FAHP) was proposed as a comprehensive framework to assess the levels of importance and priority of nineteen SME lean activities that categorized into the related five related lean dimensions. FCA was used to construct the fuzzy pairwise comparison matrix to ensure obtaining consistent experts judgment, whereas FAHP was applied to identify the level of importance and priority of lean activities. Identifying the level of importance of lean activities will be contributed in focuses SME efforts in the improvement process on the most important lean activities to ensure effective resource allocation and foster continuous improvement process and offer a practical tool for enhancing their competitiveness and sustainability. The proposed model was applied in Iraqi SME. The result showed that FCA is an efficient approach to construct a consistent judgment matrix. Efficient manger, Kaizen team, supplier relationship, execution customer suggestions and customer satisfaction job rotation are the most important lean activities with level of importance 58.90%, 21.30%, 49.80%, 38.50%, 41.20% respectively. The proposed model can be used for small or medium size enterprise for various production industries.

**Keywords**
Fuzzy Consistency Algorithm, FAHP, Lean Production, Lean Activities, SME.

## Introduction

SME expansion began in the 1970s, when Schumpeter laid the foundations for the importance of SMEs and illustrated that capitalism can't sustain without continuous creation of new companies, where most of these companies are SMEs, by focusing on its crucial role in the economy by growing the economy and employment (Wach, 2018). SME can be defined as independent, non-subsidiary enterprises which employ limited number of employees (OECD, 2000) and typically, The organizational structure of SME is simple with very few levels, leading to high communication and involvement with top management for immediate decision-making and rapid implementation of management strategies (Saini & Singh, 2020). SMEs have significant contributions for any country through solving employment problems, making a significant contribution of GDP, providing a valuable contribution to the development of large companies and making a significant contribution to the export and import of the country (Morina & Gashi, 2017). Continuously, SMEs pursue in the current competitive environment to improve their performance to ensure staying competitive with their global rivals and satisfying the highly changing needs of customers through using an efficient production system like Lean Production (LP). LP is an efficient and powerful system that leads to improve quality, efficiency, productivity, and reduce costs of any organization by eliminating all types of waste (Al-Baldawi et al., 2024).

The philosophy of lean production provides a new way of guiding enterprises' efforts and mindset to become more responsive to customers' demands while continuously challenging waste and costs all over the supply chain. Consequently, most large companies have

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reached a high level of optimization and have gained a competitive edge by implementing the lean concept. Lean production can be considered an efficient management practice in 21st century for ensuring that SMEs could sustain in global competitiveness in the 21st century by implementing lean philosophy as an effective management technique to improve their performance (Sabah et al., 2024).

Lean philosophy is known as production without waste, where the goal from implementing it is to reduce the waste in human effort, time to market, inventory, cost and manufacturing space to become highly responsive to customer needs while producing high-quality products by economical and efficient manner (Nasser et al., 2009).

## Literature Review

FAHP and FCA have been used in developing the fuzzy assessment model.

### Fuzzy Analytic Hierarchy Process (FAHP)

Analytic Hierarchy Process (AHP) is a widely applied as a multi-criteria decision-making method to identify the weights of criteria and priorities of alternatives in a structured way based on pairwise comparison that based on a subjective judgment of experts (Liu et al., 2020; (Badri-Koohi et al., 2019). In spite of the expert judgment or the expert's preference are considered the main input of AHP matrix, this method is difficult to make decisions in some problems that involve uncertain and incomplete data, thus leading to shortage in use of the traditional AHP (Ishak & Wanli, 2020; Al-Kindi & Al-Baldawi, 2024). The fuzzy sets proposed by Zadeh (1965) are combined with AHP to form the fuzzy AHP, also known as FAHP, for handling imprecision. The FAHP was published in 2008 and used for decision-making problems in industry and other fields, especially the various selection problems (Liu et al., 2020; Ateekh-Ur-Rehman & Alkahtani, 2017). FAHP is unique Fuzzy Multi Criteria Decision Making (FMCDM) method due to its ability to deal with vagueness and fuzziness of linguistic judgments compared with inability of AHP (Ghaffari et al., 2017). It has been used for solving both qualitative and quantitative problems, identifying an effective prioritization using pair-wise comparison process, and handling uncertainty and vagueness in the given weights when evaluating alternatives (Aikhuele et al., 2014; Torfi et al., 2010, Ishak & Wanli, 2020).

Some methods can be used to compute the fuzzy weights of the criteria, referring to (Onay et al., 2016; Ahmed & Kilic, 2019; Liu et al., 2020; Torfi et al., 2010) for more details. Defuzzification of fuzzy weights is the process of transforming the fuzzy numbers into a crisp numeric value. Compared with a fuzzy value, a crisp value is more intuitive and easier for the final comparison because fuzzy sets have partial ordering. The centroid method, also known as Center of gravity (COG) or center of Area (COA) and Center of maximum method (COM) are the common defuzzification methods that are easy to use (Liu et al., 2020; Serafim and Tzeng, 2003). Bueno et.al. (2020) proposed a hierarchical approach to assess the level of importance of six criteria: process, inspection, stocking, capacity, cost, and management, with 33 sub-criteria in three companies. Cost has the highest level of importance (20%), followed by management (23%) and capacity (22%), where these three criteria have a 65% impact degree on lean decisions. Sathiya Narayana et.al. (2020) evaluated the performance of ten medium-scale Indian automobile manufacturing industries regarding lean and green implementation for assessing near these industries to ideal implementation of lean and green concepts. AHP was used to identify the level of importance of lean criteria to clarify which criteria are more important, identify the essential and critical criteria for implementing the lean and green concepts, and then assess the lean level of these medium-scale enterprises by TOPSIS. (Alhuraish et.al (2017) developed model based on AHP to analyze and rank companies performance based on financial performance, operational performance, and innovation performance as criteria with twelve sub-criteria. AHP was constructed to rank the characteristics in terms of their effectiveness in improving company performance. results show that companies that implement Six Sigma and lean manufacturing are more effective in improving their financial and operational performance in addition, the results has illustrated that implementing lean manufacturing alone is sufficient for improving innovation performance. (Susilawati et.al. (2016) developed a Fuzzy Analytical Hierarchy Process (FAHP) algorithm-based Performance Measurement System (PMS) for assessing the lean level of an automotive company in the Indonesian manufacturing industry to measure and improve the company's overall performance using six specific perspectives: financial perspectives, customer issues, supplier issues, people, and process. (Ravikumar et.al. (2015) proposed a model that combined interpretive structural modeling (ISM), AHP, and FAHP to investigate and evaluate the lean implementation performance of six Indian MSMEs based on eleven lean criteria. ISM is used to find criteria weights, then AHP model was applied to find the best one in lean implementation from a group of six MSMEs by comparing one criterion over another and FAHP was used to rank these six industries.

### Fuzzy Consistency Algorithm (FCA)

The inconsistency of expert' responses in pairwise comparison is considered one of the big challenge that may be faced in questionnaire data analysis when conducting criteria evaluation. Sometimes, the expert fails to achieve an appropriate and consistent evaluation when dealing with several criteria (Yousif and Shaout, 2016). The Fuzzy Consistency Algorithm (FCA) is a systematic algorithm for getting a consistent pairwise criteria comparison matrix that achieves the consistency ratio condition (CR $\leq 0.1$) (Yousif and Shaout, 2016). FCA proposes a consistent preference linguistic value(s) that used by expert in evaluating importance of criteria (Yousif and Shaout, 2018). Shaout, A. and Yousif, M. proposed FCA for inferring and constructing the decision matrix for performance evaluation of Sudanese Universities and academic staff (Yousif and Shaout, 2016; Yousif and Shaout, 2018). The consistency of expert' judgments during the pairwise comparison of the decision criteria is considered a key factor in the evaluation process and has a direct impact on the final results of performance measurement, so checking and analyzing the consistency of the individual experts' judgments is important to ensure correct results. Saaty proposed the consistency index (CI) and the consistency ratio (CR) to check and analyze the consistency of comparison matrices. Checking the Consistency of expert judgments is an important step in AHP and FAHP because a big inconsistency may indicate a lack of understanding of the problem, thus, the experts need to review their judgment and compare the criteria again when CI is above 0.10 (Najmi and Makui, 2012) which it is not easy request the expert to redo the evaluation again which will cost time and effort, thus, the inconsistent evaluations will be neglected from the evaluations (Yousif and Shaout, 2016). There are two ways of measuring the consistency of matrix of the fuzzy pairwise comparison: (Yousif and Shaout, 2016):

Crisp consistency – it is calculated by translating the fuzzy matrix to a representative crisp one.

Fuzzy consistency – it computes a consistency index directly from a fuzzy matrix.

In this paper, fuzzy assessment methodology has been proposed that integrates the Fuzzy Consistency Algorithm (FCA) and FAHP to make an accurate and consistent decision related on identifying the most important lean dimensions and lean activities that have high impact on SMEs lean performance. FCA was used to infer and construct a consistent pairwise comparison matrix, and FAHP was used to identify the level of importance of SMEs lean activities.

## The Fuzzy Assessment Model

The structure of the proposed fuzzy assessment methodology for assessing the importance level of SMEs lean activities is illustrated in (Fig. 1).

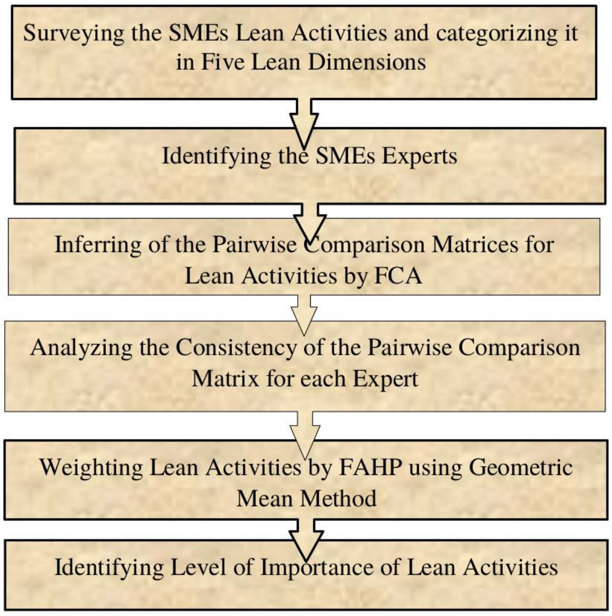


Fig. 1. Structure of the Fuzzy Assessment Methodology

**Step 1:** Surveying the SMEs Lean Activities and categorizing it into Five Lean Dimensions.

Papers related to lean production have been surveyed from 2015 to 2022 to extract the most applying SMEs lean activities using Google Scholar and Research Gate and key words: lean assessment, lean production, lean activities, SMEs. Finally, nineteen lean activities have been identified. The surveyed lean activities were categorized into five related lean dimensions, namely, management, process, supplier, customer, and employee, as shown in (Tab. 1).

**Step 2:** Identifying the SMEs Experts.

The optimal number of experts to participate in group decision-making for accurate decisions is between five to seven (Cathay et al., 2022). In this paper, five experts were asked from SMEs to evaluate the importance of lean activities on their enterprise leanness.

**Step 3:** Construction of the Pairwise Comparison Matrix by FCA.

The inconsistency of pairwise comparison matrix due to sometimes, the experts is fail to achieve an appropriate and consistent evaluation when deal with several criteria is considered one of the big challenge

Table 1
The Surveyed Lean Activities

| Lean Dimensions | Lean Activities | Symbol | (Harjanto and Karningsih, 2024) | (Bueno et al., 2020) | (Sathiya Narayana et al., 2020) | (Yadav et al., 2019) | (Vishal and Ankur Chaurasia, 2019) | (Saini and Singh, 2019) | (Belhadi et al., 2018) | (Sahoo and Yadav, 2018) | (Rajpurohit, 2017) | (Abreu and Calado., 2017) | (Cengiz and Taşkin, 2017) | (Vidyadhar et al., 2016) | (Thanki et al., 2016) | (Zanjbeel, 2016) | (Balasubramanian & Hemamala, 2016) | (Zhou, 2016) | (Godinho Filho et al., 2016) | (Laoha & Sukto, 2015a) | (Laoha & Sukto, 2015b) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Management | Efficient Manager | T1 | | | | | | | | | | | | | | | | | | | |
| | Motivating and Supporting Employees | T2 | • | | | | • | | | | • | | • | • | | | • | | | | |
| | Employee Involvement and empowerment | T3 | | | | | • | | | | | | • | • | | | • | | | | |
| Processes | Pull approach (Kanban) | P1 | | | | | | • | | • | • | • | | • | | | • | • | • | | |
| | Lot Size Reduction | P2 | | | | • | | | | • | | | | | | | • | | | | |
| | Workplace Organization | P3 | | | | | • | • | | • | • | • | | | | • | • | • | | • | • |
| | Preventive Maintenance | P4 | | • | | • | | | • | • | • | • | | • | | • | • | • | • | • | • |
| | Visual Management System | P5 | | | | • | | • | | | | • | | • | | • | • | • | | • | • |
| | Poka Yoke | P6 | • | | | | • | | | • | • | | | • | | • | • | • | | • | • |
| | Kazien Team | P7 | | | | | | | | | | | | | | • | | | | | |
| Suppliers | Supplier Relationship | S1 | • | | • | | • | | | | • | • | | • | | | | | • | | |
| | Evaluation Suppliers' Performance | S2 | | | | | • | | | | • | | | | | | | | | | |
| | JIT Deliveries by Supplier | S3 | • | | | | • | | • | | • | | | | | | | | • | | |
| Customers | Execution the Customer Suggestions and requirements | C1 | | | | | | | | | • | | | • | | | | | | | |
| | Handling and Solving Customer Complaints | C2 | • | | • | | • | | | | • | | | • | | | • | | | | |
| | Customer Satisfaction | C3 | | | • | | | | | | • | | | • | | | | | | | |
| Employees | Flexible/ Multiskill Workforce | E1 | • | | | • | • | | • | | • | • | | • | | | • | | | | • |
| | Employee Training | E2 | • | • | | • | | | | • | • | | | • | | | | | | | |
| | Job Rotation between Employees | E3 | • | • | | • | • | | | | • | | | • | | | • | | | | |

when conducting the criteria importance evaluation. Fuzzy Consistency Algorithm (FCA) was used to deal with this challenge to infer and construct consistent pairwise comparison matrices that achieve the consistency ratio condition (CR $\leq 0.1$) for ensuring making reliably and appropriate decision. Calculations by FCA to construct and infer the pairwise comparison matrix are based on FCA scale, (Tab. 2), which is considered the standard table and reference for all the following computation steps:

Table 2
FCA Scale (Yousif and Shaout, 2016)

| Scale Rank (SR) | Linguistic Variables of importance Type (IT) | Fuzzy Triangular Scale | Fuzzy Triangular Scale | Distance Value (DV) |
|---|---|---|---|---|
| 1 | Absolutely less Important | 2/9, 1/4, 2/7 | 0.22, 0.25, 0.28 | –4 |
| 2 | Very Strongly Less Important | 2/7, 1/3, 2/5 | 0.28, 0.33, 0.40 | –3 |
| 3 | Fairly Strongly Less Important | 2/5, 1/2, 2/3 | 0.40, 0.50, 0.66 | –2 |
| 4 | Weakly Less Important | 2/3, 1, 3/2 | 0.66, 1, 1.50 | –1 |
| 5 | Equal Important | 1, 1, 1 | 1.00, 1.00, 1.00 | 0 |
| 6 | Weakly More Important | 2/3, 1, 3/2 | 0.66, 1.00, 1.50 | 1 |
| 7 | Fairly Strongly More Important | 3/2, 2, 5/2 | 1.50, 2.00, 2.50 | 2 |
| 8 | Very Strongly More Important | 5/2, 3, 7/2 | 2.50, 3.00, 3.50 | 3 |
| 9 | Absolutely More Important | 7/2, 4, 9/2 | 3.50, 4.00, 4.50 | 4 |

Let, $C_x$, $C_y$, $C_z$ are lean activities to be compared, $C_{xy}$ refer to compare lean activity $x$ over lean activity $y$ also $C_{yx}$, $C_{yz}$, $C_{xz}$, $C_{zx}$ are the same definition. The structure of the inferred pairwise comparison matrix of FAHP by FCA was illustrated by (Tab. 3).

1. Identifying, the importance of lean activity $C_x$ over lean activity $C_y$ by experts using FCA scale $1 \to 9$, (Tab. 2).
$$C_{xy} = X_{xy} \tag{1}$$
$X_{xy}$, refer to importance of lean activity $C_x$ over lean activity $C_y$ ($C_{xy}$) using FCA nine scale.
2. Calculating the preference of importance of lean activity $C_y$ over lean activity $C_x(X_{yx})$ where, this step constructs the base data table to check the consistency of all comparison layers data.
if $C_{xy} = X_{xy}$ consequently $C_{yx} = X_{yx}$, then,
$$X_{yx} = \text{MaxSR} + 1 - X_{xy} \tag{2}$$
MaxSR, is the maximum scale of FCA Scale = 9. $X_{yx}$, refer to Importance of lean activity $C_y$ over lean activity $C_x(C_{yx})$.
3. Calculating $Xxz$ the preference level of activity $C_x$ over activity $C_z(C_{xz})$.
if $C_{xz} = X_{xz}$ consequently $C_{zx} = X_{zx}$, Then,
$$X_{zx} = \text{MaxSR} + 1 - X_{yz} \tag{3}$$
4. Computing $X_{yz}$, the preference level of lean activity $C_y$ over lean activity $C_z(C_{yz})$ through the following steps:
   4.1. Identifying the distance value DV for $X_{yx}$ ($DV(X_{yx})$) and the distance value DV for $X_{zx}$ ($DV(X_{zx})$) from (Tab. 2). where, $DV(X_{yx})$ is the distance value of lean activity $C_y$ to lean activity $C_x$, $DV(X_{zx})$ is the distance value of lean activity $C_z$ to lean activity $C_x$.
   4.2. Calculating the $DV(X_{yz})$ by Eq. 4.
$$DV(X_{yz}) = DV(X_{yx}) - DV(X_{zx}) \tag{4}$$
   4.3. Identifying $X_{yz}$, preference level of lean activity $C_y$ over lean activity $C_z(C_{yz})$ by Eq. 5 where, the result of Eq. 4 is used to identify the type of importance of the preference between lean activity $C_y$ and lean activity $C_z$ ($C_{yz}$) as follow:

The important Type (IT) =
$$\begin{cases} \text{More important, if } DV(X_y) - DV(X_z) > 0 \\ \text{Less important, if } DV(X_y) - DV(X_z) < 0 \\ \text{Equal important, if } DV(X_y) - DV(X_z) = 0 \end{cases} \tag{5}$$

5. Equal important = 5 according to FCA scale for the pairwise comparison of the same lean activities.

Table 3
The Inferred FAHP matrix by FCA

<table>
<tr><td>Lean Activities C</td><td>1</td><td>...</td><td>...</td><td>$n$</td></tr>
<tr><td>1</td><td>Equal Importance = 5<br>Diagonal of Matrix</td><td colspan="3">$X_{xy}$, the Experts Preference<br>by FCA Scale 1 → 9</td></tr>
<tr><td>...</td><td rowspan="3">$X_{yx}$<br>the calculated<br>preference<br>by Eq. 2</td><td>Equal Importance = 5</td><td colspan="2">$X_{yz}$ the Calculated Preference by Eqs. 4, 5</td></tr>
<tr><td>...</td><td>$X_{zx} = X_{xz}$<br>Same Lean Criteria</td><td>Equal Importance = 5</td><td></td></tr>
<tr><td>$n$</td><td colspan="2">$X_{zx}$ the Calculated Preference by Eq. 3</td><td>Equal Importance = 5</td></tr>
</table>

**Step 4:** Analyzing the Consistency of the Pairwise Comparison Matrix for each Expert

Fuzzy consistency analysis has been used to analysis consistency of the pairwise comparison matrix of each expert that has been inferred by FCA to ensure getting consistent experts judgments when the acceptable consistency ration CR $\geq 0.01$. Consistency analysis steps can be illustrated as follow:

$$A = [x_{ij}^k]_{n\times n} = \begin{bmatrix} x_{11}^k & x_{12}^k & \dots & x_{1j}^k \\ \dots & \dots & \dots & \dots \\ x_{i1}^k & x_{i2}^k & \dots & x_{nn}^k \end{bmatrix} \tag{6}$$

Let, $x_{ij}^k = (l_{ij}, m_{ij}, u_{ij})$, $l_{ij}$, $m_{ij}$ , $u_{ij}$ lower, middle and upper limits of TFN fuzzy number which, refer to the fuzzy expert preference $k$ for lean activity $C_i$ over lean activity $C_j$.

1. Sum up each column of the inferred comparison matrix by Eq. 7.

$$S_j = \sum_{C=1}^{n} (l_{ij}, m_{ij}, u_{ij}) \tag{7}$$

where, $S_j$ is sum of rows of the comparison matrix for each column, $C$ refers to lean activities, $i = j = 1, 2, \dots, n$, $C = 1, 2, 3, \dots, n$

2. Normalizing the fuzzy matrix by Eq. 8 by divide values of each column on its column sum where sum of each normalized column must equal 1.

$$N_j = \frac{x_{ij}}{S_j} \tag{8}$$

$N_j$ = Normalized values, $a_{ij}$ indicates the fuzzy matrix values.

3. Averaging the rows of the normalized matrix to obtain principle Eigen vector (P).

$$P_i = [El_i, Em_i \text{ and } Eu_i] = \left[ \frac{\left(\sum_{j=1}^{n} l_{ij}\right)}{n}, \frac{\left(\sum_{j=1}^{n} m_{ij}\right)}{n}, \frac{\left(\sum_{j=1}^{n} u_{ij}\right)}{n} \right] \tag{9}$$

$El_i, Em_i$ and $Eu_i$, are the average of $l_{ij}$, $m_{ij}$, $u_{ij}$ lower, middle and upper limits of TFN fuzzy number respectively.

4. Computing Eigen value ($\gamma$) by Eq. 10, by multiplying sum of each columns of the fuzzy matrix by principle Eigen vector calculated in 3.

$$\gamma_i = S_i \times P_i \tag{10}$$

5. Calculating of consistency index (CI) by Eq. 11.

$$\text{CI} = \frac{\sum_{C=1}^{n} (\gamma_{ij} - n)}{n - 1} \tag{11}$$

6. Computing the consistency ratio (CR) by Eq. 12.

$$\text{CR} = \frac{\text{CI}}{\text{RI}} \tag{12}$$

CI = Consistency index that obtained by step 5.
RI = Random index, (Fig. 2), N refer to number of criteria.
$\gamma$ = Max Eigen value that obtained by step 4.

| **N** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **RI** | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

Fig. 2. Random Consistency Index

**Step 5:** Weighting Lean Activities by FAHP using Geometric Mean Method

Buckley's Column Geometric Mean Method or also known as Geometric Mean Method was applied to calculate the fuzzy importance weights of the lean activities through the sequential following steps:

1. Aggregating the Pairwise Comparison Matrices
   Aggregating the expert's judgments matrices to construct the aggregated matrix using arithmetic mean
   Let: $k_1, k_2 \ldots k_p$ are the experts no, $k = 1, 2, \ldots, p$.
   Let: $A^{\sim k} = [x_{ij}^{\sim k}]_{n\times n}$ is the fuzzy pairwise comparison matrix for expert $k$.
   Let's $l_{ij}$, $m_{ij}$, $u_{ij}$ are the lower, peak and upper limits of TFN, $x_{ij}^{\sim} = (l_{ij}, m_{ij}, u_{ij})$ be a Triangular Fuzzy Number(TFN), $i = j = 1, 2, \ldots, n$.

$$x_{ij}^{\sim} = \frac{\sum_{k=1}^{p} x_{ij}^{k}}{k} \tag{13}$$

   $x_{ij}^{\sim k} = (l_{ij}^{k}, m_{ij}^{k}, u_{ij}^{k})$ be a Triangular Fuzzy Number (TFN) representing the relative importance of lean activity $C_i$ over lean activity $C_j$ judged by expert $k$.
2. Calculating the fuzzy geometric mean $z_i^{\sim}$ for each lean activity using Eq. 14.

$$z_i^{\sim} = \left[\Pi_{j=1}^{n} X_{ij}^{\sim}\right]^{1/n} \tag{14}$$

   $z_i^{\sim}$ refer to fuzzy geometric mean of lean criteria.

$$\Pi_{j=1}^{n} x_{ij}^{\sim} = x_{i1} \times x_{i2} \times, \ldots, \times x_{nn}$$

   $\Pi$ is a capital Pi that refers to multiply all value within a sequential range.
   $x_{ij}^{\sim}$ refer to triangular fuzzy number that represent importance of lean activities $i_{th}$ over lean activities $j_{th}$.
3. Calculating the fuzzy weights $w_i^{\sim}$ for each lean activities by Eq. 15.

$$w_i^{\sim} = z_i^{\sim} \times (z_1^{\sim} + z_2^{\sim} + \ldots z_m^{\sim})^{-1} \tag{15}$$

   $w_i^{\sim} = (l_i, m_i, u_i)$, $z_i^{\sim}$ is the geometric mean of the triangular fuzzy number.
4. Utilizing the Center of Area (COA) defuzzification method to transform the fuzzy weight of lean activities $C_i$ into crisp weights by Eq. 16.

$$W_{Ci} = \frac{l_i \oplus m_i \oplus u_i}{3} \tag{16}$$

5. Normalizing weights by Eq. 17 to obtain weights of importance of lean activities $W_{Ci}$.

$$W_{Ci} = \frac{W_{Ci}}{\sum_{C=1}^{n} W_{Ci}} \tag{17}$$

**Step 6:** Identifying the Level of Importance $\mathrm{LI}_{Ci}$ of Lean Activities

$$\mathrm{LI}_{Ci} = W_{Ci} \times 100 \tag{18}$$

## The Application Part

The proposed fuzzy model has been applied in Iraqi SME for producing healthy water, juice and soft drink. Five experts with years of working experience have been asked to compare importance of lean activities for each lean dimension based on its impact on SME lean performance.

## Results and Discussion

Firstly, FCA has been applied for inferring and constructing the pairwise comparison matrices for lean activities where each expert has been asked to give their opinion about importance and impact of lean activities of each lean dimension. Figure 4 illustrates steps of inferring and constructing the first pairwise comparison matrix using the opinion of the first expert using scales from 1–9, (Tab. 2). The opinion of expert about impact and importance of lean activity T1 on lean Performance compared with the other lean activities T2 and T3 was represented by $C_{xy}$. The inverse comparison $C_{yx}$ for lean activities will be inferred by Eq. 1 and the inferred scales will be defined as shown in (Fig. 3a), the rest lean activities will be inferred and defined based on expert judgment so, the expert will be only given his opinion about the first lean activity T1 and the rest will be inferred based on it (Fig. 3b), using Eq. 2, Eq. 3, Eq. 4, Eq. 5. Similarly, (Fig. 3c) illustrates the inferred judgment matrix of expert 1 and these steps will be done for the rest four experts where finally five pairwise comparison matrices will be obtained. The inferred judgment matrix for each expert will be transformed into fuzzy value using Table 2, column 4 then the fuzzy inferred matrix for each expert will be analyzed to check consistency of expert judgment as shown in (Fig. 4).

Consistency Ratio analysis (CR) for ensuring that the five experts judgments are consistent without any conflict has conducted using MICREOSOFT EXCEL

| Lean Activities | Importance Level | Cxy =Scale Rank(SRxy) | Cyx = SRyx= Max SR +1- SRxy | Important Level |
|---|---|---|---|---|
| T1 & T2 | T1 is Absolutely More Important than T2 | 9 | 1 | T2 is Absolutely Less Important than T1 |
| T1 & T3 | T1 is Absolutely More Important than T3 | 9 | 1 | T3 is Absolutely Less Important than T1 |

(a)

| Lean Activities | SRxy (Cxy) | SRyx(Cyx) | DV(SRxy) | DV(SRyx) | DV(SRx)- DV(SRy) | SR(DV) | Important Level |
|---|---|---|---|---|---|---|---|
| T2 & T3 | 1 | 1 | -4 | -4 | 0 | 5 | T2 is Equal Important T3 |

(b)

| Lean Activities | T1 | T2 | T3 |
|---|---|---|---|
| T1 | 5 | 9 | 9 |
| T2 | 1 | 5 | 5 |
| T3 | 1 | 5 | 5 |

(c)

Fig. 3. Inferring and Constructing the Fuzzy Matrix of Expert 1 for Lean Activities of Management Dimension

| Lean Activities | T1 | | | T2 | | | T3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 1.00 | 1.00 | 1.00 | 3.50 | 4.00 | 4.50 | 3.50 | 4.00 | 4.50 | | Expert 1 | | | |
| T2 | 0.22 | 0.25 | 0.28 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | | | | | |
| T3 | 0.22 | 0.25 | 0.28 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | | | | | |
| Columun Sumation | 1.44 | 1.50 | 1.56 | 5.50 | 6.00 | 6.50 | 5.50 | 6.00 | 6.50 | | | | | |
| | | | Construction Fuzzy Matrix | | % | | | | | | | | | |
| Lean Activities | T1 | | | T2 | | | T3 | | | | Lean Activities | ∑ L | ∑ M | ∑ U |
| T1 | 0.69 | 0.67 | 0.64 | 0.64 | 0.67 | 0.69 | 0.64 | 0.67 | 0.69 | | T1 | 0.66 | 0.67 | 0.68 |
| T2 | 0.15 | 0.17 | 0.18 | 0.18 | 0.17 | 0.15 | 0.18 | 0.17 | 0.15 | | T2 | 0.17 | 0.17 | 0.16 |
| T3 | 0.15 | 0.17 | 0.18 | 0.18 | 0.17 | 0.15 | 0.18 | 0.17 | 0.15 | | T3 | 0.17 | 0.17 | 0.16 |
| Columun Sumation | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | | | | | |
| | | | | | Normlization the Fuzzy Matrix | | | | | | | | | |
| Lean Activities | ∑ L | ∑ M | ∑ U | | | | N | 3 | | | | | | |
| T1 | 0.94 | 1.00 | 1.05 | | | | CI | 0.00 | | | | | | |
| T2 | 0.95 | 1.00 | 1.06 | | | | RI | 0.58 | | | | | | |
| T3 | 0.95 | 1.00 | 1.06 | | | | CR | 0.00 | | | | | | |
| Columun Sumation | 2.84 | 3.00 | 3.16 | Average | 3.00 | | | | | | | | | |
| CI | -0.08 | 0.00 | 0.08 | | | | | | | | | | | |

Fig. 4. Consistency Analysis of judgment of expert 1

where, each pairwise comparison matrix will be analyzed to check its consistency within the acceptable limit CR≥ 0.1.The Consistency analysis will be done using Equations. 6–13 and by the same way the rest four matrices have been checked, where the five pairwise comparison matrices have the consistent judgments. The first matrix of the first expert has CR equal 0 and it is acceptable so this judgment is consistent and the second has CR equal 0, the rest matrices have sequentially CR equal 0, 0 and 0.01 and all are acceptable so these matrices are valid and consistent for conducting FAHP to getting accurate level of importance of lean activities.

The five fuzzy Expert judgments matrices were aggregated to construct the fuzzy aggregated matrix using Eq. 14 (Fig. 5) illustrate the aggregation step to construct the fuzzy aggregated matrix.

The fuzzy aggregated matrix has been used to conduct all FAHP calculations to identify the level of importance of lean activities.

All steps of FCA that illustrated for lean activities related management dimension have been repeated and done for lean activities of process, supplier, customer and employee dimensions.

Levels of importance of lean activities for each lean dimension have been identified using Eq. 20 as shown in (Tab. 5). Identifying the level of importance of lean activities for each lean dimension will help SMEs management focus their efforts and resources in the continuous improvement process on the most important lean activities that have high importance and impact on SMEs lean performance. The continuous improvement of lean activities will ensure stay this type of companies in the competitive markets due to its ability to be highly responsive to customer needs by producing high-quality products by economical and efficient manner. Efficient manager is the most important lean activity for the management dimension that has a level of importance of 59.90%, as shown in (Fig. 6) and (Tab. 5). This activity can be improved by continuously presence of SMEs manger in the shop floor, meeting directly with employees, listening to employee problems, improving working conditions, establishing a fair reward system, and so on.

Kazien team is the most important lean activity for process dimension that has a level of importance of 21%, as shown in (Fig. 7), where this team has an important role in the continuous improvement process

Table 4
Weights of Importance of SMEs Lean activities for each lean dimension

| Weights of Importance of Lean activities of Managements Dimensions | Lean Activities | Weights of Importance (WI) |
|---|---|---|
| | T1 | 0.589 |
| | T2 | 0.243 |
| | T3 | 0.168 |
| | ∑W | 1.00 |
| Weights of Importance of Lean activities of Process Dimension | Lean Activities | Weights of Importance (WI) |
| | P1 | 0.117 |
| | P2 | 0.084 |
| | P3 | 0.174 |
| | P4 | 0.171 |
| | P5 | 0.122 |
| | P6 | 0.118 |
| | P7 | 0.213 |
| | ∑W | 1.00 |
| Weights of Importance of Lean activities of Supplier Dimension | Lean Activities | Weights of Importance (WI) |
| | S1 | 0.498 |
| | S2 | 0.190 |
| | S3 | 0.312 |
| | ∑W | 1.00 |
| Weights of Importance of Lean activities of Customer Dimension | Lean Activities | Weights of Importance (WI) |
| | C1 | 0.385 |
| | C2 | 0.229 |
| | C3 | 0.385 |
| | ∑W | 1.00 |
| Weights of Importance of Lean activities of Employee Dimension | Lean Activities | Weights of Importance (WI) |
| | E1 | 0.411 |
| | E2 | 0.177 |
| | E3 | 0.412 |
| | ∑W | 1.00 |

of lean activities and solving problems, so choosing skilled employees with high experiences and knowledge to lead the improvement process is an important issue for successfully implementing lean philosophy.

Then supplier relationship has the highest level of importance (40.80%), as shown in (Fig. 8), Improving this activity can be done by sustaining long and good relationships with a few good- performing suppliers.

Execution of customer suggestions and customer satisfaction, both lean activities of the customer dimension that have a level of importance of 38.50%, as shown in (Fig. 9), so these activities can be improved by interviewing the customers and listing their suggestions and requirements to improve product performance.

Finally, job rotation and multi-skilled employees activities have the highest level of importance (41.20%, 41.10), as shown in (Fig. 10); thus, this indicates that SMEs employees have multiskill to do multitasks, so improving these activities can be done by employment only with skilled employees and training them on various tasks.

SMEs have limited resources, so their lean performance can be improved by focusing their resources and efforts on improving the most important activities that have high importance and impact on SMEs performance.

| Lean Activities | T1 | | | T2 | | | T3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| T1 | 1.00 | 1.00 | 1.00 | 3.50 | 4.00 | 4.50 | 3.50 | 4.00 | 4.50 | Expert 1 |
| T2 | 0.22 | 0.25 | 0.28 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | |
| T3 | 0.22 | 0.25 | 0.28 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | |
| Lean Activities | T1 | | | T2 | | | T3 | | | |
| T1 | 1.00 | 1.00 | 1.00 | 1.50 | 2.00 | 2.50 | 2.50 | 3.00 | 3.50 | Expert 2 |
| T2 | 0.40 | 0.50 | 0.66 | 1.00 | 1.00 | 1.00 | 0.66 | 1.00 | 1.50 | |
| T3 | 0.28 | 0.33 | 0.40 | 0.66 | 1.00 | 1.50 | 1.00 | 1.00 | 1.00 | |
| Lean Activities | T1 | | | T2 | | | T3 | | | |
| T1 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.50 | 3.00 | 3.50 | Expert 3 |
| T2 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 2.50 | 3.00 | 3.50 | |
| T3 | 0.28 | 0.33 | 0.40 | 0.28 | 0.33 | 0.40 | 1.00 | 1.00 | 1.00 | |
| Lean Activities | T1 | | | T2 | | | T3 | | | |
| T1 | 1.00 | 1.00 | 1.00 | 3.50 | 4.00 | 4.50 | 1.50 | 2.00 | 2.50 | Expert 4 |
| T2 | 0.22 | 0.25 | 0.28 | 1.00 | 1.00 | 1.00 | 0.40 | 0.50 | 0.66 | |
| T3 | 0.40 | 0.50 | 0.66 | 1.50 | 2.00 | 2.50 | 1.00 | 1.00 | 1.00 | |
| Lean Activities | T1 | | | T2 | | | T3 | | | |
| T1 | 1.00 | 1.00 | 1.00 | 2.50 | 3.00 | 3.50 | 3.50 | 4.00 | 4.50 | Expert 5 |
| T2 | 0.28 | 0.33 | 0.40 | 1.00 | 1.00 | 1.00 | 0.66 | 1.00 | 1.50 | |
| T3 | 0.22 | 0.25 | 0.28 | 0.66 | 1.00 | 1.50 | 1.00 | 1.00 | 1.00 | |
| Lean Activities | T1 | | | T2 | | | T3 | | | |
| T1 | 1.00 | 1.00 | 1.00 | 2.40 | 2.80 | 3.20 | 2.70 | 3.20 | 3.70 | Agraggation Matrix |
| T2 | 0.42 | 0.47 | 0.52 | 1.00 | 1.00 | 1.00 | 1.04 | 1.30 | 1.63 | |
| T3 | 0.28 | 0.33 | 0.40 | 0.82 | 1.07 | 1.38 | 1.00 | 1.00 | 1.00 | |

Fig. 5. Aggregation the of Expert's judgments

Table 5
Level of Importance of Lean Activities of each Lean Dimension

| Lean Dimension | Lean Activities | Level of Importance | Ranking of Importance |
|---|---|---|---|
| Management | Efficient Manager | 58.90% | 1 |
| | Motivating, and Supporting Employees | 24.30% | 2 |
| | Employee Involvement and empowerment | 16.80% | 3 |
| Process | Pull system | 11.70% | 6 |
| | Lot Size Reduction | 8.40% | 7 |
| | Workplace Organization | 17.40% | 2 |
| | Preventive Maintenance | 17.10% | 3 |
| | Visual Management System | 12.20% | 4 |
| | Poka Yoke | 11.80% | 5 |
| | Kazien Team | 21.30% | 1 |
| Supplier | Supplier Relationship | 49.80% | 1 |
| | Evaluation Suppliers' Performance | 19.00% | 3 |
| | JIT Deliveries by Supplier | 31.20% | 2 |
| Customer | Execution the Customer Suggestions and requirements | 38.50% | 1 |
| | Handling and Solving Customer Complaints | 22.90% | 3 |
| | Customer Satisfaction | 38.50% | 2 |
| Employee | Flexible and Multi Skilled Employees | 41.10% | 2 |
| | Employee Training | 17.70% | 3 |
| | Job Rotation between Employees | 41.20% | 1 |

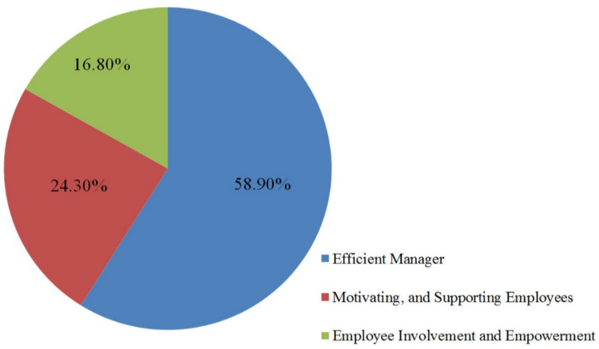


Fig. 6. Level of Importance of Lean Activities of Management Dimension

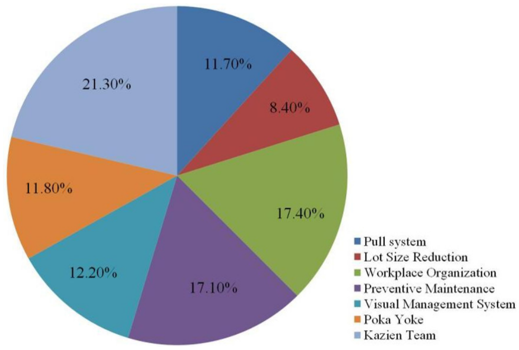


Fig. 7. Level of Importance of Lean Activities of Process Dimension

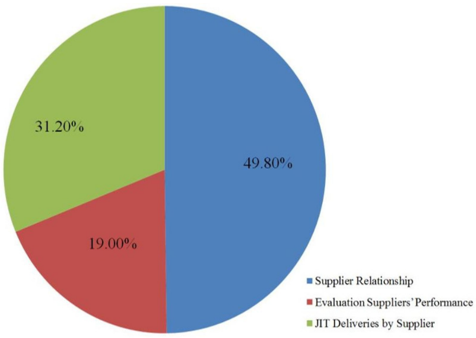


Fig. 8. Level of Importance of Lean Activities of Supplier Dimension

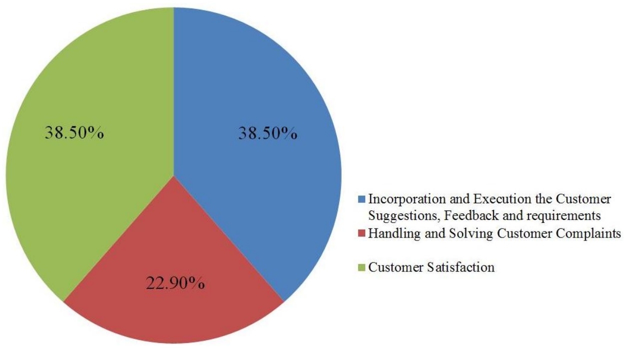


Fig. 9. Level of Importance of Lean Activities of Customer Dimension

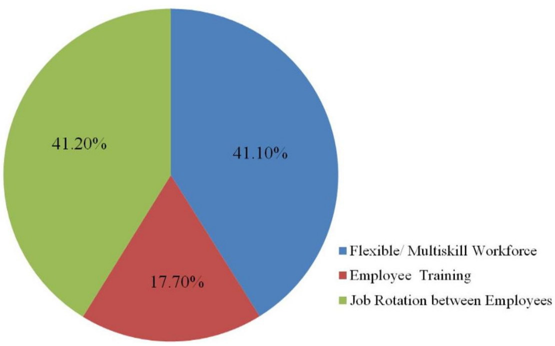


Fig. 10. Level of Importance of LeanActivities of Customer Dimension

## Conclusions

SME continuously pursue improving their performance to stay competitive in global markets through adoption of lean production as a continuous improvement philosophy to eliminate waste and improve quality, performance, and productivity. The improvement process will be efficient when management understands and focuses their efforts on the important activities that have a high impact on SMES lean performance. The fuzzy assessment methodology was proposed that integrates FCA and FAHP. FCA was used to infer and construct the pairwise comparison matrices for ensuring obtain consistent experts judgments that will later aggregate into one aggregated matrix to form the FAHP matrix. The consistent aggregated matrix that involved expert's judgments has been used to identify the levels of importance of lean dimensions and lean activities using FAHP to help SME management understand the most important lean activities that have a high impact on SMES lean performance for the five lean dimensions. The proposed fuzzy model was applied in Iraqi SMEs for producing healthy water, juice, and soft drinks, where five experts were asked to give their opinions and compare the importance of lean activities on SMEs lean performance. The results show that FCA is an efficient approach to infer, construct and obtain consistent judgment matrix in the case of a limited number of experts through sequential calculating steps. The resulted matrices were analyzed by fuzzy consistency analysis, and the results show that these matrices are consistent and achieve a consistency ratio CR less than or equal to 0.1, so this refers to consistent matrices. FAHP is an efficient FMCDM method to assess the level of importance of lean activities. The efficient manager was the most important activity for the management dimension (58.90%), and the Kazien team was the most important activity for process dimension (21.30%). Supplier relationship was the most important activity for the supplier dimension that has high impact on SMEs performance (49.80%). Customer satisfaction and execution of its suggestions and requirements are the most important activities for the customer dimension, while job rotation and multi-skilled employees are the most important activities for the employee dimension. So, this proposed fuzzy model will help decision-makers make robust decisions based on consistent judgment for identifying the most important lean activities that have a high impact on SME lean performance. This step is an important issue for SMEs that help them focus their efforts and resources in the improvement process on the most impacted lean activities on their performance. Although the proposed methodology identified the level of importance of lean activities using FAHP based on accurate judgments inferred by FCA in an efficient way, it has weaknesses related to the limited number of lean dimensions, activities, and experts.

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