RESEARCH ARTICLE OPEN ACCESS

# Analysis The Leanness of The Supply Chain By Fuzzy QFD

Mukesh Singh Baghel ,Pavan Agrawal
Mechanical Engg.Deptt.

**Abstract**
The new systems of doing business in manufacturing have evolved in recent decades Lean production. Lean production can be traced to the 1960s in Japan, when Toyota Motors started innovating changes in mass production to deal with its domestic automotive market. The term "Lean production" was coined around 1989 with the popularity of the book, the machine that can change the world written by researchers at the Massachusetts Institute of Technology (MIT). The term itself was coined by researcher to describe the collection of efficiency improvements that Toyota motors undertook to service in Japanese automobile business after World War II. Because of its origins to Toyota Motors the same collection of improvements has also been called the "Toyota Production System".

## I. Introduction

Let us provide two definitions of lean production. Our first definition is a paraphrase of two of the authors of the machines that can change the world. Womack and Jones define Lean as doing "more and more with less and less - less human effort, less equipment, less time and less space while coming closer and closer to providing customers with exactly what they want".

The second definition is developed to introduce our discussion of the principles of Lean production. Lean production can be defined as an adaption of mass production in which workers and work cells are made more flexible and efficient by adopting methods that reduce wastes in all forms.

The lean production is based on four principles:-

1. Minimise waste.
2. Perfect first time quality.
3. Flexible production line.
4. Continuous improvement.

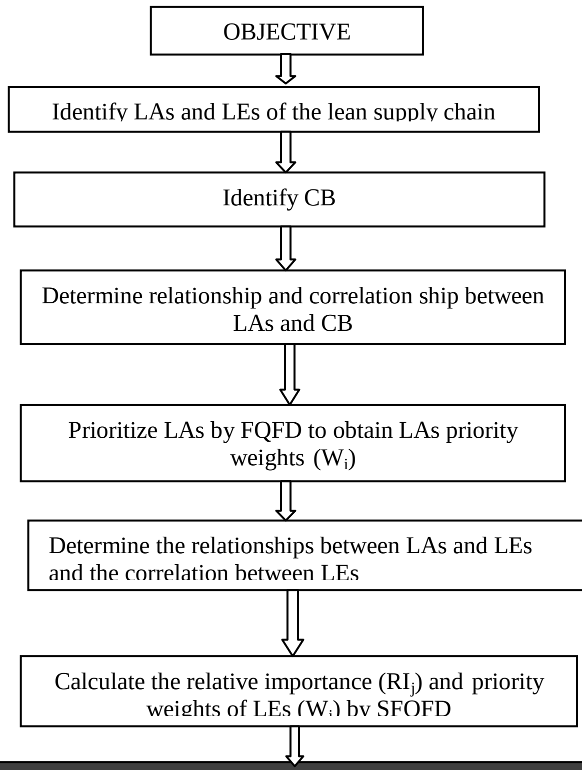
A lean supply chain can take reduce time by 10 to 40%, inventories by 10% to 30% and costs by 10% to 25%. Continuous improvements can take payback to the upper range-and beyond.

## II. Fuzzy Qfd

In the present approach, QFD and HOQ principles are translated from the new product development field to that of the lean context.HOQ represents a practical tool that allows the direct assessment of the impact of LEs on LAs through relationships matrices. It also allows the identification of possible correlations between enablers. However, lean assessment is often dealt with through fuzzy logic because of the imprecise definition of lean indicators. Owing to the vagueness frequently represented in decision data, crisp values are inadequate for modelling real-life situations. As the functional relationships between LAs and LEs are typically imprecise or vague, it is difficult to identify them. Fuzzy logic permits consideration of the different meanings that may be given to the same linguistic expression . Thus, the major contribution of the fuzzy set theory is its ability to represent vague data.

## III. Methodology

The framework for achieving a lean supply chain by Fuzzy- QFD comprises four main parts. It has a stepwise description as shown in Fig. 4.1 and below. The fuzzy HOQ whose specific structure is detailed in Fig. 4.2 is adopted here



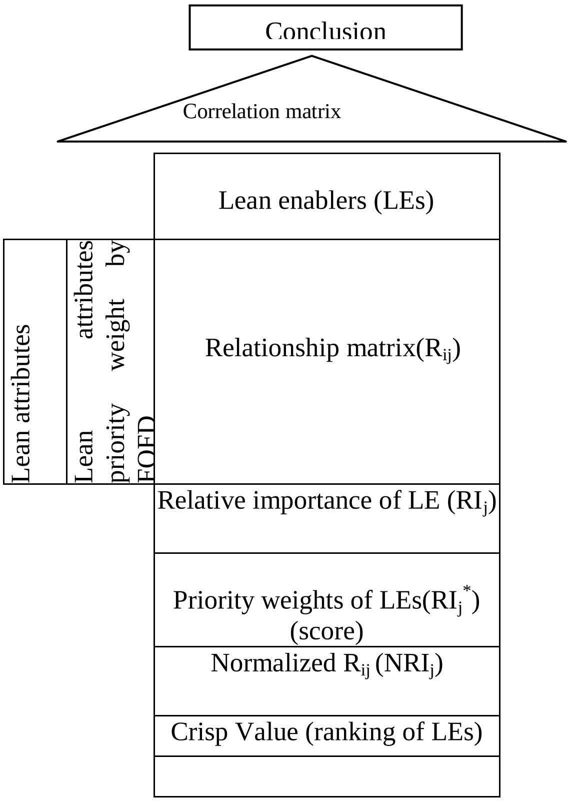



FIG PROPOSED FUZZY QFD STRUCTURE

## IV. IDENTIFY LAs AND LEs OF THE SUPPLY CHAIN

To be truly lean, a supply chain must possess a number of distinguishing attributes and enablers. LAs here after are defined as elements which constitute the underlying structure of a lean organization. They were originally conceived as core concepts of lean manufacturing. Accordingly, LEs are enabling tools, technologies, and methods critical to successfully accomplish lean supply chain. LAs enhancing supply chain leanness and LEs to be exploited in order to achieve the required LAs, as accepted by several authors, were identified. On the basis of a review of the normative literature some LAs and LEs were defined for the lean supply chain, as shown in Table 4.1. Furthermore, suggestions to identify viable sets of lean attributes and enablers can be found in literature, and different or additional LAs/LEs may be listed

Table
Lean attributes and enablers defined for lean supply chain from related company.

| Lean enablers (LEs) | Lean attributes (LAs) |
|---|---|
| Service level improvement | Conformance quality |
| Eliminate obvious wastes | Delivery reliability |
| Pull production | Low buffering cost |
| JIT manufacturing | Low variability in process time |
| Continuous improvement | Cost efficiency |
| Human resource training | Low variability in delivery time |
| Quality improvement | Low variability in demand rates |
| FMS | Delivery speed |
| Vendor management inventory | |
| Total quality management | |
| Supplier management | |

**Relation between weld time and strength in energy mode**

## V. PRIORITIZE LAs BY FQFD TO OBTAIN LAs PRIORITY WEIGHTS ($W_i$)

Due to its wide applicability and ease of use, the FQFD, has been studied extensively for the last twenty years. It has been widely used to address multi-criterion decision- making problems. The FQFD consists of three main operations: relationship between competitive base and LAs, co-relationship between LAs, priority analysis. This discrete scale of the Fuzzy has the advantage of simplicity and ease of use. Researches showed that the focus has been confined to the applications of integrated Fuzzy QFD rather than stand-alone QFD. Moreover, QFD is one of the five tools that are commonly combined with the Fuzzy. In this study, the QFD was deployed to prioritize LAs. After defining LAs, their priority weights were computed by using FQFD for this purpose, first, the pair-wise assessment matrices were prepared to evaluate the eight alternatives, i.e. LAs with respect to criteria; the criteria were then evaluated with respect to the goal. Effective management of the supply chain is viewed as the driver of decreasing the cost of material, services, and manufacturing, reducing lead times and improving product quality and responsiveness. Therefore, after evaluating the related project, five criteria

## VI. DETERMINE THE RELATION BETWEEN LAs AND LEs AND CORRELATION BETWEEN LEs

Because of the qualitative and ambiguous attributes linked to lean implementation, most measures are described subjectively using linguistic terms that cannot be handled effectively using conventional approaches. However, fuzzy logic provides an effective means of dealing with problems involving imprecise and vague phenomena. It was exploited to translate linguistic judgments required for relative importance of LAs, relationships, and correlations matrices into numerical values. In this step, the degree of relationship between LAs and LEs was stated by the corresponding TFNs and placed in the HOQ matrix. Moreover, the degree of correlation between LEs was then expressed by TFNs in the fuzzy HOQ. Both of these correspondences are shown in Tables.

Table
Degree of relationships, and corresponding fuzzy numbers

| Degreeofrelationship | Fuzzy no. |
|---|---|
| Strong | (.7; .1; .1) |
| Medium | (.3; .5; .7) |
| Weak | (0; 0; .3) |

Table
Degree of correlations, and corresponding fuzzy numbers

| Degreeofcorrelation | Fuzzy no. |
|---|---|
| Strongpositive(SP) | (0.3; 0.5; 0.7) |
| Positive(P) | (0; 0.3; 0.5) |
| Strongnegative(SN) | (-0.5;-0 .3; 0) |
| Negative(N) | ( 0.7; -0.5 ;-0.3) |

## VII. THE PROPOSE APPROACH

In the proposed methodology, QFD and HOQ principles are translated from the new products development field to the leanness context. Specially, we propose to exploit HOQ to first relate competitive bases to lean attributes, then lean attributes, in turn, to leanness enablers. Accordingly, the basic structure of the approach proposed, as well as the conceptual model it follows, are shown in figure.

As can be seen from the figure, the approach proposed requires building HOQs whose specific structure is detailed in fig.

Details on how to build the HOQS are provided in the followings.

### 7.1 FIRST HOUSE OF QUALITY

The first HOQ aims at identifying the relevant lean attributes ($LA_j$ j=1,........,8) that enhance company's competitiveness according to a defined set of competitive bases ($CB_i$ i=1,....,5). Consequently, CBs appear as ''whats" in the HOQ, since companies should first identify and rank appropriate dimensions to complete, while LAs appears as "hows'', since they express attributes to be enhanced depending on the competitive bases companies are willing to excel in.

Focusing on the methodological point of view, in this study we do not deal with the definition of a specific set of CBs and LEs to be adopted in applying the methodology; they should be identified according to the peculiarities of the company in exam. suggestions to identify both CBs and LEs can be found in literature, and depending on the specific case study, they may either be considered as exhaustive, or different or additional CBs/LAs could be defined and listed in the HOQ as "whats"/ "hows''.

Moreover, due to trade-off between competitive priorities and to the impossibility to excel in all simultaneously, a proper ranking of CBs should be assigned, by pondering their priority weights $W_i$ (i=1,...,n). Again, importance weights of CBs should be defined according to the case in exam, although suggestions to rank them are provided in literature.

In this regard, it should be remarked that, in real case applications, the assessment of the relative importance of CBs, as well as of the relationships and correlations in both HOQs, mainly rely on human judgements. Thus, in our approach, we propose to exploit fuzzy logic as an effective mean to deal with them.

To well cope with vagueness of linguistics judgements required in building the HOQs, be propose to express importance weights as well as relationships and correlations, with fuzzy triangular numbers. Thus, unless specified, all terms computed should be considered as fuzzy numbers. According to this premise, the importance weights $W_i$ is a fuzzy vector expressing the relative importance of CBs based on a defined fuzzy linguistic scale.

The relationships matrix $R_{ij}$ (i=1,....5, j=1,...,8) of the first HOQ is a matrix whose generic entry (i,j), assesses how the j-th lean attribute performs against the i-th competitive base. In the traditional QFD methodology, graphic symbols express three degrees of relationship (weak, medium strong), which are translated in a rating relationships, graphic symbol and corresponding fuzzy number scale, such as 1-3-9 or 1-5-9. In our approach, since fuzzy logic is exploited to deal with the ill-defined nature of human judgements, graphics symbol s expressing the degree of relationship are translated in to fuzzy triangular numbers. Bottani and Rizzi, proposed a possible correspondence between degree of relationships and fuzzy numbers, which can be usefully exploited in the approach developed in this thesis.

According to the traditional QFD, once relationships between LAs and CBs have been assessed, the relative importance $RI_j$ of the j-th lean attribute can be computed as a fuzzy weighted average, according to following formula :

$$RIj = \sum W_i \times R_{ij} \qquad j=1,2,3\ldots\ldots m$$

Being $W_i$ the weighted importance of the i-th competitive base and $R_{ij}$ the fuzzy number expressing th relationship between the j-th LA and the i-th CB.

The generic entry of the "roof" of correlations, referred to as $T_{jj'}$ expresses the correlation between the j-th and the j'-th (jj'=1,....,m, j≠j') lean attributes. Correlations are usually expressed by graphics symbols following a 4-level scale, ranging from "strong negative" to "strong positive". As in the case of relationship, in the approach proposed symbols are translated in to fuzzy triangular numbers, according to the correspondence shown in table .

Tang et al., have proposed an analytical approach to quantitatively ponder the correlations in the final ranking of "hows''. Specifically, the generic entry Tjj'of the correlation matrix is assumed as the incremental change of the degree of attainment of the j-th "how'' when the attainment of the j-th one is unitary increased. According to this definition, the final $score_j$ of the j-th lean attributes can be computed as follows:

$Score_j=RI_j+\sum T_{jj'}*RI_{j'}$  j=1,2…..m  j'= lean attribute , j= lean enablers (9)

Being $RI_j$ the relative importance of LAs derived from EQ. (6). It should be remarked that Eq. (6) describes a computation between fuzzy numbers; thud' the resulting score of lean attributes is a fuzzy number too. The result of the first HOQ is the ranking of lean attributes in descending importance order. TO rank LAs, scores should be de-fuzzified. Yager procedure is suggested to this extent, due to this extent, due to its simplicity. According to the author, the crisp value of a fuzzy triangular a(l, m, u), is computed as described.

Based on the crisp values, LAs with the highest score have a significant impact on the set of competitive bases examined, and should be thus enhanced to achieve competitive advantage.

### 7.2SECOND HOUSE OF QUALITY

The second HOQ stives to identified viable lean enablers to be practically implemented to achieve a defined sat of lean attributes. Consequently, lean attributes ($LA_j$, j =1, ....,m) represent company's requirements, and appear as "whats'' in the HOQ, while lean enablers ($LE_k$ k =1,.....,p )are listed as "hows'', since they are considered as practical tools the company can implement to achieve leanness. Moreover, as shown in fig.2\\\\ , the ranking of AAs resulting from the previous set of the starting point to build the second HOQ, and importance judgements $W_j$ of LAs in the second HOQ can be derived as the $score_j$ previously obtained. In this regard, scores can be directly exploited as importance weights, or normalisation of the results, may be required, to make importance weights of LAs consistent with those adopted in the first HOQ.

Moreover, depending on the case examined, either al LAs can be transferred to the second HOQ to analyse their relationships with lean enablers, or companies can focus subsequent analyses only on some of them. If only some of the original LAs are used in the second HOQ, they should be selected based on the importance ranking expressed by the crisp scores. Conversely, LEs should be defined in section2 , viable sets of lean enablers are also available in literature.

Once LEs have been defined and added in the HOQ, together with AAs and related fuzzy scores, the HOQ is completed following the same procedure shown in the previous section. Specifically, based on the assessment of relationships $R_{jk}$ between LEs and LAs and correlations $T_{kk'}$ between ''hows'', the relative importance $RI_k$ the final scores of the lean enablers can be calculated according to the following equations;

$RI_k= \sum W_j*R_{jk,}$  k=1,……p  (10)

$Score_k= RI_k+\sum T_{kk'}*RI_{k'},$  k=1,….p  (11)

Eq. (3) finally applied to compute de-fuzzified scores which provide the final ranking of LEs. Again, high crisp scores indicate that lean enablers can be usefully exploited to enhance relevant lean attributes; thus, such enablers should be selected for implementation

## VIII. STEP OF ANALYSIS

The analysis performed on data collected can be summarised into the following steps. First, to provide an overview of the sample of companies surveyed, descriptive statistics were preliminary performed, on the basis of questions proposed in Sections 1 and 2 of the questionnaire.

As a second step, once lean companies have been identified, subsequent analyses were focused on investigate their drivers, attributes and enablers. As previously mentioned, these points are addressed by Sections 4–6 of the questionnaire. Items in all sections are first used to derive some descriptive statistics.

As third step by the fuzzy QFD find the relation between different lean enablers and attributes (data for calculation find out by survey) and the correlation between LEs and calculate crisp value then rank LEs according to importance. After ranking of LEs find most appropriate LEs.

Table 5.1
Structure of the questionnaire adopted in the empirical study.

Section 1: General overview of the company
1.1. Market segment where the company operates
1.2. Role of respondent to the questionnaire
1.3. E-mail address
1.4. Number of employees
1.5. Annual aggregate turnover
1.6. Average number of new products developed per year

Section 2: Please rank the performance level of your company in the following sector as compared to your industrial average? (scale9=extremely better, scale 1 = extreme worst)
2.1 Current market share.
2.2 Average annual increase of turnover and market share.
2.3 Current competitive position.

Section 3:Please indicate the importance of following attribute of lean supply chain for your company scale 1-9? (9=extreme important, 1=extreme worse)
3.1 Conformance quality
3.2 Delivery reliability
3.3 Low buffering cost
3.4 Low variability in process time
3.5 Low variability in delivery times
3.6 Low variability in demand rates
3.7Cost efficiency
3.8 Delivery speed

Section 4: please indicate the importance of the following enablers of lean supply chain for your company scale 1-9 ? (9= extreme good, 1= extreme worst).
4.1 Minimizing uncertainty
4.2 Market sensitiveness
4.3 Quality Improvement
4.4 E-Business
4.5 Flexible manufacturing system
4.6 Reduce Total operating cost
4.7 Delivery Approach For great distance
4.8 Low Physical Cost
4.9 Cross Docking
4.10 Lot size reduction
4.11 To use third part logistic
4.12 Lean purchasing
4.13 Supplier management
4.14 Design for management
4.15 Total preventive maintenance
4.16 Pull production
4.17 Elimination obvious waste
4.18 Variabi
4.19 Continuous improvement
4.20 JIT manufacturing
4.21 Human resource training
4.22 Total Quality Management
4.23 Knowledge Management
4.24 Service level improvement

Section 5 please, indicate the importance of the following drivers of change forYourcompany–scale1–9(9=extremely important; 1=not at all important)
5.1. Changes in market
5.2. Changes in competitors or competitive bases
5.3. Changes in customer's need
5.4. Technological changes
5.5. Social factors

Section 6: Please, indicate whether and to what extent the following tools are implemented or exploited by Your company–scale 1–9 (9=extremely important; 1=not at all important) and 9= not applicable
6.1 Computer aided design (CAD) or computer aided manufacturing (CAM) systems.
6.2 Flexible manufacturing systems (FMS) or flexible assembly systems (FAS)
6.3 Total quality management (TQM) systems
6.4 Enterprise Resource Planning (ERP) systems
6.5 Quality Function Deployment (QFD) for integrated product/process design and development
6.6 Failure Mode and Effect Analysis (FMEA) and robust design techniques

## IX. RESULT AND DISCUSSION

This section presents an example of the proposed approach through a case study in the industry to illustrate the usefulness and ease of application of the method as well as considering the practical implications of the approach. Focusing on the methodological point of view, the definition of a specific set of and LEs for applying the approach was not dealt with in this project; they should be identified according to the special characteristics of the company under consideration.. Then, 8 LAs and 11 LEs were identified these are shown below in Fig.

We provide a numerical example to illustrate the application of the methodology. The example aims at assessing the usefulness and ease of application of the tool, as well as at considering practical implications and limitations of the methodology proposed. Moreover, the example provides an illustration of the steps required to apply the methodology in practice; they can be summarised as follow:

**Step 1**: identifying the competitive bases a company is willing to achieve competitive advantage;

**Step 2**: identifying lean attributes enhancing the selected competitive bases and filling the first HOQ;

**Step 3**: identifying lean enablers to be exploited in order to achieve the required lean attributes, and filling the second HOQ.

**APPLICATION STEP 1**

As the starting point of the approach proposed, a company should identify the relevant competitive bases. For illustration purpose, the set of competitive bases used in the numerical example has been ground on existing studies and information available in literature. Specifically, a viable list of five competitive bases ($CB_i$, i = 1,.....,5), namely "speed", "cost", "Responsiveness", "quality" and "Comptency". These are listed as "whats" in fig..

In real case applications identifying the relevant competitive bases of a company would require direct contacts with company's members (in particular, marketing manager), either in the form of interviews or roundtable discussion. To support the application of the methodology in practice, and to quickly collect the required information, it is suggested to setup an appropriate workgroup, headed by academics and including firm's executives, reporting to the main business functions involved in the development of lean strategies.

**APPLICATION STEPS 2**

**Step 2** Requires filling the first HOQ, which, in turn, involve the following sub-steps:
Defining the fuzzy linguistics scales;
Assessing the relative importance of competitive bases;
Listing the lean attributes
Assessing the relationship between lean attributes and competitive bases;
Identifying possible correlations between lean attributes.

**Sub-step i**. Fuzzy linguistics scales to be used to assess weights of $CB_s$, relationships between $CB_s$ and $LA_s$ and correlations between LAs could be either defined by the workgroup or derived from the literature. In this example, they were taken from Bottani and Rizzi (2006).

**Sub-steps ii**. In this example, the relative importance $w_i$ of CBs was defined based on the work by Ren et al. Starting from findings by the authors, $w_i$ (i = 1,....5) were pondered based on a normalised 4-point fuzzy linguistic scale, ranging from "very low'' (VL) to "very high'' (VH), as shown in table4. Relative importance of CBs is listed in the second column of Fig. 5.2.

Table
The 4 point linguistic scale for importance judgement

| Importance judgement | Fuzzy Number |
|---|---|
| Very High(VH) | (0.7; 0.5; 0.7) |
| High ( H) | (0 ; 0.3; 0.5) |
| Low ( L ) | (-0.5; -0.3; 0) |
| Very Low ( VL) | (-0.7; -0.5;- 0.3) |

Whenever the procedure is applied to a real case, the same information can be derived asking company's members to express their judgment against the relative importance of competitive bases with regard to the overall strategy of the company. Judgement will be thus translated into fuzzy numbers according to the scale defined in the previous sub-step.

**Sub-step iii**. A viable list of LAs should be defined depending on the specific case in exam. For the purpose of this example 8 lean attributes suggested by Zarei et al. Where listed as LA1,...., LA 8 in columns in the HOQ, and their acronyms are detailed more fig.

**Sub-step iv**. The assessment of the relationships. Since the impact of those lean attributes on the above mentioned set of competitive bases was investigated by Ren et al. Accordingly, as well grounding on the fuzzy scale proposed, the relationships matrix of this example was built as shown in the centre of fig.

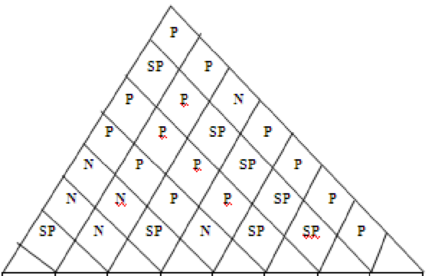
The same assessment, in real case, requires inner viewing the workgroup, to drive information concerning the impact of each LAs on the CBs identified in sub-step ii. Specifically, company's member should be asked to assess how, and to what extent, an LA has potential to enhance a given CBs; judgments could be expressed on a linguistics scale and translated into fuzzy numbers according to previous sub-step i.

**Sub-step v**. Derived correlations required in the roof of the HOQs, as all the studies cited in the table suggest possible links between LAs. According to such findings, the roof of correlations of the first HOQ was built as shown in fig. 5.2. Then, the relative importance $RI_j$ (j = 1,.....,8) and the final scores of lean attributes were computed applying Eqs. (10) and (11). Outcome of the computation are presented in the last row of fig.

The application of the methodology to a real case would require interviewing company's members, to get, based on their in- field experience, information concerning the possible impact of lean attribute on another. Such information should be expressed following the linguistics scale defined in sub-step i, and translated in fuzzy numbers for computational purpose. Nonetheless, findings from the literature could be useful to suggest possible interactions between lean attributes to interviewees, thus helping in the validation.

## X. RESULT OF FIRST FUZZY QFD (FQFD)

**Sub step vi.** To find the normalized value of LAs so this can be use in second fuzzy QFD as the relative weight ($w_i$) as shown in fig. the normalized value can be calculate by taking refrence of Zimmerman et.al.(1991)




| | LA1 | LA2 | LA3 | LA4 | LA5 | LA6 | LA7 | LA8 |
|---|---|---|---|---|---|---|---|---|
| Quality (V.H.) | W | W | S | S | M | S | S | M |
| Cost (V.L.) | S | M | M | W | S | S | M | S |
| Azility (V.H.) | M | M | S | M | M | S | S | W |
| Productivity (V.H.) | S | M | W | W | M | S | S | M |
| Inventory (V.L.) | S | S | W | W | W | M | M | S |
| RIJ | 0.70 1.50 2.60 | 0.42 1.00 2.21 | 0.98 2.00 2.60 | 0.70 1.50 2.18 | 0.63 1.50 2.49 | 1.47 3.00 3.51 | 1.47 3.00 3.42 | 0.42 1.00 2.30 |
| Normalized Value | 0.03 0.49 3.80 | -0.01 0.39 3.52 | 0.06 0.54 3.39 | 0.04 0.48 3.31 | 0.08 0.68 4.34 | 0.14 0.88 4.43 | 0.19 1.00 5.35 | -0.004 0.46 3.74 |
| Crisp value | 1.20 | 1.07 | 1.13 | 1.08 | 1.45 | 1.58 | 1.89 | 1.16 |
| Wi | 0.114 | 0.101 | 0.107 | 0.102 | 0.137 | 0.150 | 0.179 | 0.110 |

Normalized score of lean attributes

| Lean Attributes | Relative weight ($W_{i)}$ or normalized score |
|---|---|
| LA1 | 0.058 |
| LA2 | 0.15 |
| LA3 | 0.138 |
| LA4 | 0.123 |
| LA5 | 0.14 |
| LA6 | 0.143 |
| LA7 | 0.098 |
| LA8 | 0.151 |

**APPLICATION STEPS 3**

Requires building the second HOQ, which involves the following sub-steps:
defining the fuzzy linguistics scale;
assessing the relative importance of lean attributes;
listing the relevant lean enables;
assessing the relationship between lean attributes and lean enablers; and
identifying possible correlations between lean enablers.

**Sub-step i**. To be consistent with results of the previous application step, in this example we adopt the same fuzzy linguistics scales to assess weights of LAs, relationships between LAs lean LEs in the second HOQ.

**Sub-step ii**. Depending on the specific case study, the second HOQ can be built starting from all LAs examined in the previous step, or the analysis can be limited to those attributes which got the highest score in the first HOQ. In order to thoroughly illustrate the application of the methodology, in this example all LAs previously examined will be considered as "whats'' in the second HOQ. Importance weights of LAs can be derived from the final score obtained in the first HOQ. However , since a normalised fuzzy scale has been adopted to express importance judgement of competitive bases in the previous step, a preliminary normalisation of fuzzy scores of lean attributes is suggested before they are used as importance weights in this step. Normalisation is performed by divided each score of the a highest one score of c and score of b is divided by maximum score of b then finally score of c divide by maximum value of a, according to the fuzzy sets algebra. Lean attributes and related normalised importance weights are thus listed in the first columns of the second HOQ, shown in fig.

NRIj*(A, B, C,)

$A_{i=}$ $a_i/c_{max}$

$B_i$= $b_i/b_{max}$

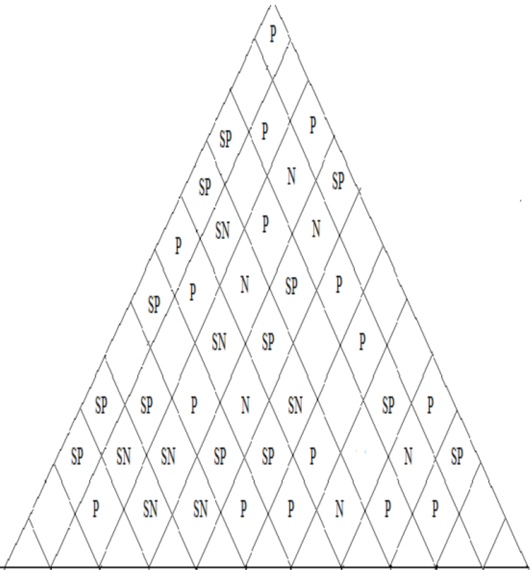
$C_i$= $c_{i/}a_{max}$

**Sub-step iii**. To our knowledge, no specific studies are currently which thoroughly describe the impact of lean enablers on lean attributes, thus directly providing the relationships matrix of the second HOQ. Such relationship, however, are partially dealt with by scientific literature. The resulting values are proposed in the centre of fig. .Findings from the literature could be useful even in a real case application, to suggest possible interviewees to help in the evaluation.

**Sub-step iv**. As per the previous sub-step, in this example possible correlations between LEs were derived from the literature. On the basis of the literature examined, as well as on the degree of correlations proposed by company, the roof of correlations of the second HOQ was built as shown in fig. Findings from the literature could also be useful in the case the second HOQ is built based on experts' opinion, to suggest possible interactions between enablers, as well as correlations between enablers, thus helping in the assessment.

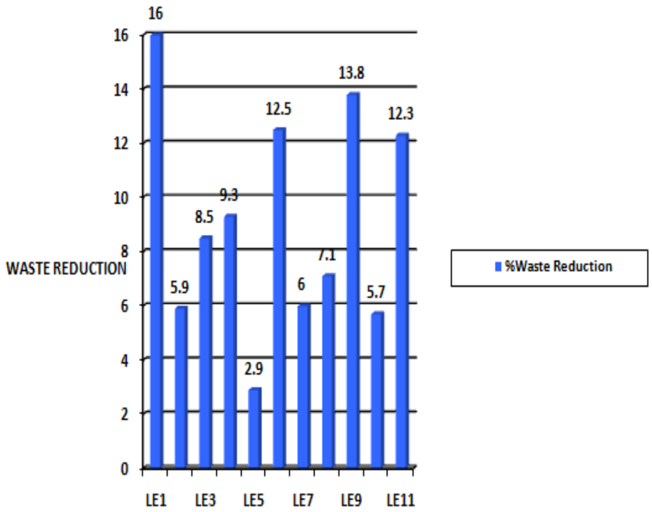
The relative importance $RI_k$ (k = 1,.....,11) and the find score of LEs were computed according to Esq. (6) and (7). Eq. (8) was finally adopted to derive crisp scores. Outcome s of the computation are presented in the last rows of fig. AS a result of the computation, supply chain management practices Service level improvement (LE1) got the highest crisp score, means if we use LE1 then we get high waste reduction that is

16.0% with respect to other shown in fig 5.4 due to both the wide number of positive correlations with others LEs and strong relationships with several LAs. Thus, such an enabler has the highest implementation priority in order to achieve leanness, followed by Vendor management inventory (LE9) and Human Resource training (LE6) shown in table.




| LAj \ LEk | Wi | $LE_1$ | $LE_2$ | $LE_3$ | $LE_4$ | $LE_5$ | $LE_6$ | $LE_7$ | $LE_8$ | $LE_9$ | $LE_{10}$ | $LE_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LA1 | 0.058 | W | S | W | W | S | M | S | M | M | S | M |
| LA2 | 0.15 | S | W | S | S | M | M | W | M | S | W | S |
| LA3 | 0.138 | S | W | S | S | M | M | M | S | S | W | S |
| LA4 | 0.123 | S | W | S | S | M | M | W | W | M | W | M |
| LA5 | 0.14 | S | S | S | W | S | M | S | W | M | S | M |
| LA6 | 0.143 | S | W | S | S | M | M | W | W | S | W | S |
| LA7 | 0.098 | S | W | S | S | S | M | S | S | M | S | M |
| LA8 | 0.151 | S | W | S | S | M | M | W | W | S | W | S |
| Rij (Relative Importance ) | | 0.659<br>0.942<br>0.959 | 0.139<br>0.198<br>0.139 | 0.659<br>0.942<br>0.959 | 0.561<br>0.802<br>0.861 | 0.419<br>0.649<br>0.790 | 0.30<br>0.50<br>0.70 | 0.249<br>0.365<br>0.563 | 0.228<br>0.340<br>0.549 | 0.533<br>0.792<br>0.875 | 0.207<br>0.296<br>0.508 | 0.708<br>0.792<br>0.875 |
| SCOREj (RIj*) | | 1.343<br>2.977<br>4.438 | -0.288<br>0.432<br>1.584 | -0.221<br>1.512<br>2.624 | 0.209<br>1.392<br>2.975 | -0.478<br>0.127<br>1.385 | 0.666<br>2.149<br>3.659 | -0.419<br>0.718<br>2.233 | -1.286<br>1.110<br>2.679 | 1.111<br>2.535<br>3.770 | -0.442<br>0.494<br>2.304 | 1.038<br>2.256<br>3.324 |
| Normalized Value (NRIj*) | | 0.204<br>1<br>3.304 | -0.065<br>0.145<br>1.179 | -0.05<br>0.508<br>1.954 | 0.047<br>0.468<br>2.215 | -0.108<br>0.043<br>1.031 | 0.15<br>0.722<br>2.724 | -0.094<br>0.241<br>1.663 | -0.290<br>0.373<br>1.995 | 0.25<br>0.852<br>2.807 | -0.099<br>0.166<br>1.715 | 0.234<br>0.758<br>2.475 |
| Crisp Value | | 1.377 | 0.504 | 0.730 | 0.799 | 0.252 | 1.079 | 0.513 | 0.613 | 1.190 | 0.487 | 1.056 |

SECOND FUZZY QFD NUMERICAL RESULT

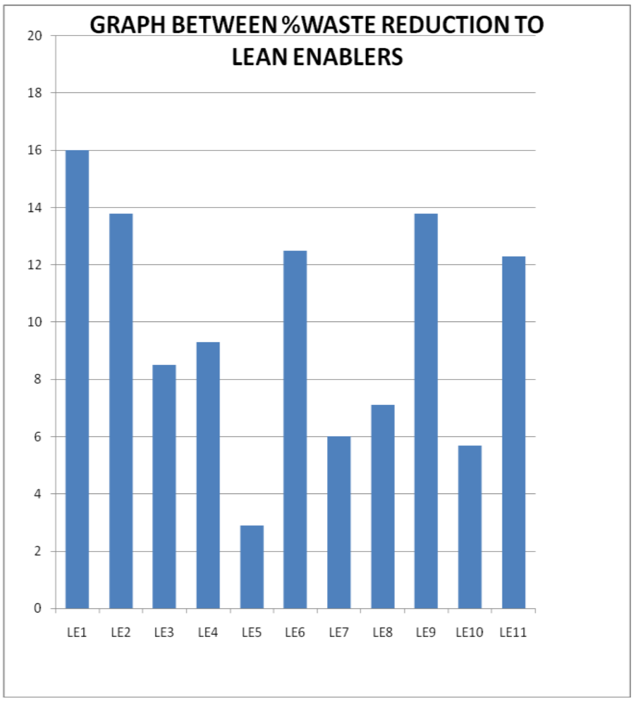



Ranking of LEs

| Rank | Les | Crisp Value | %Waste reduction |
|---|---|---|---|
| 1 | LE1 | 1.377 | 16.0 |
| 9 | LE2 | 0.504 | 5.9 |
| 6 | LE3 | 0.730 | 8.5 |
| 5 | LE4 | 0.799 | 9.3 |
| 11 | LE5 | 0.252 | 2.9 |
| 3 | LE6 | 1.079 | 12.5 |
| 8 | LE7 | 0.513 | 6.0 |
| 7 | LE8 | 0.613 | 7.1 |
| 2 | LE9 | 1.19 | 13.8 |
| 10 | LE10 | 0.487 | 5.7 |
| 4 | LE11 | 01.056 | 12.3 |

**GRAPHICAL REPRESANTATION OF WASTE REDUCTION ( IN PERCENT)TO LEAN**

**ENABLERS**




GRAPH BETWEEN WASTE REDUCTION TO LEAN ENABLERS

## XI. CONCLUSION

In this paper, an integrated Fuzzy QFD approach was proposed to enhance the leanness of the supply chain. The approach showed the applicability of the QFD methodology, especially of the HOQ, to identify viable lean enablers for achieving a defined set of LAs. The first Fuzzy QFD was used to prioritize lean attributes. In order to cope well with the vagueness of linguistic judgments required in building the HOQs, relationships, and correlations, Wi, relative importance ($RI_J$), and priority weights ($RI_J^*$) of LEs were all defined with TFNs

## REFERENCES

[1] Akao, Y., 1990. Quality Function Deployment: Integrating Customer Requirements into Product Design. Productivity Press, Cambridge, MA.
[2] Apaiah, R.K., Hendrix, E.M.T., 2005. Design of a supply chain network for pea-based novel protein foods. Journal of Food Engineering 70 (3), 383–391.
[3] Apaiah, R.K., Linnemann, A.R., van der Kooi, H.J., 2006. Exergy analysis: a tool to study the sustainability of food supply chains. Food Research International 39 (1), 1–11.
[4] Bevilacqua, M., Ciarapica, F.E., Giacchetta, G., 2009. Business process reengineering of a supply chain and a traceability system: a case study. Journal of Food Engineering 93 (1), 13–22.
[5] Bottani, E., 2009. A fuzzy QFD approach to achieve agility. International Journal of Production Economics 119 (2), 380–391.
[6] Bottani, E., Rizzi, A., 2006. Strategic management of logistics service: A fuzzy-QFD approach. International Journal of Production Economics 103 (2), 585–599.
[7] Chan, L.K., Wue, M.L., 2005. A systematic approach to quality function deployment with a full illustrative example. Omega, International Journal of Management Science 33, 119–139.
[8] Christopher, M., 1999. The agile supply chain: competing in volatile markets. Industrial Marketing Management 29, 37–44.
[9] Christopher. M., Towell, D., 2000. Supply chain migration from lean and functional to agile and customize. Supply chain management:An international journal 5(4) , 206-213.
[10] Costa, A.I.A., Dekker, M., Jonges, W.M.F., 2000.Quality function deployement in the food industry: A review. Trends in food science end technology. 11(9-10), 306-314.