



# A fuzzy decision support system for evaluating Lean-Green and company-specific production system

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## Abstract

Lean production is regarded as systematic solution for identifying and eliminating waste through continuous improvement of manufacturing processes to meet customers' requirements. Due to rising environmental concerns and the significant environmental impact of companies operations, issues such as environmental management and green production are on board agendas. In essence, green production seeks to reduce the environmental impacts of business processes. In order to examine green production, an original equipment manufacturer in the supply chain of tractor manufacturing industry is selected for this work to enable a focus on lean production aspects and its specific requirements to evaluate a company-specific production system (XPS). The results suggest that the company utilizes six lean-green production criteria including suitable and green packaging, quality improvement, waste reduction, environmental pollution reduction, transport management and additional transportation reduction, and cost reduction. Furthermore, continuous improvement and integrated auditing are selected as two critical and fundamental elements with the highest ranks, regarding the relationships between the XPS elements and lean-green production criteria.

**Keywords** Lean-green production · XPS · Multi-criteria decision-making · QFD

## Abbreviations

XPS	company-specific production system
DEMATEL	Decision-Making Trial and Evaluation Laboratory
BWM	Best Worst Method
QFD	quality function deployment
AHP	analytic hierarchy process
KPI	key performance indicator
OHS	Occupational Health and Safety
QMS	Quality Management System

## Introduction

Lean production (Womack et al., 1990) is known as a systematic solution to identify and eliminate waste through continuous improvement, with the aim of meeting customer demands at the highest quality, lowest cost, and least possible time by permanently eliminating waste and aiming for zero waste to maintain and increase capacity (Avakh and Hojjat, 2019). The main philosophy behind this productive system is to achieve zero defects within production systems. The resulting production system can be considered as lean, because it utilizes all inputs at a lower rate than mass production (Davari, 2009). Kaizen (real unending improvement) drives through a process that favors learning from past success or missteps (Tortorella et al., 2019). But the problem is about the increasing environmental concerns. Therefore, the negative effects of company's operations, production, and manufacturing processes on the environment mandates the requirement of environmental management systems and moving toward green production. It is timely to investigate lean activities that will encourage the implementation of green practices given that lean production activities aim to get rid of all forms of waste and therefore play a role in

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improving environmental performance (Inman and Kenneth, 2018). Green production seeks to reduce the environmental impacts of business processes (Fazlzadeh and Marandian Hagh, 2014). It is defined as manufacturing processes that use inputs with relatively low environmental impacts, high efficiency as well as lower waste, or pollution (Ninlawan, 2010). Increasing the effectiveness and efficiency of a company's manufacturing system through lean production has generated some consensus. There is a consensus that the commitment of senior management to the lean system is essential for sharing an organizational culture, continuous improvement, and empowering employees to improve the system in general (Liker, 2004).

However, as Kurdve et al. (2014) stated, when an Environmental Management System (EMS) stipulates improving environmental performance in accordance with ISO 14001 but neglects how this policy should be organized or what methods should be used, a knowledge gap arises. According to Kurdve et al., the production system or lean program can resolve this issue (Kurdve et al., 2014). Thus, there is a need for increased knowledge and the correct use of company specific XPS principles to resolve this issue. XPS can be thought of as a set of procedures and guidelines that are tailored to any particular company, in order to achieve the best operational practices and improvements. Literature suggests practical guidance on the usefulness of the interplay of technology maintenance, containing XPS methods and LP practices, if used to form profit for population and processes (Pozzi et al., 2022).

Today, many multinational corporations have implemented XPS, and many of these systems are integrated to lean production plans that are heavily inspired by Toyota's manufacturing system. XPS is mainly aimed at increasing competitiveness through controlled coordination and standardization of operational efforts across the production network. XPSs have been developed and expanded to help companies and their subsidiaries to excel in all the key operational objectives (Netland, 2013).

Quality Function Deployment (QFD) is a useful tool for converting customer demands into product specifications as well as deciding when a set of issues should be considered simultaneously with their requirements in decision-making (Zaim and Şevkli, 2002). QFD owes its recognition to its technological simplicity and contribution to productivity. A fact of QFD is that it outperforms traditional characteristic designs that only keep down quality non-conformances by maximizing client-required features (Gunduz et al., 2021). On the other hand, due to lean production problems in the Tractor Manufacturing Company of Iran, it is necessary to review and evaluate the XPS and consider the importance of environmental issues in the lean production. Furthermore, the factors affecting lean-green production should be investigated in the company, and ultimately, their interactions

should be determined. The proper use of the environment in the country can be a guarantee to durability, and its negligence can entail issues that destroy a set of economic, social, cultural, and political development programs of the country. Hence, proper understanding of the role of inhibiting factors and reducing them along with strengthening incentive factors can lead to success in environmental conservation.

Therefore, it can be concluded that one of these inhibiting factors is the correct recognition of production systems that are consistent with lean-green production in a company. In other words, the required context can be provided for the operation of this principle by careful examination and matching the criteria of the company's specific manufacturing systems with the lean-green standards. Operationalizing the ISO-14001 requirements through the coordination and integration of units and procedures is only possible by recognizing and applying the correct XPS based on its main criteria (Kurdve et al., 2014).

Using tractors in agricultural production enhance the crop yield per unit area and decrease the labor costs associated with harvesting operation and activities. Moreover, the role of tractors is beneficial as an agricultural implement and in many non-agricultural areas such as construction industry such as building roads, bridges, or airports (Life & Style Hub, 2022) Cabral et al. (2021) pertained in their study that increases in demand for tractors and tractor services have been attributed to structural changes in the rural economy (Cabral et al., 2021).

Therefore, this research is necessary due to the importance of tractor manufacturing and environmental issues as well as the fact that various industries have their own XPS, and it is formed based on the question of how the lean-green model can be determined based on the specific requirements of the organization using decision-making techniques and the Quality Function Deployment.

Research questions (RQ):

- I. What are the main green-lean criteria in tractor manufacturing industry?
- II. What are the relationships between XPS and lean-green criteria in tractor manufacturing industry?

Based on the above research question, the main aim of this research is to evaluate the integration between XPS and lean-green criteria in an uncertain environment using fuzzy decision-making techniques in tractor manufacturing industry.

## Research background

This section is dedicated to the investigation of the research background and reviewing the latest research.

Lotfi and Saghiri (2018) conducted research in the field of disentangling resilience, agility, and leanness. Their results suggest that a higher level of resilience will lead to a higher efficiency in terms of delivery, cost, and time to furnish, while not having a negative effect on flexibility performance. Regarding leanness, the results also emphasized that lean operations positively affect cost, delivery as well as flexibility performances.

A study was done by Avakh Darestani and Hojjat Shamami (2019) regarding the performance evaluation of lean production. They developed a performance evaluation framework based on balanced score card (BSC) using decision-making techniques for home appliance industry.

Vahabi Nejat et al. (2021) have provided scientific solutions for their work on integrated green management to modify the environment in the weaving industry by identifying and prioritizing how to deal with environmental issues. Fazlzadeh and Marandian Haq (2014) conducted research in the field of lean production system as a step toward green production. They concluded that lean production is effective in improving environmental performance. The organizational culture of waste reduction, posed in the lean system, is the same culture as the one proposed by the Environmental Protection Agency. According to Appolloni et al. (2022), multidimensional industry arrangements stimulate manufacturing companies not only to examine consumer needs from a price viewpoint but also to commit to including social and environmental attributes in their products, in the way that the green circular premium and sustainability certification.

Singh et al. (2021) worked on the key performance parameters of green lean performance in manufacturing industries. The purpose of their study was to identify and examine key performance parameters (KPP) from existing literature for measuring the effort of green lean practices on the performance manufacturing industries. Florentina and Alves (2015) conducted a study on the methods of corporate sustainability and its relationship with the lean concept. They stated that there is a link between the firm's sustainability methods and the lean concept. A truly lean company is a sustainable company by incorporating the lean culture that reduces the use of resource inputs.

Netland (2013) also examined proper ways to answer how a XPS affects the performance of the factory running XPS. The performance improved slowly at first, then, a little slower, then a little faster, and eventually, follows a slow trend again. Pampanelli et al. (2013) presented a green lean model which adopt the Kaizen approach to improve energy flows and mass production in manufacturing environments. This model is designed for cell production. Zhenyuan et al. (2011) investigated the cause of negligence in production productivity in the studied manufacturing unit. Accordingly, they began to design a facility layout with a lean production approach. Finally, based on the obtained results, they

demonstrated that lean production effectively increases the productivity in production as well as providing more efficient use of equipment.

Shahin and Janatyan (2010) described how the relationships are between group technology and the major dimensions of lean production, including production waste, startup time, quality, and inventory management, and provided a model for increasing productivity through the use of group technology in a production system. At the end, they also pointed out the correlation among the elements, dimensions of group technology, and the goals of lean production. Bergmiller and McCright (2009) concluded that there is a great deal of similarity in the structure of lean system models and green system models. In fact, even if they are not the same, many of the elements of these models will be common. By studying the outstanding theoretical models of lean and green, this study has found an unmistakable similarity between them.

One of the latest study in the area of smart lean-green production paradigm to improve operational performance is conducted by Fiorello et al. (2023). In their study, a framework was developed to analyze how a smart environment relying on the Industry 4.0 tools and technologies can support the evolution of a lean-green organization toward upper levels of operational performance.

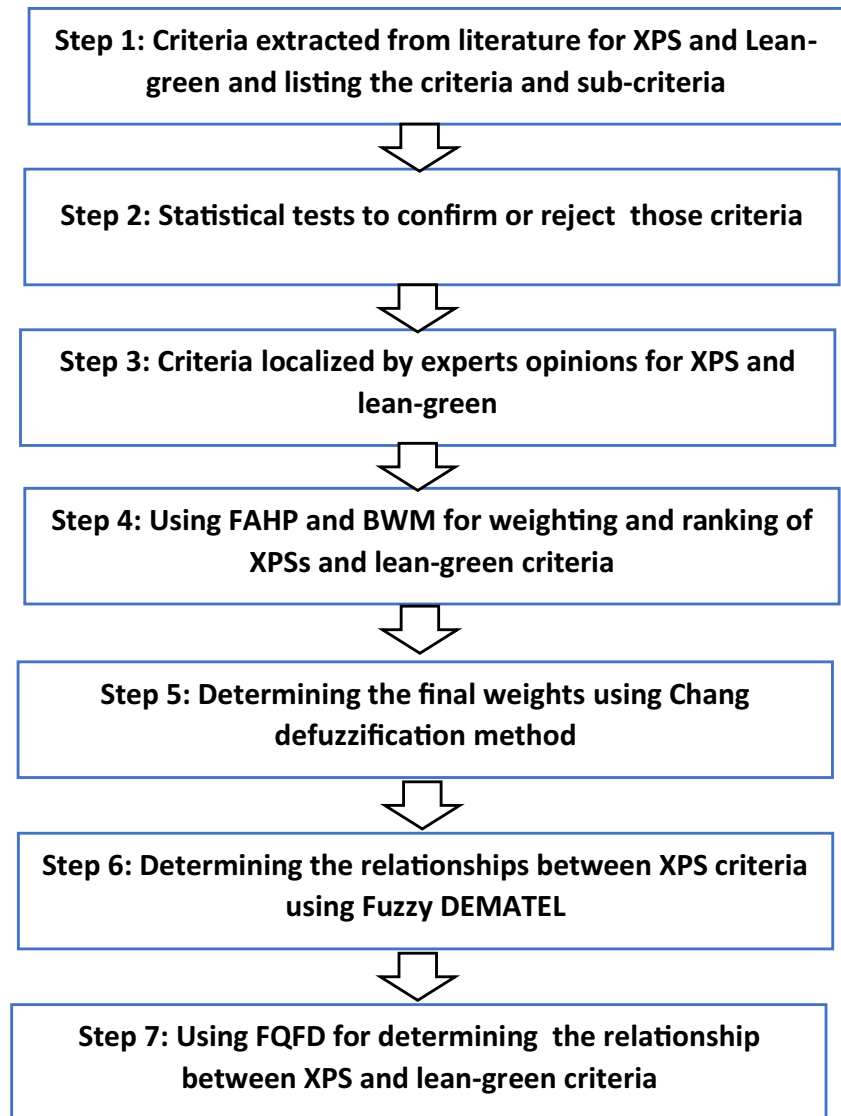
## Contribution of research

The contribution of this research is to provide a model that allows lean-green integration and assesses the specific requirements of an organization in supply chain of automotive industry. Knowing that Quality Function Deployment can integrate two XPS models and consider technical characteristics of the organization and lean-green requirements as inputs of customers' needs, we will be able to use these two models to expand the integration and use decision-making models to evaluate the criteria and sub criteria of this model. To the best of the authors' knowledge, few research studies have been performed on the specific requirements of the organization and lean-green integration. This work is unique because decision support system for evaluating lean-green and company-specific production system is proposed.

## Research methodology

XPS and Lean-Green criteria were extracted after examining the research literature. The XPS and lean-green criteria and sub criteria were determined in step 1; then, in step 2, statistical tests were performed to confirm or reject the criteria. The criteria were then localized by the experts in step 3. In step 4, the criteria were weighted and ranked using FAHP

Fig. 1 Research framework



and Best Worst Method (BWM) pairwise comparisons. In step 5, final weights of different criteria were obtained using the Chang defuzzification method. Then, the correlation between XPS and Decision-Making Trial and Evaluation Laboratory (DEMATEL) was used in step 6, and finally, in step 7, the fuzzy QFD (FQFD) was applied to determine the relationship between the XPS and green criteria. The applied steps in this research are shown in Fig. 1.

The qualified experts of the present study consists of directors, and experts with a minimum of bachelor education, experienced and from relevant departments to the scope of this study, which includes a total of 52 qualified experts. The company, as a part of the Iranian Tractor Manufacturing Industrial Group, is responsible to design, manufacture, and supply internal combustion engines and their components with various applications in agriculture, automotive industry, road manufacturing machinery, and more areas.

The initial data of this study is collected through a questionnaire. For this purpose, the five famous models of XPS in the major automotive companies (Toyota Corporation-TPS<sup>1</sup>, Scania Group-SPS<sup>2</sup>, Haldex AB, Volvo Group-VPS<sup>3</sup>, Volvo Car-VCMS<sup>4</sup>) were developed, and the indicators were determined in each of the six main criteria and discussed in a section related to the determination of the elements of a XPS. From our analysis of extant research, it can be said that an XPS has six main elements which are presented in Table 1.

In order to determine the most important criteria in each of these principles, the XPS of five major automotive companies

<sup>1</sup> Toyota Material Handling

<sup>2</sup> Scania Production System

<sup>3</sup> Volvo Production System

<sup>4</sup> Volvo Cars Manufacturing System

**Table 1** Six main elements in an XPS

Main element in XPS	References
1. Values and visions	(Kurdve et al., 2014)
2. Principles	(Netland, 2013; Blücher & Öjmertz, 2008)
3. Tools, methods, and techniques	(Kurdve et al., 2014)
4. Key performance indicators	(Kurdve et al., 2014; Harlin et al., 2008)
5. Organizing	(Magnusson et al., 2003)
6. Auditing system	(Harlin et al., 2008)

(Toyota Corporation-TPS, Scania Group-SPS, Haldex AB, Volvo Group-VPS, Volvo Car-VCMS) were studied, and the most important criteria for each of the six elements were determined based on the obtained results and presented in Table 2.

Finally, the common criteria in lean and green production were extracted as “lean-green production” and shown in Table 3.

### Data analysis

One-sample *T*-test or *T*-value tests were used to confirm or reject XPS criteria within the company using a 5-point Likert scale questionnaire.

### Prioritizing lean-green criteria

The BWM<sup>5</sup> method is used to prioritize the lean-green criteria that will be applied at the House of Quality in QFD. In this method, each of the indicators or criteria is subject to pairwise comparison and receives a numerical value from one to nine (Saati scale) just like the hierarchical analysis method.

This method is categorized among multi criteria decision-making methods by comparing the best and worst criteria with the other remaining criteria. In other words, this method only focuses on the comparison of the best and worst criteria with the other criteria, respectively, and provides a stream that frees the researcher from redundant studies in methods such as AHP and brings more precise adjustments. The steps below describe the BWM method that can be used to obtain the weights of the criteria:

- Step 1:** Specifying a set of criteria. At this step, we consider the criteria  $\{C_1, C_2, \dots, C_N\}$  that should be used in the decision-making process. For example, decision criteria such as quality (C1), price (C2), comfort (C3), safety (C4), and appearance (C5) can be considered while buying a car.
- Step 2:** Identifying the best (in other words, the most desirable and the most important) and the worst (the most unfavorable and the least important) criteria. In this section, the decision-making unit generally identifies the best and the worst criteria. There is no com-

parison in this section. For example, for a particular decision-maker, prices and shapes may be the best and worst criteria, respectively.

**Step 3:** Determining the performance of the best criteria against other criteria using numbers between one and nine. The best benchmark results for the rest of the criteria may be as follows:

$$= (A_{B1}, A_{B2}, \dots, A_{Bn} A_B) \tag{1}$$

$a_{Bj}$  defines performance of the best Bth criterion relative to the *j* criterion. Obviously,  $a_{BB} = 1$ . For example, this vector represents the performance of the price criterion relative to other criteria.

**Step 4:** Specifying the performance of all the criteria relative to the worst criteria using numbers one to nine. The vector of criteria comparison compared to the worst criteria can be as follows:

$$A_W = (a_{1w}, a_{2w}, \dots, a_{nw})^T \tag{2}$$

where  $a_{jw}$  represents the performance of criterion *j* compared to the worst *w* criterion. Obviously,  $a_{ww} = 1$ . In the present example, this vector represents the performance of all the criteria relative to the appearance criterion.

**Step 5:** Finding the optimal weights ( $W_1^{**}, W_2^*, \dots, W_n^*$ ) The optimal values for criteria are unique so as those of each pair, so we will have  $\frac{W_B}{W_j} = a_{Bj}$  and  $\frac{W_j}{W_w} = a_{jw}$ . To satisfy these conditions for all *j*, we need to find a solution that minimizes the absolute value of maximum differences  $\left| \frac{w_B}{w_j} - a_{Bj} \right|$  and  $\left| \frac{w_j}{w_w} - a_{jw} \right|$ . Given that weights are non-negative and additive, the following problem can be expressed:

$$\begin{aligned} \text{Min } \max_j & \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_w} - a_{jw} \right| \right\} \\ \text{s.t.} & \\ & \sum_j W_j = 1 \\ & W_j \geq 0 \text{ for all } j \end{aligned} \tag{3}$$

<sup>5</sup> Best-Worst Method

**Table 2** The most important criteria in each of the six elements in an XPS

XPS element	Criteria	Based on companies...	XPS names	
Values and visions element	Quality	Toyota	TPS	
	Safety	Scania	SPS	
	Environment	Haldex	HPS	
	Human respect and dignity	Volvo group	VPS	
	Customer's first choice	Volvo Car	VCMS	
Principles Key performance indicators (KPIs)	Continuous improvement	Toyota	TPS	
	Product timely delivery	Toyota	TPS	
	Quality manufacturing	Scania	SPS	
	Supporting customers	Scania	SPS	
	Stability and Strength	Haldex	HPS	
	Considering customers' rights	Haldex	HPS	
	Teamwork and participation	Volvo group	VPS	
	Timely delivery	Volvo group	VPS	
	Waste and residue removal	Volvo Car	VCMS	
	Cost management	Volvo Car	VCMS	
	Attention to customer	Volvo Car	VCMS	
	Tools, methods, and techniques	Utilizing EMS	Toyota	TPS
		Utilizing OHS	Scania	4
Utilizing QMS		Haldex	3	
Utilizing ISO		Volvo Car and Volvo group	4	
KPIs	Safety index	Toyota	TPS	
	Productivity index	Toyota	TPS	
	Staff personal index	Scania	SPS	
	Environment index	Scania	SPS	
	Cost index	Haldex	HPS	
	Timely delivery index	Haldex	HPS	
	Complaints reduction index	Volvo group	VPS	
	Rework reduction index	Volvo group	VPS	
	Respecting people index	Volvo Car	VCMS	
	Improvement index	Volvo Car	VCMS	
Organizing	EMS organization	Toyota	TPS	
	CI organization	Scania	SPS	
	QMS organization	Haldex	HPS	
	OHMS organization	Scania	SPS	
Auditing system	ISO-14001 audit	Toyota	TPS	
	OHSAS-18001 audit	Scania	SPS	
	Integrated audit in EMS with QMS or OHS	Haldex, Volvo and Volvo Car	HPS, VPS, VCMS	

**Table 3** Lean-green production criteria (based on the combination of lean and green criteria)

Lean-green criteria	References
Proper packaging	(Ninlawan, 2010; Bergmiller & McCright, 2009; Hosseini Anvari & Aghdashi, 2008).
Waste reduction	(Fazlzadeh & Marandian Hagh, 2014; Ninlawan, 2010; Bergmiller & McCright, 2009; Hosseini Anvari & Aghdashi, 2008; Rao, 2006; Powell et al., 2013)
Quality improvement	(Rao, 2006; Powell et al., 2013)
Reducing environmental pollution	(Ninlawan, 2010; Rao, 2006)
Transportation management	(Womack et al., 1990; Ninlawan, 2010)
Cost reduction	(Womack et al., 1990; Hosseini Anvari & Aghdashi, 2008; Powell et al., 2013)
Increasing production and productivity	(Womack et al., 1990; Bergmiller & McCright, 2009)

$$\begin{aligned}
 &W_j \geq 0, \text{ for all } j \\
 &\min \xi \\
 &\text{s.t.} \\
 &\left| \frac{W_B}{W_j} - a_{Bj} \right| \leq \xi \text{ for all } j \\
 &\left| \frac{W_j}{W_B} - a_{jW} \right| \leq \xi \text{ for all } j \\
 &\sum_j W_j = 1 \\
 &W_j \geq 0, \text{ for all } j
 \end{aligned} \tag{4}$$

By solving the problem, we obtain the optimal values of the weights ( $W_1^{**}, W_2^*, \dots, W_n^*$ ), and the value of  $\xi^*$  will be obtained. The  $\xi^*$  value is in fact the same as the consistency amount determined by dividing it into the consistency index of the consistency rate.

### Determining the priority of indices with fuzzy AHP technique

Fuzzy AHP approach has been used to determine the weights of related factors to experts' satisfaction. Saati's nine-degree scale is used for pairwise comparison of the elements. The fuzzy approach is also used to quantify the values.

In the next step, the sum of the elements of the row will be calculated. Equation 5 is used for this purpose:

$$\begin{aligned}
 &i = 1, 2, \dots, n \\
 &\tilde{S}_i = \sum_{j=1}^n \tilde{a}_{ij}
 \end{aligned} \tag{5}$$

In the next step, the results are normalized. The following equation is used for this purpose:

$$\tilde{M}_i = \tilde{S}_i^{-1} \otimes \left[ \sum_{i=1}^n \tilde{S}_i \right] \quad i = 1, 2, \dots, n \tag{6}$$

If we show  $\tilde{s}_i$  as  $(l_i, m_i, u_i)$ , the above equation is calculated as follows.

$$\tilde{M}_i = \left( \frac{l_i}{\sum_{i=1}^n u_i}, \frac{m_i}{\sum_{i=1}^n m_i}, \frac{u_i}{\sum_{i=1}^n l_i} \right) \tag{7}$$

In order to calculate and determine the final weights, the Chung's defuzzification method was used.

### Determining the final weight of the criteria using Chung defuzzification method

In this method, the matrix weight vector is obtained as follows:

$$w' = d'(A_1), d'(A_2), \dots, d'(A_n) \tag{8}$$

Ultimately, weights are defuzzified and normalized. By normalizing the weights vector ( $w'$ ), we obtain the final weights.

$$W = \left[ \frac{d'(A_1)}{\sum_{i=1}^n d'(A_i)}, \frac{d'(A_2)}{\sum_{i=1}^n d'(A_i)}, \dots, \frac{d'(A_n)}{\sum_{i=1}^n d'(A_n)} \right]^T \tag{9}$$

Weights obtained by this method are of crisp values (non-fuzzy). By repeating this process, all matrices weights are obtained.

### Determining the correlation between XPSs using fuzzy DEMATEL

Fuzzy DEMATEL method uses matrices based on fuzzy numbers. In these matrices, fuzzy numbers are considered to be of triangular type, so each  $\tilde{x}_{ii} = (i = 1, 2, 3, \dots, n)$  is defined as fuzzy number  $(0, 0, 0)$ . In order to include all experts' opinions in accordance with formula (10), the arithmetic average is calculated for each of them.

$$\tilde{z} = \frac{\tilde{x}^1 \oplus \tilde{x}^2 \oplus \tilde{x}^3 \oplus \dots \oplus \tilde{x}^p}{p} \tag{10}$$

In this formula,  $p$  is the number of experts and  $\tilde{x}^1, \tilde{x}^2, \dots, \tilde{x}^p$  are the pair comparison matrices of expert 1, expert 2, and expert  $p$ , respectively, and  $\tilde{z}$  is a triangular fuzzy number as  $\tilde{z}_{ij} = (l'_{ij}, m'_{ij}, u'_{ij})$ .

The following matrix is used to normalize the formulas (11) and (12):

$$\tilde{H}_{ij} = \frac{\tilde{z}_{ij}}{r} = \left( \frac{l'_{ij}}{r}, \frac{m'_{ij}}{r}, \frac{u'_{ij}}{r} \right) = (l^e_{ij}, m^e_{ij}, u^e_{ij}) \tag{11}$$

where  $r$  is obtained by the following equation:

$$r = \max_{1 \leq i \leq n} \left( \sum_{j=1}^n u_{ij} \right) \tag{12}$$

After calculating the matrices, the matrix of the total fuzzy relations is obtained according to the formulas (13) to (16).

$$T = \lim_{k \rightarrow +\infty} \left( \tilde{H}^1 \oplus \tilde{H}^2 \oplus \dots \oplus \tilde{H}^k \right) \tag{13}$$

where each of its elements is a fuzzy number as  $\tilde{t}_{ij} = (l^t_{ij}, m^t_{ij}, u^t_{ij})$  and is calculated as follows:

$$[l^t_{ij}] = H_l \times (I - H_l)^{-1} \tag{14}$$

$$[m_{ij}^t] = H_m \times (I - H_m)^{-1} \tag{15}$$

$$[u_{ij}^t] = H_u \times (I - H_u)^{-1} \tag{16}$$

In these formulas,  $I$  is the elementary matrix, and each of  $H_i$ ,  $H_m$ , and  $H_u$  are  $n \times n$  matrix in which the elements contain the lower number, the middle number, and the upper number as the triangular fuzzy numbers of the matrix  $H$ .

The next step is to calculate the sum of the rows and columns of the matrix  $\tilde{T}$ . The sum of rows and columns are obtained according to the formulas (17) and (18), respectively.

$$\tilde{D} = \left( \tilde{D}_i \right)_{n \times 1} = \left[ \sum_{j=1}^n \tilde{T}_{ij} \right]_{n \times 1} \tag{17}$$

$$\tilde{R} = \left( \tilde{R}_i \right)_{1 \times n} = \left[ \sum_{j=1}^n \tilde{T}_{ij} \right]_{1 \times n} \tag{18}$$

where  $D$  and  $R$  are the  $n \times 1$  and  $1 \times n$  matrices, respectively.

The next step is to determine the importance of the indices ( $D_i$  and  $R_i$ ) and the relationship between the criteria ( $D_i$  and  $R_i$ ). If  $D_i - R_i > 0$ , then the relevant criterion will be effective and if  $D_i - R_i < 0$ , then the relevant criterion will be affected.

In this step, the threshold value should be calculated to determine the relationship map. If the value of the numbers is higher than the threshold value, there will be relationship or correlation between the two factors, and if its value is less than this value, there would not be any relationships between the two factors.

### Investigating the relationship among XPS and lean-green indices FQFD

FQFD consists of several steps. The first step is to determine the net green indices in the target company, which is performed using  $T$ -test. In the second step, the XPS-related indices of the company should be extracted. In the next step, the weights of each lean-green feature should be determined using fuzzy AHP (FAHP) for determining the first and second priority, and the best and the worst criteria and the BWM (to determine the weights of each of the people in comparison with the best and worst indicators). In the next step, the correlation between the XPS indices was also determined using the fuzzy DMF method. The House of Quality which is obtained by combining the correlation matrices between XPSs and computing their relative importance is presented in Fig. 2.

It should be noted that considering the relationship between the lean-green indices with the XPS elements of the company ( $R_{jk}$ ) and the correlations between the elements

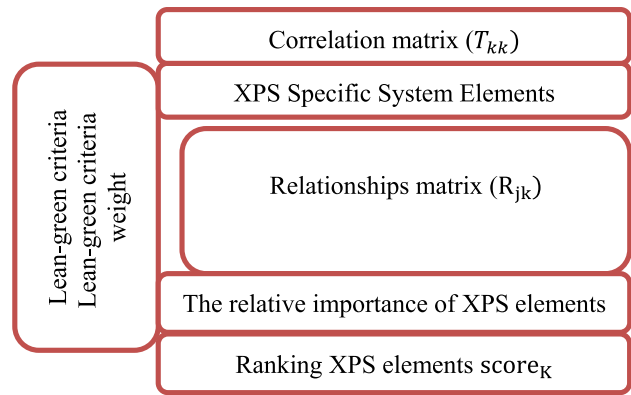


Fig. 2 Localized House of Quality (HOQ) elements in this research

of XPS ( $T_{kk}$ ), which are represented by the fuzzy DM, the relative importance ( $R_{ik}$ ) and the final score of each element of the company’s specific production system XPS (score $_K$ ) can be calculated using the following relationships:

$$R_{ik} = \sum_{j=1}^m W_j \times R_{jk} \quad k = 1, \dots, p \tag{19}$$

$$\text{score}_K = R_{ik} \sum_{k' \neq k}^m T_{k'k} \times R_{ik'} \quad k = 1, \dots, p \tag{20}$$

Finally, the obtained fuzzy values were converted to definite numbers using the defuzzification method.

### Research findings and analysis

In this section, the research findings are examined. Firstly, the central determinants (including the mean and mode of the data) and the dispersion determinants (including standard deviations of the data) are evaluated along with the maximum and minimum of the data. The results are presented in Table 4.

Among the studied elements, indices such as quality, environment and customer selection (in the vision element), continuous improvement, product quality manufacturing, teamwork and participation (in the principle element), EMS application and ISO (in the methodology dimension) and productivity, environmental, timely delivery indices (in the dimension KPI), EMS organization and Quality Management System (QMS) in the organization dimension, and finally, the auditing system, the integrated audit in EMS by QMS or Occupational Health and Safety (OHS) in the sixth element have the mean values higher than the average 3, and within the others, the mean values are reported lower than the average. As mentioned before, a 5-point Likert



**Table 4** Results of central and dispersion determinants ( $n = 52$ )

XPS element	Indices	Mean (M)	Mode	SD	Min	Max	
Vision element	Quality	3.65	4	0.48	3	4	
	Safety	2.58	3	0.848	1	4	
	Environment	3.4	3	1.176	1	5	
	Human respect and dignity	2.6	2	1.459	1	5	
	Customer's first choice	3.6	3	1.089	2	5	
Principles KPIs	Continuous improvement	3.79	4	0.412	3	4	
	Timely product delivery	2.65	4	1.251	1	4	
	Quality manufacturing	3.4	3	0.891	2	5	
	Supporting customers	2.63	4	1.314	1	4	
	Stability and strength	2.62	2	1.069	1	4	
	Considering customers' rights	2.13	2	0.793	1	4	
	Teamwork and participation	3.44	2	1.211	2	5	
	Timely delivery	2.63	3	0.486	2	3	
	Waste and residue removal	3.75	4	0.437	3	4	
	Cost management	2.71	4	1.16	1	4	
	Attention to customer	2.65	3	1.136	1	4	
	Methods	Utilizing EMS	3.69	4	0.466	3	4
		Utilizing OHS	2.58	4	1.226	1	4
		Utilizing QMS	2.75	3	1.046	1	4
Utilizing ISO		3.73	4	0.448	3	4	
KPIs	Safety index	2.23	2	0.425	2	3	
	Productivity index	3.88	4	0.323	3	4	
	Staff personal index	2.73	2	1.031	1	4	
	Environment index	3.48	3	1.146	2	5	
	Cost index	2.42	2	0.75	1	4	
	Timely delivery index	3.44	3	0.958	2	5	
	Complaints reduction index	2.73	4	1.069	1	4	
	Rework reduction index	2.79	4	1.016	1	4	
	Respecting people index	2.73	3	1.05	1	4	
	Improvement index	2.69	4	1.147	1	4	
Organizing	EMS organization	3.5	3	0.939	2	5	
	CI organization	2.81	3	0.595	1	4	
	QMS organization	3.58	4	0.499	3	4	
	OHMS organization	2.73	3	0.819	1	4	
Auditing system	ISO-14001 audit	2.77	2	1.022	1	4	
	OHSAS-18001 audit	2.63	2	1.03	1	4	
	Integrated audit in EMS with QMS or OHS	3.75	3	1.027	2	5	

scale questionnaire was employed for this section. For more investigation, the Kolmogorov-Smirnov normality test was employed. Other variables with abnormal distribution are examined through binomial test, and the results are shown as the elements of the XPS in Table 5.

Then, the priorities of the indices are determined using fuzzy AHP technique, we firstly use the FAHP method and then the BWM method, to determine the weight of each lean-green index. Fuzzy approach is used to determine the weight of the factors involved in the experts' satisfaction and Chung's method for calculating and determining the final

weights. Table 6 shows the defuzzified and final weights of the Chung's method in comparison to lean-green indices.

The final results of the indices weight of lean-green indices by Chun's method is shown in Fig. 3.

The inconsistency rate of 0.08 is reported using the Expert Choice Software. In general, according to the findings of the present research, priorities of lean-green criteria are as follows using the FAHP method: (1) quality improvement, (2) cost reduction, (3) reduction of environmental pollution, (4) waste reduction, (5) reduction of additional transportation, and (6) appropriate

**Table 5** XPS elements

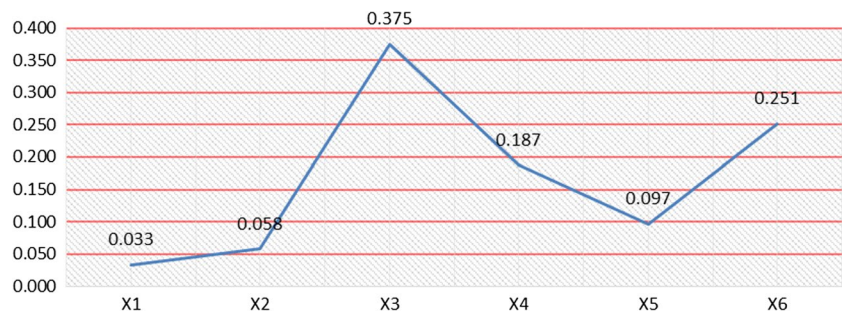
XPS element	Indices	Mean (M)
Vision element	Quality	3.65
	Environment	3.4
	Customer’s first choice	3.6
Principles	Continues improvement	3.79
	Quality manufacturing	3.4
	Teamwork and participation	3.44
	Waste and residue removal	3.75
Methods	Utilizing EMS	3.69
	Utilizing ISO	3.73
KPIs	Productivity index	3.88
	Environment index	3.48
	Timely delivery index	3.44
Organizing	EMS organization	3.5
	QMS organization	3.58
Auditing system	Integrated audit in EMS with QMS or OHS	3.75

**Table 6** Defuzzified and final weights of Chung’s method compared to lean-green indices

Probability degree	Chung’s defuzzification	Variable	Final weight
dx1	0	X1	0.000
dx2	0	X2	0.000
dx3	1	X3	0.564
dx4	0.22474615	X4	0.127
dx5	0	X5	0.000
dx6	0.546923104	X6	0.309

packaging. Based on these findings, the priorities of the indicators are determined that can be used as input values for the BWM method. The best indicator (B) is the quality improvement index, and the least important index is green packaging (W). These indices provide the BWM method with a basic comparison model.

**Fig. 3** Final weights of lean-green indices by Chung’s method



**Determination of the weights of lean-green indices by BWM method**

Comparing two mentioned indices as the best and the worst indices leads to the following results which are shown in Table 7.

Accordingly, the consistency rate is obtained by dividing  $\min \xi$  by the consistency index (CI), which is equal to:

$$\text{Consistency Ratio} = 0.76/4.47 = 0.170$$

According to Best-Worst method and based on the findings, it can be stated that the obtained consistency ratio (CR) of the current study is worth considering.

**Determination of the correlations between XPSs using fuzzy DEMATEL**

To determine the correlation between XPSs, a fuzzy DEMATEL is used. In the present study, the threshold value is equal to 0.58. Figure 4 shows the significance, impact, and impressibility of the criteria. Horizontal axis shows the importance of criteria, while the vertical axis shows the impact or impressibility of the indicators.

As it is obvious, the continuous improvement index has greater latitude to the origin compared with the other indicators, which means that this indicator is the most important one within the impact and impressibility indices of the XPS system.

Furthermore, group work and participation indicators with the value of 1.86 and QMS organization with the value of 1.68 are the most influential indicators while environmental index with the value of  $-4.09$  is the most impressible indicator.

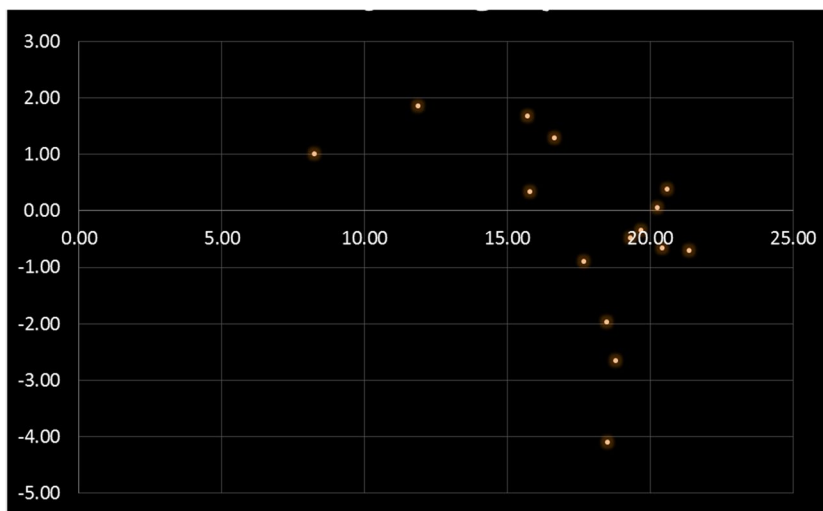
The results of combining XPS with lean-green in FQFD demonstrate that continuous improvement and integrated audit are two important elements of XPS with final weights of 4.12 and 3.82, respectively. Accordingly, timely delivery index is one of the lowest-weight items with a value of 0.05. Therefore, The company should

**Table 7** Lean-green indices weights

Lean-green indices	Quality improvement	Cost reduction	Reducing environmental pollution	Waste reduction	Reducing extra transport	Appropriate packaging
	C1	C2	C3	C4	C5	C6
Indices weight	0.4109	0.2562	0.1360	0.0913	0.0597	0.0456

The calculated value of  $\min \xi$  is equal to 0.76. The consistency index (CI) is also reported to be 4.47, according to BWM.

**Fig. 4** A relationship chart showing the importance, impact, and impressibility indicators



focus on two main elements of XPS, i.e., continuous improvement and integrated auditing, more than anything else to achieve lean-green features in the manufacturing system. The significance of other elements is determined, and then, they are ranked in a descending order in the fourth column of Table 8.

**Table 8** Ranking of each XPS element based on FQFD method

Ranking XPS elements		Crisp value	Rank
Continuous improvement	D	4.12	1
Integrated audit	O	3.82	2
Attention to environment	B	3.56	3
Customer’s first choice	C	3.44	4
Waste and residue removal	G	3.24	5
Quality manufacturing	E	3.23	6
QMS organization	N	3.06	7
Utilizing ISO	I	2.89	8
Productivity	J	2.76	9
Utilizing EMS	H	2.64	10
Attention to quality	A	2.56	11
Environment indicator	K	1.99	12
EMS organization	M	1.91	13
Teamwork and participation	F	0.24	14
Timely delivery	L	0.05	15

Regarding Table 8, continuous improvement can be considered as the most important and essential element of XPS for the company, which should be given special attention to meet lean-green production requirements.

### Discussion

After determining all the indicators that were classified in the form of six main elements, distributing questionnaires and using inferential tests to determine the specific XPS for the company, the obtained results offered the following cases:

1. Vision: quality, environment, and customer first choice
2. Principles: continuous improvement, quality manufacturing, teamwork and participation, and waste residue removal
3. Methods: EMS application, ISO application
4. KPI: Productivity index, environmental index, and timely delivery indicator
5. Organizing: EMS organization, QMS organization
6. Auditing system: integrated audit in EMS with QMS or OHS

Lean production criteria include reduction of waste, costs, product prices, production space, manpower, production time, environmental pollutants and transportation, and increase in product quality, teamwork, safety, productivity, multipurpose manpower, continuous improvement as well as aiming at timely production and delivery, long life of equipment, and suitable packaging.

On the other hand, conducted surveys demonstrate that green standards also include recycling, proper packaging, prolonging product life, improving quality, managing transport, increasing production, and efficiency and reducing waste, energy consumption, environmental pollution, and costs.

## Conclusion

Previous research had connected the performance measuring of manufacturing and business service companies with the QFD approach and decision-making methods based on lean activities. Here, the similarities and differences between the results of this study with one of the most esteemed prior studies will be discussed. Reda and Drivedi in 2022 designed lean tools using a fuzzy QFD and FMEA approach in manufacturing industry. They concluded that their study would help experts and decision-makers to recognize the most important criteria, resources, important waste, and critical and less essential actions.

The present study has investigated the importance and impact dimensions of performance measurements of an original equipment manufacturer in the supply chain of tractor manufacturing industry in Iran. This has focused on the importance of environmental issues in lean production to evaluate a company-specific production system (XPS) using fuzzy QFD. Based on the results, the overlapped criteria within lean and green production scopes contain six lean-green production indicators which are proper and green packaging, quality improvement, reduction of waste, environmental pollution, costs, and extra transportation.

## Implication of research for practitioners and researchers

Regarding the relationships between XPS elements and lean-green production indicators, the two most important elements of XPS are continuous improvement and integrated auditing, and in conjunction with ranking of XPS indicators, continuous improvement is also chosen as the most essential element of XPS for the company. Therefore, special attention should be given to achieve the lean-green indices. Based on the results obtained, it is concluded that continuous improvement, integrated audit, and attention to environment are ranked as first, second, and third as company-specific production system

(XPS) elements for the selected company. In line with our findings, Kurdve et al. (2014) also concluded that auditing operations are needed in a production and manufacturing system and that auditing would be a crucial part of monitoring the system. They also emphasized that incorporation of environmental management systems (EMS) into XPS was observed as an effective way of establishing company commonality in continuous improvement and consequently resulting in organization performance improvement. Further research can be conducted to focus on the role of various XPS elements on issues such as improving the level of companies export or its financial performance, or meeting customers' demands and achieving customer satisfaction using other decision-making techniques using the Stepwise Weight Assessment Ratio Analysis (SWARA) method and Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) for evaluating companies.

**Author contribution** Elmira Aghaei (EA) has contributed to the methodology, investigation, project administration, validation, data collection, and software. Soroush Avakh Darestani (SAD) contributed to the conceptualization, writing—review and editing, visualization, and supervision.

**Data availability** The data that support the findings of this study are openly available. The authors declare that the data are not available and can be presented upon the request from the readers.

## Declarations

**Consent to participate** The authors declare that they agree with the participation of the journal.

**Consent for publication** The authors declare that they agree with the publication of this paper in this journal.

**Conflict of interest** The authors declare no competing interests.

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