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ORIGINAL RESEARCH

A fuzzy model for achieving lean attributes for competitive advantages development using AHP-QFD-PROMETHEE

E. Roghanian · Mohammad Alipour

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Abstract Lean production has become an integral part of the manufacturing landscape as its link with superior performance and its ability to provide competitive advantage is well accepted among academics and practitioners. Lean production helps producers in overcoming the challenges organizations face through using powerful tools and enablers. However, most companies are faced with restricted resources such as financial and human resources, time, etc., in using these enablers, and are not capable of implementing all these techniques. Therefore, identifying and selecting the most appropriate and efficient tool can be a significant challenge for many companies. Hence, this literature seeks to combine competitive advantages, lean attributes, and lean enablers to determine the most appropriate enablers for improvement of lean attributes. Quality function deployment in fuzzy environment and house of quality matrix are implemented. Throughout the methodology, fuzzy logic is the basis for translating linguistic judgments required for the relationships and correlation matrix to numerical values. Moreover, for final ranking of lean enablers, a multi-criteria decision-making method (PROMETHEE) is adopted. Finally, a case study in automotive industry is presented to illustrate the implementation of the proposed methodology.

Keywords Lean production · Fuzzy quality function deployment (Fuzzy-QFD) · House of quality (HOQ) · Fuzzy analysis hierarchy process (Fuzzy-AHP) · PROMETHEE

Introduction

Today, the world is witnessing the globalized advancement of science and technology enriched by new theories, models and approaches, which has made managers rethink about production techniques. Shorter product lifecycles, increase in product variety, and also intensification of challenges ahead of competitors at global level, have motivated many manufacturing firms to step towards new manufacturing techniques (Hofer et al. 2012; Priyanto et al. 2012). Because of the growing dynamics and variation in demand, modern production systems have to be lean and flexible in order to strengthen the company's competitive position (Abele and Reinhart 2011). Up to now, some have succeeded in overcoming the challenges through utilizing modern production concepts, techniques and models. One of the latest production approaches is lean production, which has powerful tools and enablers, and holds big promises for producers (Chen et al. 2013).

Lean production system is one of the leading approaches adopted by many leading businesses in the world to keep their competitive advantages in the growing global market (Schonbergerm 2007). Lean production is often regarded as the gold standard of modern operations and supply chain management (Guinipero et al. 2005; Goldsby et al. 2006). It holds significant promises for substantial advantage for improvement of communication and integration within the organization and supply chain (Scherrer-Rathje et al. 2009).

E. Roghanian
Department of Industrial Engineering,
K. N. Toosi University of Technology, Tehran, Iran
e-mail: e_roghanian@kntu.ac.ir

M. Alipour (✉)
Sustainable Energies Group, AUT Office of Sustainability,
Amirkabir University of Technology (Tehran Polytechnic),
P.O. Box: 15875-4413, Tehran, Iran
e-mail: Alipour.m.86@gmail.com

Lean enablers are considered as a set of tools, techniques and suggestions for implementation and execution of lean principles and help business units to step toward leanness (De Treville and Antonakis 2006; Hopp and Spearman 2004; Narasimhan et al. 2006). Numerous business units either in manufacturing or service sectors have been helped by lean enablers to enhance their efficiency, profitability and competitiveness. Developed originally for Toyota Production System, the application of lean enablers has empowered various organizations to improve their quality, productivity and customer services, significantly (Riezebos 2009).

Lean manufacturing paradigm encompasses several tools/techniques to achieve leanness in manufacturing organizations (Vinodh et al. 2010) and firms have a problem of selecting the best lean concept for the immediate implementation as most enterprises are not capable of implementing all these techniques (Vinodh et al. 2012). Besides, most organizations have limited resources such as budget, human resources, time, etc. Hence, identifying and selecting the most appropriate and efficient tool can be a significant challenge for many companies. In this way, this study tries to propose an integrated approach, based on quality function deployment (QFD) and in particular HOQ technique, towards improving leanness of business units. The first objective is to determine the relationship between the organization's competitive advantages and lean attributes in the HOQ, and then, ranking the most necessary and efficient lean attributes to achieve competitive advantages. The second goal is to determine the most significant and efficient lean enablers and then, ranking them through PROMETHEE. In addition, the present approach uses fuzzy logic to minimize the gap between judgment and scoring and the reality. The proposed model of this paper uses competitive advantages, lean attributes and lean enablers based on fuzzy analytical hierarchy process (F-AHP), while geometric mean method is applied for calculating fuzzy weights. Finally, to show merits of the methodology, a case study is represented as well.

The remainder of this study is organized as follows: "Literature review" presents a literature review of competitive advantages, F-QFD and HOQ, PROMETHEE, and F-QFD calculations. The Fuzzy-AHP-QFD-PROMETHEE model for increasing leanness of the organization is proposed in "Fuzzy-AHP-QFD-PROMETHEE model". A case study in an industry is discussed in "Case study" as an illustrative example along with outcomes of the model. And finally, concluding remarks are given in "Conclusion".

Literature review

This paper draws on and contributes to the following research streams: competitive advantages, F-QFD and HOQ, and PROMETHEE. An overview of the related works in each area and their implications for this research are provided as follows. Fuzzy-QFD calculations are provided at the end of this section.

Current world of business is a dynamic space in which the rate of change and development is extensively high. Therefore, firms seek to understand customer needs in order to achieve a competitive advantage and improve the organizational performance. To specify the impact of competitive advantages, several MCDM methods have been provided. Nayebi et al. (2012) applied VIKOR for ranking the indices of organizational entrepreneurship development. Sun and Lin (2009) used fuzzy TOPSIS method for evaluating the competitive advantages of shopping websites. In measuring the competitive advantage and risk of a product supply chain, Hung (2011) used decision-making trial and evaluation laboratory (DEMATEL) to analyze and determine the interdependence relationships between the criteria. Hsu et al. (2008) adopted an optimal resource-based allocation strategy for senior citizen housing to gain a competitive advantage. They used analytic hierarchy process (AHP) to determine each criteria weight and the arrangement of importance. Like their work, this research uses AHP to determine the weight of competitive advantages; which fuzzy logic is supported to deal with the deficiency in the classical AHP, referred to as FAHP. The traditional AHP requires crisp judgments and also due to the complexity and uncertainty involved in real world decision problems, a decision maker (DM) may sometimes feel more confident to provide fuzzy judgments rather than crisp comparisons. The weights determined by F-AHP unlike approaches like extent analysis method, represent the relative importance of decision criteria or alternatives and can correctly be adopted as their priorities (Wang et al. 2008).

QFD is a methodology for translating customer requirements (CRs) into product design requirements (DRs). It helps to address customer requirements into engineering specifications for a product by prioritizing each product attribute while simultaneously assigning development goals for the same product. The house of quality (HOQ), for instance is an approved tool used by QFD wherein visually appealing graphical illustrations are used to define the relationships between customer desires and the product features (Smith 2011). Various optimization methods have been applied in the field of QFD for helping decision makers in product planning and improvement (Chen and Ko 2009, 2010; Lai et al. 2007; Delice and Güngör 2009; Bhattacharya et al. 2010; Chien et al. 2010; Hajji et al. 2011; Karipidis 2011). Moreover, several researchers have generated substantial attention on fuzzy QFD during the last decades. Zaim et al. (2014) synthesized renowned capabilities of ANP and Fuzzy

Logic to better rank technical characteristics of a product (or a service) while implementing QFD. Raissi et al. (2012) prioritized engineering characteristic in QFD using fuzzy common set of weight. Bottani (2009) presented an approach aims at identifying the most appropriate enablers to be implemented by companies starting from competitive characteristics of the related market. The approach was based on QFD and in particular HOQ, in which the whole scaffold exploits fuzzy logic, to translate linguistics judgments required for relationships and correlations matrixes into numerical values. As one of the key issues in F-QFD is to derive the technical importance ratings of design requirements (DRs) in fuzzy environments and prioritize them, Wang and Chin (2011) investigated how the technical importance of DRs can be correctly rated in fuzzy environments. In this paper, F-QFD is adopted instead of crisp QFD model to determine the effect of lean attributes on competitive advantages. The distinctions between the F-QFD system and the traditional QFD methodology is that the QFD relevant data are symbolized as linguistic terms rather than crisp numbers, and the linguistic data is processed by algorithms embedded in the system's internal environment (Mehrjerdi 2010).

Multiple criteria decision making (MCDM), often called multi-criteria decision aid (MCDA) and multi-criteria analysis (MCA), is a set of methods which allows the aggregation and consideration of numerous (often conflicting) criteria in order to choose, rank, sort or describe a set of alternatives to aid a decision process (Zopounidis 1999). There is no single method considered as the most suitable for all types of decision-making situations, and it has also been acknowledged that several methods can be potentially valid for a particular decision-making situation (Mulliner et al. 2013).

There is a well-developed body of research on MCDM methods with a view to rank and select the best alternatives. For example, Faghihinia and Mollaverdi (2012) presented a model for establishing a proper maintenance policy to make the best compromise between three criteria and establish replacement intervals using PROMETHEE II. As a process of selecting a suitable manufacturing system is highly complex and strategic in nature, Anand and Kodali (2008) applied PROMETHEE to analyze how companies make a strategic decision of selecting lean manufacturing systems (LMS) as part of their manufacturing strategy. There are also other methods like TOPSIS, AHP, ELECTRE, COPRAS, etc. that researchers apply for prioritizing their options considering the related problem. Each one reflects a different approach to solve a given discrete MCDM problem of choosing the best among several preselected alternatives. These methods can be adopted appropriately based on the criteria, alternatives, and generally the problem that a researcher is faced with. For example, ELECTRE is especially convenient when there are decision problems that involve a few criteria with a large number of alternatives. This study deals with the lean enablers selection in business units and several criteria have to be considered in this selection process, therefore it is a typical MCDM problem and out ranking method would be suitable for this concept selection. Hence, in the present study, PROMETHEE II, an outranking method is used as a MCDM method for ranking the best suitable concept. The mathematical model in PROMETHEE is relatively easy for the decision makers to understand (Gilliams et al. 2005). It is closely coinciding with the human perspectives and can easily find out the preferences among multiple decisions (Ballis and Mavrotas 2007) and therefore, PROMETHEE methods occupies an significant place among the outranking methods (Vinodh and Girubha 2012).

Fuzzy-QFD calculations

The main objective of F-QFD is to find final weight or importance of "hows". The general structure of house of quality matrix with fuzzy technique is equal to the mentioned house of quality. F-QFD calculations and HOQ matrix are described in the following three steps (Bottani 2009).

Step 1: Identification of importance of customer requirements (CRs)/"whats"

First, W_i as weighted importance of i-th CR is calculated directly by customers or experts using linguistic terms or obtained using more accurate techniques such as paired comparison and F-AHP and other fuzzy weighting methods.

Step 2: Calculation of relative weight/importance of engineering characteristics (ECs)/"hows"

RI_j as relative importance of j-th EC is obtained based on its effect on CRs as follows:

$$\mathrm{RI}_j = \sum_{i=1}^{n} W_i \otimes R_{ij}, \quad j = 1, \ldots, m \tag{1}$$

where, R_{ij} is fuzzy number, which represents the relation between i-th CR and j-th EC.

Step 3: Calculation of final weight of ECs

Having correlation between ECs in the roof of the HOQ matrix obtained, following relation gives us its effect on RI_j and consequently $\mathrm{RI}_j{*}$ as final weigh of jth EC.

$$\mathrm{RI}_j{*} = \mathrm{RI}_j \oplus \sum_{k=j} T_{kj} * \otimes \mathrm{RI}_k, \quad j = 1, \ldots, m \tag{2}$$

where T_{kj} shows the degree of correlation between k-th and j-th EC, and RI_k is the relative importance of k-th EC.

Fuzzy-AHP-QFD-PROMETHEE model

The framework applied by Fuzzy-AHP-QFD-PROMETHEE to achieve leanness has three major parts which are depicted in Fig. 1. QFD and HOQ, in the approach, are translated from the field of new product development into lean context. Exploitation of HOQ for first competitive advantages to lean attribute is recommended, as it is shown in Fig. 2. This section delves deeper into how to build a HOQ.

Phase I: Introduce competitive advantages and determine the weight of competitive advantages using fuzzy-AHP

Competitive advantages Facing tight competition from all over the world, an organization is required to have a strong strategy to be able to stay afloat (Priyanto et al. 2012). In other words, if he wants to remain competitive, he must have a sustainable competitive advantage (Hitt et al. 2001). Majority of organizations, along with intensification of competition in the market, strive for realization of such advantages. Lean production, among many, is one of the approaches to make this possible; mainly due to the high efficiency for enabling. To reduce costs, remove waste of resources, increase profitability, and improve performance as much as possible, a firm must use requirements of leanness, and employs the most efficient lean enablers. This stage is constituted of 2 steps.

Step 1: Determining and selecting the most significant competitive advantages

The present work seeks to reach lean requirements for empowering competitive advantages of the organization. Moreover, regarding the necessity of reaching competitive advantages for each organization, the first step is to select, based on experts' opinion and data collected through questionnaire and interviews, the most necessary and efficient competitive advantages.

Step 2: Determining fuzzy weights of competitive advantages through pair comparison and using Fuzzy-AHP

Paired comparison matrix and AHP are implemented to determine relative weights of competitive advantages. Proper linguistic variables are employed by the experts to carry out the comparison and determine relative importance and weight of advantages. Because of quantitative nature of linguistic variables, ambiguity is intrinsic to them

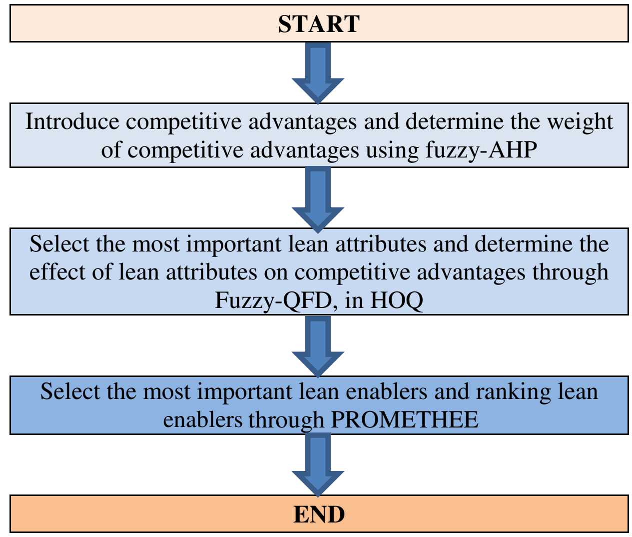


Fig. 1 Schematic representation of the algorithm

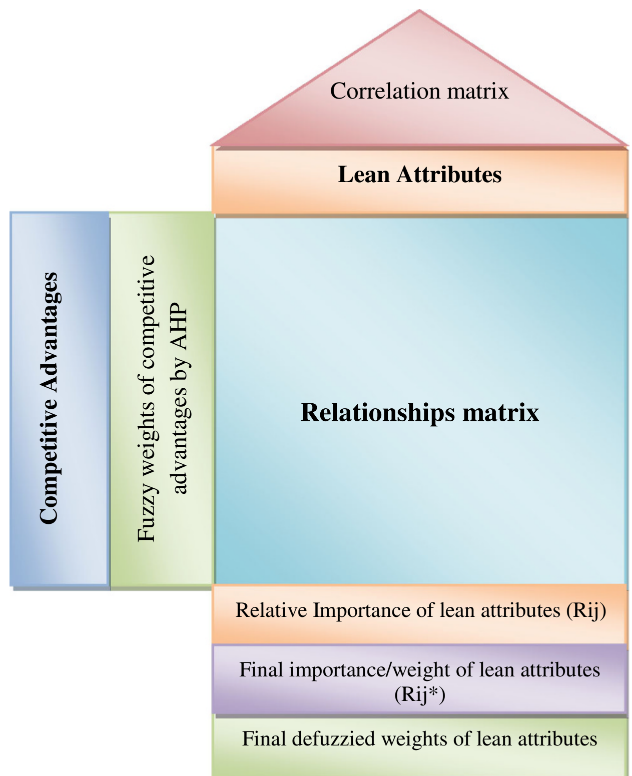


Fig. 2 Structure of the house of quality

and fuzzy logic helps removal of the ambiguities. Hence, triangular fuzzy numbers are adopted to determine value of the variables. Linguistic variables in this work implemented for pairwise comparison, determination weights and corresponding fuzzy numbers are listed in Table 1.

By ascertaining consistency of the judgments, an AHP method must be implemented for calculating fuzzy weights of competitive advantages. There are numerous methods

Table 1 Linguistic variables and corresponding fuzzy numbers for expressing the relationships

Linguistic variables	Fuzzy numbers
Equal importance	(1; 1; 1)
Weak importance	(2/3; 1; 3/2)
Moderate importance	(3/2; 2; 5/2)
Strong importance	(5/2; 3; 7/2)
Absolute importance	(7/2; 4; 9/2)

Based on Dagdeviren et al. (2008)—distorted data

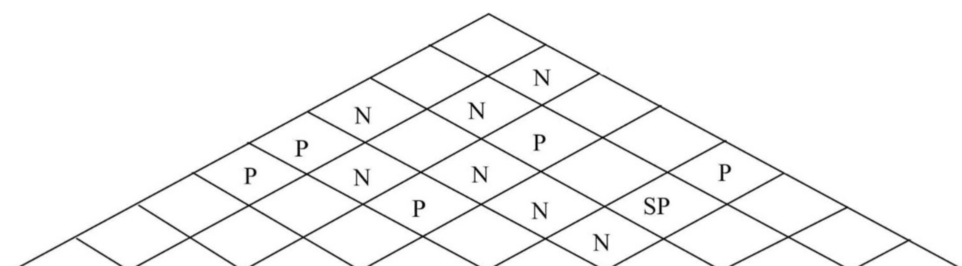
introduced by researches for deriving priority weights in the AHP. In operation process of applying AHP method, it is more easy for evaluators to assess "criterion A is much more important than criterion B" than to consider "the significance of principle A and principle B is seven to one". Therefore, Buckley extended Saaty's AHP to the case where the evaluators are allowed to employ fuzzy ratios in place of exact ratios to handle the difficulty for people to assign exact ratios when comparing two criteria and derive the fuzzy weights of criteria by geometric mean method (Chen et al. 2011). Hence, fuzzy weights of the competitive advantages obtained by geometric mean method are listed in the second column of HOQ (Fig. 3).

Phase II: Selecting the most significant lean attributes and determine the effect of lean attributes on competitive advantages through Fuzzy-QFD, in HOQ

When competitive advantages (the final objective of the organization) and fuzzy weights of the advantages are acquired through F-AHP, surveying lean attributes is under consideration afterward. There are four steps involved in this part.

Step 1: Surveying attributes under consideration by the organization and selecting the best attributes (lean attributes) for minimizing wastes

The ultimate goal of lean production is to reduce costs through removing waste of resources in the system. To step toward being lean, organizations must focus on removal of wastes and consequently reduction of costs and more profitability and productivity. Hence, it is essential to lead the firm towards removal of waste and improvement of the attributes, if it is supposed to be lean. Among several attributes about organizations' objectives and processes, those effective on removal or reduction of waste and consequently on leanness of organization, therefore, are adopted as most important lean attributes.



Competitive Advantages	Fuzzy weights of competitive advantages	Lean Attributes							
		Production planning success rate	Education effectiveness	machineries failure	transportation cost to sale cost rate	Extra works	Actual inventory to standard inventory rate	Part Per Million (PPM)	extra costs of transportation rate
Financial Resources	(0.215; 0.219; 0.220)	(0.151; 0.173; 0.196)	(0.042; 0.044; 0.046)	(0.067; 0.074; 0.084)	(0.072; 0.093; 0.12)	(0.079; 0.088; 0.099)	(0.207; 0.233; 0.252)	(0.141; 0.165; 0.186)	(0.113; 0.127; 0.143)
Market share	(0.205; 0.210; 0.212)	(0.157; 0.178; 0.199)	(0.053; 0.058; 0.063)	(0.069; 0.079; 0.092)	(0.063; 0.079; 0.099)	(0.087; 0.097; 0.107)	(0.215; 0.239; 0.257)	(0.194; 0.211; 0.224)	(0.051; 0.058; 0.067)
Quality	(0.190; 0.190; 0.189)	0.063; 0.068; 0.075)	(0.124; 0.143; 0.164)	(0.147; 0.164; 0.18)	(0.054; 0.064; 0.076)	(0.142; 0.156; 0.168)	(0.078; 0.091; 0.109)	(0.239; 0.264; 0.276)	(0.046; 0.051; 0.057)
success of planning	(0.157; 0.156; 0.156)	(0.264; 0.264; 0.281)	(0.076; 0.086; 0.098)	(0.106; 0.122; 0.136)	(0.046; 0.052; 0.061)	(0.081; 0.091; 0.101)	(0.234; 0.255; 0.273)	(0.063; 0.07; 0.079)	(0.053; 0.059; 0.067)
Human Resource	(0.054; 0.050; 0.047)	(0.125; 0.146; 0.16)	(0.323; 0.323; 0.323)	(0.066; 0.077; 0.088)	(0.067; 0.084; 0.103)	(0.059; 0.07; 0.083)	(0.101; 0.123; 0.143)	(0.095; 0.113; 0.128)	(0.056; 0.064; 0.075)
Products variety	(0.095; 0.093; 0.095)	(0.055; 0.063; 0.074)	(0.273; 0.288; 0.298)	(0.277; 0.235; 0.241)	(0.046; 0.052; 0.061)	(0.108; 0.122; 0.134)	(0.091; 0.102; 0.114)	(0.077; 0.086; 0.096)	(0.045; 0.051; 0.059)
After-sales services	(0.080; 0.078; 0.078)	(0.087; 0.102; 0.119)	(0.212; 0.238; 0.254)	(0.168; 0.19; 0.207)	(0.057; 0.062; 0.068	(0.101; 0.117; 0.135)	(0.112; 0.132; 0.154)	(0.095; 0.111; 0.132)	(0.043; 0.048; 0.052)
Relative Importance of lean attributes (Ri_j)		(0.119; 0.15; 0.186)	(0.103; 0.124; 0.15)	(0.1; 0.124; 0.153)	(0.051; 0.071; 0.096)	(0.086; 0.107; 0.133)	(0.142; 0.184; 0.225)	(0.131; 0.164; 0.198)	(0.055; 0.07; 0.087)
Final weights of lean attributes (RI_j)		(0.189; 0.331; 0.528)	(0.103; 0.227; 0.36)	(0.209; 0.37; 0.597)	(0.111; 0.232; 0.394)	(0.316; 0.607; 0.946)	(0.279; 0.427; 0.661)	(0.242; 0.396; 0.56)	(0.098; 0.183; 0.295)
Final Defuzzied weights of lean attributes		0.349	0.23	0.392	0.245	0.623	0.455	0.399	0.192

Fig. 3 HOQ

Step 2: Determining effect of lean attributes on competitive advantages, in HOQ

An organization normally tries to reach pre-set competitive advantages through concentrating the attributes determined as lean attributes and requirements. Thus, supervision of experienced experts for determination of the impacts of lean attributes of organization on competitive advantages is vital. F-QFD as one of strongest and most common quality management tools is implemented in this stage. The HOQ, used in this work as pictured in Fig. 3, is comprised of competitive advantages in matrix rows (whats) and lean attributes in columns (hows). Central cells of HOQ, known as relationships matrix, are devoted to impact of the lean attributes on competitive advantages. These cells ought to be filled out based on linguistic variables under experts' opinions. Linguistic variables in Table 1 are used for pairwise comparison of lean attributes. In the same way, experts for the other competitive advantages perform pair comparisons of lean attributes in separate matrixes.

By ascertaining consistency of the pairwise comparison matrixes, logarithmic least square (LLS) nonlinear programming model for each matrix is acquired. Afterwards, the models are solved using a simple mathematical optimization software and fuzzy weights of every attribute, relative to other attributes from the same competitive advantage, are calculated. The obtained figures are then inserted in the related row in HOQ. The same process is repeated for all pairwise comparison matrixes and all rows of relationships matrix are filled out in the HOQ matrix.

Step 3: Determining effect of lean attributes on each other, in the roof of HOQ (correlation matrix)

Among lean attributes, some have positive or negative correlation with others. That is, improvement of one attribute may affect others, either positively or negatively. Thus, studying correlation among all the attributes is essential. In doing so, experts' opinions and linguistic variables defined in Table 2 are used to determine correlations, if any, in the roof of HOQ.

Table 2 Linguistic variables and corresponding fuzzy numbers for expressing the correlations

Linguistic variables	Fuzzy numbers
Strong positive (SP)	(0.7; 1; 1)
Positive (P)	(0.5; 0.7; 1)
Negative (N)	(0; 0.3; 0.5)
Strong negative (SN)	(0; 0; 0.3)

Source: adapted from Bottani and Rizzi (2006)

Step 4: Fuzzy-QFD calculations for HOQ and obtaining final fuzzy weights and ranking of the lean attributes

First, fuzzy weight of each competitive advantage is inserted according to matrix (Eq. 1) and relative fuzzy importance/weight of each lean attribute (RI_j) is calculated. Subsequently, correlations among lean attributes are employed in relative importance of each attribute (RI_j) (Eq. 2) to obtain final importance/weights of the attributes (RI_j*). Finally, fuzzy weights can be defuzzied via the following equation.

$$DF_i = \frac{l_i + m_i + u_i}{3} \tag{3}$$

Phase III: Select the most important lean enablers and ranking lean enablers through PROMETHEEII

Step 1: Surveying enablers used in the organization and electing the most effective lean enablers in achievement to lean attributes

Lean production comprises variety of tools and techniques known as lean enablers. Several researchers have introduced and employed various sets of techniques as lean enablers for implementation of the principles of leanness (Shah and Ward 2003; Browning and Heath 2009) Thus, there is a lack of a generally accepted set of tools as lean enablers. Considering impact in realization of lean attributes, some of the most important enablers used or potentially usable by the organization are selected in this step.

Step 2: Ranking lean enablers through PROMETHEEII

The PROMETHEE method is applied for the problems like the ones below:

$$\text{Max (Min)}\{f_1(a), f_2(a), \ldots, f_r(a) \mid a \in A\} \tag{4}$$

where A represents the set of decision criteria and $f_r(a)$ and $i = 1, 2, \ldots, r$ consist of a set of indices based on which the criteria are assessed. In PROMETHEE II, the net flow $\phi(a)$ (difference in leaving flows minus entering flows) is used, which permits a complete ranking of all alternatives (Gurumurthy and Kodali 2008). The alternative with the highest net flow is superior. A decision maker always demands a complete ranking, as making decision will be more convenient. Calculation of a net flows of ranking provides such conditions:

$$\phi(a) = \phi^+(a) - \phi^-(a) \tag{5}$$

The complete ranking through PROMETHEE II are as follows:

$$\begin{aligned} &(aP^{II}b) \quad \text{if } \phi(a) > \phi(b) \\ &(aI^{II}b) \quad \text{if } \phi(a) = \phi(b) \end{aligned} \tag{6}$$

The best alternative is the one with the highest net dominance (Vinodh and Girubha 2012). In this model, all the options will be comparable.

Having final ranking of lean enablers, management can make a decision on the relative importance and priority of lean enablers. Consequently, the organization may concentrate, with less energy and time and higher efficiency, on the most important enablers with highest priority and stop wandering between varieties of techniques and lean enablers. In this way, the organization will have the upper hand and ever increasing development.

Case study

Automotive industry is the key driver of any growing economy. It plays a pivotal role in any country's rapid economic and industrial development (Business Knowledge Resource 2013). Hence, the case study has been elected from this industry."Avrin Auto", manufacturer of dynamo and automobile starts, has been selected for implementing the model. The company aims on wide range of large quantities of products of the company and plans to penetrate into a world class producer of parts in global supply chain. The company is more concerned on implementation of lean principles and utilization of lean enablers. In what follows, all steps in the model are explained numerically and based on data from the company.

Phase I: Identify competitive advantages and their weights through Fuzzy-AHP

Step 1: Identifying all competitive advantages and selecting the most important competitive advantages of the organization

Seven advantages can be identified based on competitive advantages introduced by Yusuf et al. (2000) and Ren et al. (2003) and opinions of the team of experts. These competitive advantages are taken as macro goals of the organization, which are listed in Table 3 as the main competitive advantages.

Step 2: Determining the fuzzy weights of competitive advantages through pair comparison by Fuzzy-AHP

Seven advantages are compared using pair comparison matrix. Table 4 represents relative importance of the competitive advantages. As the table lists, the experts used linguistic variables and corresponding triangular fuzzy numbers for the comparison. Then, fuzzy weights of competitive advantages were obtained by geometric mean method.

Phase II: Select the most important lean attributes and determine the effect of lean attributes on competitive advantages using Fuzzy-QFD, in HOQ

Step 1: Identifying attributes under consideration in the organization and selecting the best attributes, as lean attributes, based on wastes reduction

When the team of the experts appraises all the attributes under consideration by the organization, the main attention, for determination of lean attributes, is shifted to the attributes effective on removal of wastes. Consequently, eight attributes were selected as the most important attributes (Table 3).

Step 2: Determining effects of lean attributes on competitive advantages, in HOQ

The impacts of the eight lean attributes on achievement to the seven competitive advantages (HOQ) are discussed in this step. HOQ (Fig. 3) is comprised of competitive advantages in the rows (whats) and lean attributes of the organization in the columns (hows).

Table 3 Competitive advantages, lean attributes and wastes related to each attributes, and lean enablers of Avrin Auto

Competitive advantages	Lean attributes	Waste related to each attributes	Lean enablers
Financial resources	Production planning success rate	Waits	Continuous improvement (Kaizen)
Market share	Education effectiveness	Waits	Preventive maintenance (PM)
Quality	Machineries failure	Unnecessary process	Supply chain management (SCM)
Success of planning	Transportation cost to sale cost rate	Excess production	Pull system (KANBAN production control)
Human resource	Extra works	Inventory	Failure mode and effect analysis (FMEA)
Products variety	Actual inventory to standard inventory rate	Faulty product	Job rotation
After-sales services	Part per million (PPM)	Transportation	Human resource management (HRM)
	Extra costs of transportation rate	Movements	

Table 4 Fuzzy pair comparison matrix for competitive advantages

	Financial resources	Market share	Quality	Success of planning	Human resource	Products variety	After-sales services
Financial resources	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)	(2/3,1,3/2)	(7/2,4,9/2)	(3/2,2,5/2)	(5/2,3,7/2)
Market share	(2/3,1,3/2)	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)	(5/2,3,7/2)	(5/2,3,7/2)	(3/2,2,5/2)
Quality	(2/5,1/2,2/3)	(2/3,1,3/2)	(1,1,1)	(3/2,2,5/2)	(5/2,3,7/2)	(3/2,2,5/2)	(5/2,3,7/2)
Success of planning	(2/3,1,3/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(5/2,3,7/2)	(3/2,2,5/2)	(5/2,3,7/2)
Human resource	(2/9,1/4,2/7)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(1,1,1)	(2/7,1/3,2/5)	(2/5,1/2,2/3)
Products variety	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(5/2,3,7/2)	(1,1,1)	(2/3,1,3/2)
After-sales services	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(3/2,2,5/2)	(2/3,1,3/2)	(1,1,1)

Table 5 Fuzzy pair comparison matrix for lean attributes regarding the first competitive advantage (financial resources)

Financial resources	Education effectiveness	Machineries failure	Extra works	Production planning success rate	Actual inventory to standard inventory rate	Part per million (PPM)	Transportation cost to sale cost rate	Extra costs of transportation rate
Education effectiveness	(1,1,1)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(2/9,1/4,2/7)	(2/9,1/4,2/7)	(2/7,1/3,2/5)	(2/3,1,3/2)	(2/9,1/4,2/7)
Machineries failure	(5/2,3,7/2)	(1,1,1)	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(2/5,2,2/3)	(2/3,1,3/2)	(2/7,1/3,2/5)
Extra works	(5/2,3,7/2)	(3/2,2,5/2)	(1,1,1)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(2/3,1,3/2)	(2/5,1/2,2/3)
Production planning success rate	(7/2,4,9/2)	(5/2,3,7/2)	(5/2,3,7/2)	(1,1,1)	(2/3,1,3/2)	(2/5,1/2,2/3)	(2/3,1,3/2)	(3/2,2,5/2)
Actual inventory to standard inventory rate	(7/2,4,9/2)	(3/2,2,5/2)	(5/2,3,7/2)	(2/3,1,3/2)	(1,1,1)	(3/2,2,5/2)	(7/2,4,9/2)	(3/2,2,5/2)
Part per million (PPM)	(5/2,3,7/2)	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)
Transportation cost to sale cost rate	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/9,1/4,2/7)	(2/3,1,3/2)	(1,1,1)	(2/3,1,3/2)
Extra costs of transportation rate	(7/2,4,9/2)	(5/2,3,7/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/3,1,3/2)	(1,1,1)

The impact of lean attributes on competitive advantages is listed in internal cell of HOQ (relationships matrix). For filling out the relationships matrix, eight lean attributes are compared pairwise from the first competitive advantage viewpoint and relative importance of the attributes, regarding their effect on realization of the first competitive advantage, is obtained based on linguistic variables. Fuzzy pair comparison matrix for lean attributes regarding the first competitive advantage (financial resources) is represented in Table 5. In the same way, pair comparison of lean attributes is carried out based on the experts' opinion for other viewpoints of competitive advantages. The obtained fuzzy weights (by LLSM) for the first matrix of pair comparison of attributes (financial resources) is listed on first row of HOQ matrix, while the other six rows of the relationships matrix are dedicated for the remaining six pair comparison matrixes solved by nonlinear programming model.

Step 3: Determining mutual effect of lean attributes in the roof of HOQ (correlation matrix)

There are positive/negative correlations among some of lean attributes, between machineries failure and PPM, for instance, there is a positive correlation; so that, the more failure of the machineries, the more rate of broken products and vice versa. Additionally, a negative correlation is found between education effectiveness index and rate of extra works. That is to say, rate of parallel works declines with more efficient education. Linguistic variables and equivalent triangular fuzzy numbers (Table 2) are used for finding correlation, if any, between the lean attributes.

Step 4: Fuzzy QFD calculations for HOQ and obtaining final fuzzy weights and ranking of the lean attributes

Fuzzy weight of each competitive advantage is first implemented in the relationships matrix (Eq. 1) for obtaining relative fuzzy importance/weight of each lean

Table 6 Ranking lean enablers through PROMETHEE

Lean enablers	Lean attributes							
	Production planning success rate	Education effectiveness	Machineries failure	Transportation cost to sale cost rate	Extra works	Actual inventory to standard inventory rate	Part per million (PPM)	Extra costs of transportation rate
Continuous improvement (Kaizen)	7	4	3	4	6	8	7	6
Preventive maintenance (PM)	5	6	5	6	6	3	5	3
Supply chain management (SCM)	4	7	6	5	4	4	3	4
Pull system (KANBAN production control)	5	3	6	8	3	7	8	5
Failure mode and effect analysis (FMEA)	3	4	4	7	6	5	5	7
Job rotation	4	3	5	4	5	3	4	4
Human resource management (HRM)	7	6	3	3	7	4	4	3
Weights	0.349	0.23	0.392	0.245	0.623	0.455	0.399	0.192
Normalized weights	0.120	0.079	0.136	0.084	0.216	0.157	0.138	0.066

attribute (RI_j). Afterwards, correlations between the lean attributes were implemented on relative importance of each attribute (RI_j) (Eq. 2) and final importance/weight of each attribute (RI_j*) was obtained. Finally, fuzzy weights were defuzzied through the Eq. (3).

Phase III: Select the most important lean enablers and ranking lean enablers through PROMETHEE II

Step 1: Identifying enablers under consideration by the organization and selecting the best enablers for finding the lean attributes

A list of enablers is arranged through literature review. Considering available tools and techniques or potentially applicable techniques in the organization, seven lean enablers are selected as the most important and essential factors (Table 3).

Step 2: Ranking lean enablers through PROMETHEE II

Final ranking of lean enablers is carried in this section. Using the experts' opinion, numbers of the Table 6 can be attained. Normalized weights are shown in the last line. By applying the PROMETHEE II method on these data, Table 7 is obtained. This table summarizes the input, output and net flows (using Eq. 5). Final ranking of lean enablers is also achieved through the Eq. (6). As it is shown in Table 7, ranking results indicate that human resource management (HRM) is the most influential lean enablers among all the others.

Table 7 Final ranking for lean enablers

PROMETHEE ranking		Net flow	Input-flow Sum = $\Phi-$	Output-flow Sum = $\Phi+$
Continuous improvement (Kaizen)	3	0.0732	0.2681	0.3413
Preventive maintenance (PM)	5	−0.0760	0.2847	0.2087
Supply chain management (SCM)	2	0.1743	0.1914	0.3657
Pull system (KANBAN production control)	6	−0.0959	0.3884	0.2925
Failure mode and effect analysis (FMEA)	7	−0.2519	0.3889	0.1370
Job rotation	4	−0.0726	0.2508	0.1782
Human resource management (HRM)	1	0.2491	0.1440	0.3930

Conclusion

This article has explored the relationship between the organization's competitive advantages and lean attributes and subsequently ranking them. In determining weights of competitive advantages and to specify the impact of lean attributes on competitive advantages, F-AHP and F-QFD were applied, respectively. Afterwards, the effects of lean enablers and their ranks using a MCDM method (PROMETHEE II) were covered to improve the leanness of the organization. Selecting and prioritizing lean attributes and enablers in the context of lean production is a MCDM problem as it involves several criteria. Therefore, an outranking method like PROMETHEE which is fast use, easy-to-analyze results, and has a flexible comparison process can be appropriately applied to solve the problem. Efficiency and functionality of the model were also ascertained by implementing the model for a company as a case study.

This integrated approach utilizes the data from the research in an appropriate way. Moreover, compared to other methods, the technique applied in this research is dynamic and compatible in terms of composition and structure. This approach can guide leaders and decision makers to make the best choice among other options which may broaden the traditional approach to the leadership and decision making and form a new perspective. Directions for future research may comprise the application of an extended version of PROMETHEE called the PROMETHEE V or study of other aspects of the lean production, under the same framework.

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References

Abele E, Reinhart G (2011) Zukunft der Produktion. Carl Hanser Verlag, Munich, p 15

Anand G, Kodali R (2008) Selection of lean manufacturing systems using the PROMETHEE. J Model Manag 3(1):40–70

Ballis A, Mavrotas G (2007) Freight village design using the multicriteria method PROMETHEE. Oper Res An Int J 7(2):213–232

Bhattacharya A, Geraghty J, Young P (2010) Supplier selection paradigm: an integrated hierarchical QFD methodology under multiple-criteria environment. Appl Soft Comput 10:1013–1027

Bottani E (2009) A fuzzy QFD approach to achieve agility. Intl J Prod Econ 119:380–391

Bottani E, Rizzi A (2006) Strategic management of logistics service: a fuzzy-QFD approach. Int J Prod Econ 103:585–599

Browning TR, Heath RD (2009) Reconceptualizing the effects of lean on production costs with evidence from the F-22 program. J Oper Manag 27:23–44

Business Knowledge Resource (2013) Automobile Industry. Industry and Services. http://business.gov.in/Industry_services/automobile_industry.php. Accessed 2013

Chen LH, Ko WC (2009) Fuzzy linear programming models for new product design using QFD with FMEA. Appl Math Model 33:633–647

Chen LH, Ko WC (2010) Fuzzy linear programming models for NPD using a four-phase QFD activity process based on the means-end chain concept. Eur J Oper Res 201:619–632

Chen VYC, Lien HP, Liu CH, Liu JJH, Tzeng GH (2011) Fuzzy MCDM approach for selecting the best environment-watershed plan, Yi-Chun Chen. Appl Soft Comput 11:265–275

Chen JC, Cheng CH, Huang PB (2013) Supply chain management with lean production and RFID application: a case study. Expert Syst Appl 40(9):3389–3397

Chien CF, Chen YJ, Peng JT (2010) Manufacturing intelligence for semiconductor demand forecast based on technology diffusion and product life cycle. Int J Prod Econ 128(2):496–509

Dagdeviren M, Yuksel I, Kurt M (2008) A fuzzy analytic network process (ANP) model to identify faulty behavior risk (FBR) in work system. Saf Sci 46:771–783

De Treville S, Antonakis J (2006) Could lean production job design be intrinsically motivating? Contextual, configurational, and levels-of-analysis issues. J Oper Manag 24:99–123

Delice EK, Güngör Z (2009) A new mixed integer linear programming model for product development using quality function deployment. Comput Ind Eng 57:906–912

Faghihinia E, Mollaverdi N (2012) Building a maintenance policy through a multi-criterion decision-making model. J Ind Eng Int 8(1):8–14

Gilliams S, Raymaekers D, Muys B (2005) Comparing multiple criteria decision methods to extend a geographical information system on afforestation. Comput Electron Agric 49:142–158

Goldsby TJ, Griffis SE, Roath AS (2006) Modeling lean, agile, and leagile supply chain strategies. J Bus Logist 27:57–81

Guinipero LC, Pillai KG, Chapman SN, Clark RA (2005) A longitudinal examination of JIT purchasing practices. Int J Logist Manag 16:51–70

Gurumurthy A, Kodali R (2008) A multi-criteria decision-making model for the justification of lean manufacturing systems. Int J Manag Sci Eng Manag 3(2):100–118

Hajji A, Mhada F, Gharbi A, Pellerin R, Malhamé R (2011) Integrated product specifications and productivity decision making in unreliable manufacturing systems. Int J Prod Econ 129(1):32–42

Hitt MA, Ireland RD, Hoskisson RE (2001) Manajemen Strategi (edisi Bahasa Indonesia). Salemba Empat, Jakarta

Hofer C, Eroglu C, Hofer AR (2012) The effect of lean production on financial performance: the mediating role of inventory leanness. Int J Prod Econ 138:242–253

Hopp WJ, Spearman ML (2004) To pull or not to pull: what is the question? Manuf Serv Oper Manag 6:133–138

Hsu PF, Wu CR, Li ZR (2008) Optimizing resource-based allocation for senior citizen housing to ensure a competitive advantage using the analytic hierarchy process. Build Environ 43:90–97

Hung SJ (2011) Activity-based divergent supply chain planning for competitive advantage in the risky global environment: a DEMATEL-ANP fuzzy goal programming approach. Expert Syst Appl 38:9053–9062

Karipidis PI (2011) Market evaluations of dimensions of design quality. Int J Prod Econ 129(2):292–301

Lai X, Xie M, Tan KC (2007) Optimizing product design using quantitative quality function deployment: a case study. Qual Reliab Eng Int 23:45–572

Mehrjerdi YZ (2010) Quality function deployment and its extensions. Int J Qual Reliab Manag 27(6):616–640

Mulliner E, Smallbone K, Maliene V (2013) An assessment of sustainable housing affordability using a multiple criteria decision making method. Omega 41:270–279

Narasimhan R, Swink M, Kim SW (2006) Disentangling leanness and agility: an empirical investigation. J Oper Manag 24:440–457

Nayebi MA, Mosadegh MJ, Mahdavi Rad A (2012) Application of VIKOR-BSC model in development of organizational entrepreneurship. World Appl Sci J 18(8):1163–1171

Priyanto A, Aslichati L, Kuncoro S (2012) The custom made strategy of "SatuKayu Design Enterprise" in efforting to achieve sustainable competitive advantage. Proc Econ Fin 4:54–58

Raissi S, Izadi M, Saati S (2012) Prioritizing engineering characteristic in QFD using fuzzy common set of weight. Am J Sci Res 49:34–49

Ren J, Yusuf YY, Burns D (2003) The effects of agile attributes on competitive priorities: a neural network approach. Integr Manuf Syst 14:489–497

Riezebos J (2009) Advancing lean manufacturing, the role of IT. Comp Ind 60:235–236

Scherrer-Rathje M, Boyle TA, Deflorin P (2009) Lean, take two! Reflections from the second attempt at lean implementation. Bus Horiz 52:79–88

Schonbergerm RJ (2007) Japanese production management: an evolution with mixed success. J Oper Manag 25:403–419

Shah R, Ward PT (2003) Lean manufacturing: context, practice bundles, and performance. J Operat Manag 21:129–149

Smith AD (2011) Competitive approaches to new product development: a comparison of successful organizations in an unstable economic environment. Team Perform Manag 17(3/4):124–145

Sun CC, Lin GTR (2009) Using fuzzy TOPSIS method for evaluating the competitive advantages of shopping websites. Expert Syst Appl 36:11764–11771

Vinodh S, Girubha RJ (2012) PROMETHEE based sustainable concept selection. Appl Math Model 36:5301–5308

Vinodh S, Arvind KR, Somanaathan M (2010) Application of value stream mapping in an Indian camshaft manufacturing organization. J Manuf Technol Manag 21(7):889–900

Vinodh S, Shivraman KR, Viswesh S (2012) AHP-based lean concept selection in a manufacturing organization. J Manuf Technol Manag 23(1):124–136

Wang YM, Chin KS (2011) Technical importance ratings in fuzzy QFD by integrating fuzzy normalization and fuzzy weighted average. Comput Math Appl 62:4207–4221

Yusuf YY, Ren J, Gunasekaran A (2000) An integrated framework for agility-based decision making system. In: Proceedings of the Third Int Conference Intelligent Manufacturing Processes and System, MIT, Cambridge

Wang YM, Leu Y, Hua Z (2008) On the extent analysis method for fuzzy AHP and its applications. Eur J Oper Res 186:735–747

Zaim S, Sevkli M, Camgöz-Akdağ H, Demirel OF, Yesim Yayla A, Delen D (2014) Use of ANP weighted crisp and fuzzy QFD for product development. Expert Syst Appl 41(9):4464–4474

Zopounidis C (1999) Multicriteria decision aid in financial management. Eur J Operat Res 119:404–415