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Enhancing Leanness in Manufacturing Process of Small Scale Industry Using Fuzzy QFD Approach

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Abstract:
The Small Scale Industries are the integral part of Indian economy with significant contribution to GDP and employment generation in India. Due to insufficient resources, implementing lean manufacturing has still a good option for Small Scale Industries to improve its productivity. The main objective of lean is to utilize less manpower, less time to respond to customer demand, less inventory, less time to develop products and lesser space to produce top quality products in the most efficient and economical manner as possible. The purpose of this research is to identify the lean enablers and to select the most suitable of them to enhance leanness in manufacturing. In this research, Fuzzy logic – based Quality Function Deployment (QFD) was employed for the selection of most appropriate Lean Enablers helps in Lean Manufacturing.

Keywords: *Quality Function Deployment (QFD), House of Quality (HOQ), Fuzzy logic, Lean Attributes, Lean Enablers etc*

1. Introduction

Today, many big organizations involved in producing products with a high degree of customer satisfaction. The success of a product or service largely depends on how they meet the customer's requirements. Understanding of customer needs leads to successful products and shorter development time. In large scale industries work is distributed among the trained employees according to their efficiency which improves the productivity. Also, these industries also use huge modern capital with latest technologies which raises productivity and reduces cost per head.

It has been observed that the factories in the small-scale sector in India are generally less efficient in process and energy utilization as compared to larger enterprises in India as well as to enterprises of equivalent capacity in other countries. There have been very few studies aimed at strategy development by Small Scale Industries (SSIs) for sustaining their competitiveness. Also, SSIs face many pressures and constraints due to their limited resources such as lack of capital, skilled manpower and latest technology. Due to insufficient resources as compared to large scale industries implementing lean manufacturing has still come as an option for small scale industries to improve productivity.

The main purpose of this study is to find out the factors which will be fruitful in achieving leanness in manufacturing under all kinds of small scale industries. The company under our study is small scale paint manufacturing unit located in Gwalior, involves in manufacturing of all kinds of paints, distemper and varnishes. During our visit, we find there, the main concerns of the management of the company are low profitability, low productivity, employee dissatisfaction and their inability to invest money in new technologies, machineries etc.

Therefore, competitive bases of the company were identified to have a competitive advantage. An integrated Fuzzy QFD method is applied in which first HOQ aims at identifying the relevant lean attributes that enhance the company's competitiveness according to a defined set of filled competitive bases. The second HOQ aims to identify viable lean enablers to be practically implemented to achieve a defined set of lean attributes. Finally, we find the relations between different lean enablers and attributes and the correlation between LEs and calculate the crisp value, then rank LEs according to importance. After ranking of LEs find most appropriate LEs were selected.

2. Quality Function Deployment

Quality Function Deployment (QFD) was developed in the late of 1960's in Japan by Professors Yoji Akao, Shigeru Mizuno and other quality experts as they wanted to develop a quality assurance method that considers customer satisfaction of a product before it was manufactured at the time that quality control methods were primarily aimed at fixing a problem during or after manufacturing.

QFD is a quality tool that helps to translate the Voice of the Customer (VOC) into new products that truly satisfy their needs. It has been successfully applied in many Japanese organizations to improve processes and to build competitive advantages. Today, companies are successfully using QFD as a powerful tool that addresses strategic and operational decisions in businesses. It is also known by the terms “Customer - oriented engineering” and “Matrix product planning”. The whole QFD concept is based on a sequence of operations to convert the voice of the customer (VOC) into the final product or service.

3. The Proposed Methodology

In the proposed methodology, QFD and HOQ principles are translated from new product development field to the leanness context. It can be better understood from the definition which summarizes the purposes of the technique: “QFD is a method for structured product planning and development that enables a development team to specify clearly the customer’s requirements, and then to evaluate each proposed product or service capability systematically in terms of its impact on meeting those requirements”. This method involves building of one or more matrices known as “House of Quality” (HOQ). Figure-1 shows each of the sections contained in the HOQ which holds important data for the further analysis in QFD. In this approach our purpose is to exploit HOQ to first relate competitive bases to lean attributes, then lean attributes, in turns to lean enablers. How to build HOQs are provided under the following headings.

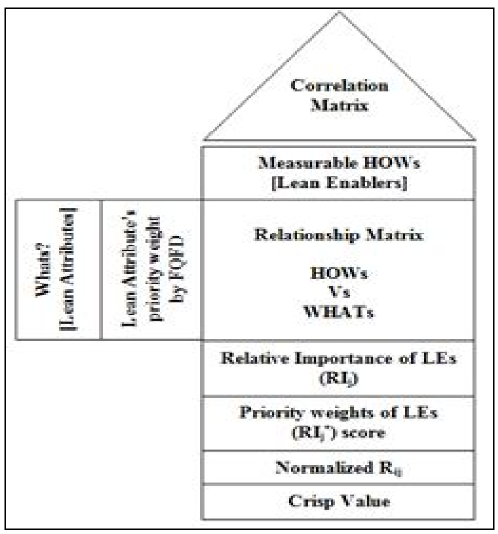


Figure 1: Proposed Fuzzy QFD Structure

3.1. First House of Quality

The following steps are involved in building of First House of Quality:

3.1.1 Identifying the Competitive Bases

As a first step the competitive bases should be identified for which a company is willing to achieve competitive advantage. It require direct contacts with the industry members (in particular, marketing manager, production manager), either in the form of interviews or discussion. Competitive bases (CBs) appear as “Whats?” in the first HOQ. A proper ranking of CBs should be assigned, by pondering there priority weights Wi (i =1...............n).

3.1.2 Identifying Lean Attributes in Manufacturing

A viable list of LAs should be identified that enhance the company’s competitiveness according to a defined set of filled competitive bases. Lean attributes (LAs) are defined as elements which constitute the underlying structure of a lean organization.

3.1.3 Determine relationship between LAs and CBs and Correlationships between LAs

Fuzzy linguistics scales to be used to assess weights of CBs, relationships between CBs and LAs and correlation between LAs. LAs appear as “Hows?” since they express attributes to be enhanced depending on the competitive bases companies are willing to excel in.

3.1.4 Prioritize LAs by FQFD to obtain LAs priority weight (Wi)

After defining LAs, their priority weights were computed by using FQFD. The output of this QFD, i.e. LAs priority weights, represented as Wi, is the input of the second HOQ component of the proposed model.

3.2. Second House of Quality
Building of Second HOQ involves following steps:

3.2.1 Identifying Lean Enablers in manufacturing
A viable list of lean enablers is identified to achieve a defined set of lean attributes. LAs (LA_j, j=1,............m) represent company's requirements, and appear as "Whats?" in the HOQ, while LEs (LE_k k =1,........,p) are listed as "Hows?", since they are considered as practical tools the company can implement to achieve leanness.

3.2.2 Determine the relationship between LAs and LEs and Correlation between LEs
Fuzzy logic was exploited to translate linguistic judgments required for relative importance of LAs, relationships, and correlations matrices into numerical values. The degree of relationship between LAs and LEs and correlation between LEs was stated by the corresponding TFNs and placed in the HOQ matrix. Both of these correspondences are shown in Table 1 & 2.

Degree of relationship	Fuzzy numbers
Strong	(0.7, 1,1)
Medium	(0.3,0.5,0.7)
Weak	(0,0,0.3)

Table 1: Degree of relationships, and corresponding Fuzzy numbers

Degree of correlations	Symbol	Fuzzy numbers
Strong positive	(SP)	(0.3,0.5,0.7)
Positive	(P)	(0,0.3,0.5)
Negative	(N)	(-0.5,-0.3,0)
Strong Negative	(SN)	(-0.7,-0.5,-0.3)

Table 2: Degree of correlations, and corresponding Fuzzy numbers

Triangular Fuzzy Number (TFN)
The TFN can be denoted as a triplet (a, b, c) as shown in fig., where, $a \leq b \leq c$.
When a = b = c, it is a non-fuzzy number by convention. The membership function can be defined as:
(x-a)/(b-a), x is a function of [a,b]
μn(x) : (c-x)/(c-b)x is a function of [b,c] ……….(1)

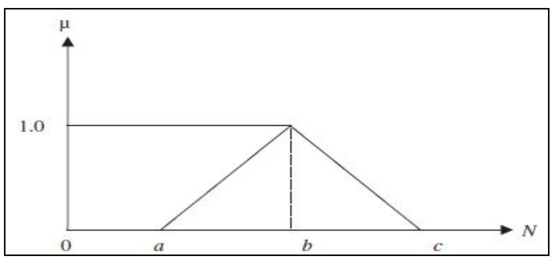


Figure 2: Triangular fuzzy number (TFN)

If M = (a_1, b_1, c_1) and N = (a_2, b_2, c_2) represent two TFNs, then the required fuzzy calculations are performed as given below:
Fuzzy addition : M + N = ($a_1 + a_2$; $b_1 + b_2$; $c_1 + c_2$) ………… … (2)
Fuzzy multiplication: M x N = (a_1 x a_2; b_1 x b_2; c_1 x c_2) …………. (3)
M ×1/N = (a_1/c_2; b_1/b_2; c_1/a_2) ……………...... (4)
Fuzzy and natural number multiplication: r x M = ($r.a_1$; $r.b_1$; $r.c_1$)……..... (5)
Calculate the Relative Importance (RI_j) and Priority Weights of LEs (W_i) by SFQFD. The aim of computing these two parameters was to determine which LE has the most effect on the lean manufacturing. RI_j was computed by fuzzy multiplication of W_i to R_{ij}.
$RI_j = \sum W_i \times R_{ij}$ j= 1,2,3,4......................m (6)
$RI_j^* = RI_j \times \sum T_{kj} \times RI_k$ j =1, 2, 3, 4......................m (7)
T_{kj} was shown in the roof part of HOQ. Furthermore, normalization was performed by dividing each RI_j^* by the highest one according to the fuzzy set algebra. Then, in order to rank the LEs, the normalized scores of RI_j^* were de-fuzzified. Suppose M (a, b, c) is a TFN, then the crisp value is computed as:
(a+2b+c)/4 ………… (8)
LEs with high crisp values indicate that they can be usefully exploited to enhance relevant LAs. Thus, such enablers must be selected for implementation.

4. Application -Case Study
The case study is undertaken at a small scale process industry involved in producing paint products. Here, we are providing an example to illustrate the application of the methodology. The application of the methodology to a real case would require

interviewing industries members, to get information based on their infield experience. Such information should be expressed following the linguistics scale and should be translated in fuzzy numbers for computational purpose.
Focusing on the methodological point of view, a specific set of LAs and LEs should be identified according to the special characteristics of the company under consideration. Here, 8 LAs and 13 LEs were identified which are shown below in Table-3.

Lean Enablers (LEs)	Lean Attribute (LAs)
Speed	Conformance quality
Employee motivation	Delivery reliability
Maintenance	Low variability in process time
Processing steps	Cost efficiency
Wastes	Low variability in delivery time
Inventory	Low variability in demand rates
Trained employees	Delivery speed
Material handling	Availability of content
Demand and supply	
Market value	
Availability of raw material	
Means of transportation	

Table 3: Lean Attributes and Enablers to achieve Leanness in Manufacturing from related Small Scale Industry

5. Sample and Data Collection

An appropriate questionnaire was organized to collect information related to the respondent company. Examples of such information include market segment where the company operates, amount of annual turnover, number of employees, lean attributes of the company, drivers for change, company's competitive priorities and attitude to change. Finally, the last section of the questionnaire was designed to collect the information related to practical tools exploited to achieve leanness.

6. Steps of Analysis

Collected data provides an illustration of the steps required to apply the methodology in practice. They can be summarized as follows:

- ***Step1:*** Identifying the competitive bases an industry is willing to achieve competitive advantage.
- ***Step2:*** 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.

6.1. Application Step 1

As the starting point of the approach proposed, an industry should identify the relevant competitive bases. Specifically, a viable list of five competitive bases (CB_i , i =1,2,3......5), namely quality, cost, time, customer satisfaction, and flexibility are selected here. These are listed as "Whats?" in fig. -3.

6.2. Application Step 2

Requires filling the first HOQ, which in turn, involve the following sub-steps:

6.2.1. Assessing the Relative Importance of Competitive Bases

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 four point fuzzy linguistic scale, ranging from "very low" (VL) to "very high" (VH), as in shown in table-4. Relative importance of CBs is listed in the second column of fig.

Importance judgement	Symbol	Fuzzy number
Very high	(VH)	(0.7;0.5;01)
High	(H)	(0;0.3;0.5)
Low	(L)	(-0.5;-0.3;0)
Very low	(VL)	(-0.7;-0.5;-0.3)

Table 4:The four point linguistic scale for importance judgement

6.2.2. Listing the lean attributes

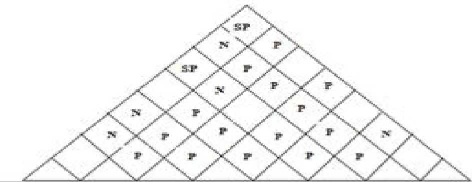
A viable list of LAs should be defined depending on the specific case. For the purpose of this example, 8 lean attributes suggested by Zarei et al. were (listed as LA1,.....,......., LA8 in columns in the HOQ as shown in fig.-3).

6.2.3. Assessing the relationship between LAs and CBs

Derive the relationship between LAs ("Hows?") and CBs ("Whats?") grounding on the fuzzy scale proposed. The degree of relationship in the form of linguistic variables with their corresponding fuzzy number is shown in the table-4.

6.2.4.Identifying possible Correlations between Lean Attributes

Derive the possible correlations between LAs which is required to be filled in the roof of the first HOQ having degree of correlation with corresponding fuzzy numbers as listed in the table-2.



LAi / CB_s	Wi	LA1	LA2	LA3	LA4	LA5	LA6	LA7	LA8
Quality	VH	S	S	W	W	W	M	W	S
Cost	VH	S	M	S	S	M	M	M	S
Time	H	W	S	S	W	S	S	S	W
Flexibility	VH	M	W	M	M	W	S	M	S
Customer Satisfaction	H	S	S	M	S	S	S	S	S
Relative Importance (RI_j)		1.19 1.55 3.35	0.7 1.35 3	0.7 1.2 2.55	0.7 1.05 2.65	0.21 0.55 2.3	0.91 1.6 3.4	0.42 1.1 2.7	1.47 1.8 3.65
Score (RI_j')		0.994 2.245 5.285	0.245 2.67 10.075	0.70 2.1 6.675	0.7 2.655 5.675	0.21 1.66 5.35	0.175 1.39 4.75	-0.175 2.45 9.5	1.372 2.515 5.52
Normalised Value (NRI_j)		0.0956 0.797 6.035	0.0243 0.945 7.343	0.0694 0.746 4.565	0.0694 0.943 6.322	0.0208 0.539 3.599	0.0173 0.493 3.462	-0.017 0.870 7.142	0.136 1 6.425
Crisp Value		1.932	2.315	1.606	2.069	1.274	1.116	2.216	2.141

Figure 3: Result of first fuzzy QFD (FQFD).

The relative importance RI_j (j =1,.....,.....,.8) and the final scores of lean attributes were computed applying eqn. (6) & (7). Outcome of the computation are presented in the last row of fig. -3

The normalized value of LAs were determined so that this can be used in second Fuzzy QFD as shown in fig. - 4. The normalized value can be calculated by taking reference of Zimmerman et al (1991).

Lean Attributes	Relative Weight (W_i) or Normalised Score
LA1	0.131
LA2	0.157
LA3	0.109
LA4	0.141
LA5	0.086
LA6	0.076
LA7	0.151
LA8	0.145

Table 5:Normalized score of Lean Attributes

6.3. Application Step 3

Requires building the second HOQ, which involves the following sub-steps:

6.3.1. Assessing the Relative Importance of Lean Attributes

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 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. Since a normalized fuzzy scale has been adopted to express importance judgment of competitive bases in the previous step, therefore, normalization of fuzzy scores of lean attributes is suggested before they are used as importance weights in SFQFD.

Normalization is performed by dividing each score of the highest one score of c and score of b is divided by maximum score of b, then finally score of c divided by maximum value of a, according to the fuzzy sets algebra.

NRI_j*(A,B,C)

$A_i = a_i/c_{max}$

$B_i = b_i/b_{max}$

$C_i = c_i/a_{max}$

Lean attributes and related normalized importance weights are thus listed in the first columns of the second HOQ, shown in figure – 4

6.3.2. Listing the relevant lean enablers

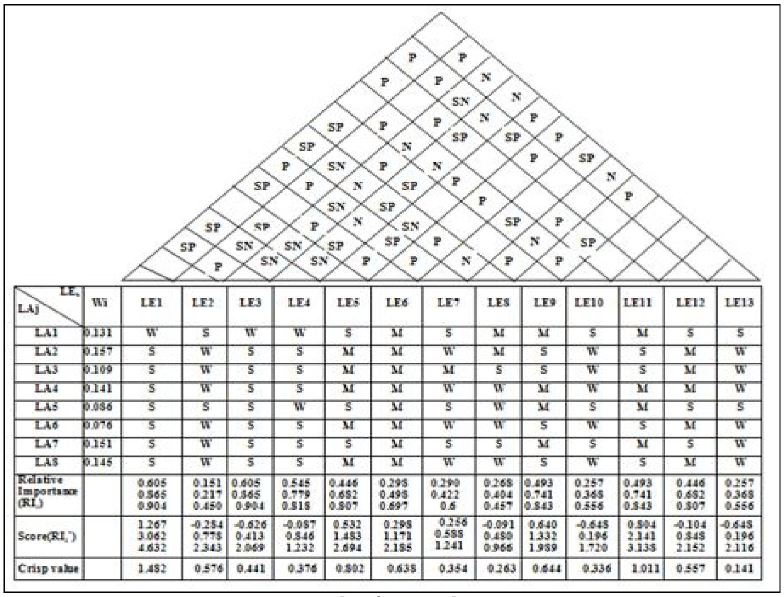
A viable list of lean enablers are selected in order to achieve the required LAs, as accepted by various authors, were identified. Lean enablers are considered as practical tools that the company can implement to achieve leanness. The resulting values are proposed in the center of fig.

6.3.3. Assessing the relationship between Lean Attributes and Lean Enablers

Relationship between Lean Enablers and Lean Attributes was determined based on proposed fuzzy scale. The degree of relationship between LAs and LEs was stated by the corresponding TFNs and placed in the HOQ matrix.

6.3.4. Identifying possible Correlations between Les

On the basis of the literature examined, as well as on the degree of correlations proposed by industry the roof of correlation of the second HOQ was built as shown in figure-4. The relative importance RI_k (k =1,…..13) and the final $score_k$ of LEs were computed according to eqs. (6) & (7). Eq. (8) was finally adopted to derive crisp scores.



LE, / LAj	Wi	LE1	LE2	LE3	LE4	LE5	LE6	LE7	LE8	LE9	LE10	LE11	LE12	LE13
LA1	0.131	W	S	W	W	S	M	S	M	M	S	M	S	S
LA2	0.157	S	W	S	S	M	M	W	M	S	W	S	M	W
LA3	0.109	S	W	S	S	M	M	M	S	S	W	S	M	W
LA4	0.141	S	W	S	S	M	M	W	W	M	W	M	M	W
LA5	0.086	S	S	S	W	S	M	S	W	M	S	M	S	S
LA6	0.076	S	W	S	S	M	M	W	W	S	W	S	M	W
LA7	0.151	S	W	S	S	S	M	S	S	M	S	M	S	W
LA8	0.145	S	W	S	S	M	M	W	W	S	W	S	M	W
Relative Importance (RI)		0.605 0.865 0.904	0.151 0.217 0.450	0.605 0.865 0.904	0.545 0.779 0.818	0.446 0.682 0.807	0.298 0.498 0.697	0.290 0.422 0.6	0.268 0.404 0.457	0.493 0.741 0.843	0.257 0.368 0.556	0.493 0.741 0.843	0.446 0.682 0.807	0.257 0.368 0.556
Score(RI)		1.267 3.062 4.632	-0.284 0.778 2.343	-0.626 0.413 2.069	-0.087 0.846 1.232	0.532 1.483 2.694	0.298 1.171 2.185	0.256 0.588 1.241	-0.091 0.480 0.966	0.640 1.332 1.989	-0.648 0.196 1.720	0.804 2.141 3.138	-0.104 0.848 2.152	-0.648 0.196 2.116
Crisp value		1.482	0.576	0.441	0.376	0.802	0.638	0.354	0.263	0.644	0.336	1.011	0.557	0.141

Figure 4: Result of Second FQFD

7. Result

Outcomes of the computation are presented in the last rows of fig. -4. As a result of the computation, speed (LE1) got the highest crisp value, means if we use LE, then we get high waste reduction i.e. 18% w.r.t other in fig. Thus, such an enabler has the highest implementation priority in order to achieve leanness, followed by wastes (LE5) and demand and supply (LE11) as shown in figure 4.

Rank	LEs	Crisp values	% Waste Reduction
1	LE1	0.187	18.7%
6	LE2	0.072	7.2%
8	LE3	0.055	5.5%
10	LE4	0.047	4.7%
3	LE5	0.101	10%
5	LE6	0.080	8%
11	LE7	0.044	4.4%
13	LE8	0.033	3.3%
4	LE9	0.081	8.1%
12	LE10	0.042	4.2%
2	LE11	0.128	12.8%
7	LE12	0.070	7%
9	LE13	0.0524	5.2%

Table 6: Ranking of LEs according to fig.5.2

8. Conclusion & Future scope

In this research the final result and the graph can be concluded that LE8 is rated as the best choice because of least waste, but the other LE1 is the worst one for manufacturing process due to lot of waste outcome. By using this proposed method, an alternative way of lean enablers selection is described, also, the critical success factors for leanness can be identified. According to the evaluations of each decision maker, “speed” has the highest waste % and identified as the most important factor, followed by

"wastes in all forms", "demand and supply" and "processing steps", respectively. These four factors have relatively higher waste % than the others including "employee motivation", "inventory", "maintenance", and "material handling" etc.
For getting better results in our research we uses Fuzzy QFD, but for future work the attention may be focused on the integration of other useful methods with QFD to prioritize LEs in order to enhance leanness in Small Scale Industry. Future researches may also utilize other ranking methods instead of FQFD such as TOPSIS, ANP, AHP, to prioritize the LAs and compute priority weights. Same method may also applies to more case studies for other manufacturing products in small scale industries.

9. Acknowledgement

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