International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-6, August, 2019

Assessing Leanness of Fast-Moving Consumer Goods (FMCG) Industry with Fuzzy Logic

Narender Kumar, S. K Jarial, M. S Narwal

Abstract: ***The purpose of the study is to calculate the leanness of FMCG (fast moving consumer goods) industry. For this a questionnaire was prepared on the basis on enablers and criteria. Interviews were conducted with the Manager (Admin), Production Manager, Quality Officer, Sale and Purchase officer, Lab Chemist, Engineers based on the questionnaire. The case industry is availing benefits of Lean concept since three year and six months. However, there is room for further improvement.***

Keywords: Measurement of leanness, lean concept, Fuzzy Logic, FMCG Industry.

I. INTRODUCTION

Every industry wants to reduce the wastes. Lean concept is concentrated on the reduction of industrial wastes. Lean concept help to minimize seven wastes. There are lots of industries using lean concept in various sectors like manufacturing, automobile, pharmaceuticals, textile etc. There was the need of leanness assessment because benefits of assessment are to identify the current state, track the overall performance of production plant and to find weak areas. A number of researchers have used certain methodologies to measure leanness of manufacturing sector. Most of the researchers use fuzzy logic approach to calculate leanness index. There is need of leanness assessment in FMCG industries.

II. LITERATURE REVIEW

M.E. Bayou and A. de Korvin [1] developed an efficient measure of leanness for an automobile industry with the fuzzy-logic methodology. Bhim Singh, S.K. Garg and et al. [2] provided an efficient assessment method to assess leanness by using fuzzy theory to calculate leanness index for Indian auto component industry. Farzad Behrouzi, Kuan Yew Wong and et al. [3] developed a model to calculate the leanness of performance of supplier on the basis of fuzzy. Seyed Mahmod Zanjirchi, Hossein Sayyadi Tooranlo and et al. [4] developed a methodology based on fuzzy numbers for assessing degree of leanness in tile and ceramic manufacturing company. Farzad Behrouzi and Kuan Yew Wong [5] presented an inventive methodology to assess the lean performance of manufacturing organizations by using fuzzy terms. S. Vinodh and S.R. Balaji [6] designed a system of decision support for the measurement of leanness of a modular switches manufacturing organization using fuzzy logic. S. Vinodh N. Hari Prakash and et al. [7} measured the leanness of a modular manufacturing industry using fuzzy approach. S. Vinodh and Suresh Kumar Chintha [8] developed a model using multi-grade fuzzy method for calculation of leanness of manufacturing industry. S. Vinodh and Suresh Kumar Chintha [9] integrated fuzzy numbers with a QFD framework to identify competitive bases, judgmental fields, lean aspects and enablers for an Indian electronics switches manufacturing industry.

Alireza Anvari, Norzima Zulkifli and et al. [10] presented an inventive method to assess the importance of the effect of lean elements on manufacturing organization by fuzzy. K. E. K. Vimal and S. Vinodh [11] developed a theoretical model to calculate leanness level of manufacturing organization using IF-THEN method. Pius Achanga, Essam Shehab and et al. [12] made a tool for decision support to measure the effect of implementation of lean concept in (SMEs). S. Vinodh and K. E. K. Vimal [13] made a theoretical model to calculate leanness of industry on the basis of thirty criteria. FLI showed the level of leanness of the manufacturing organization and FPI is calculated to identify the hurdles for leanness. Sekar Vinodh and C. Dinesh Kumar [14] developed a system for decision support to calculate leanness of a manufacturing industry using fuzzy. Farzad Behrouzi and Kuan Yew Wong [15] made a model to calculate the leanness of supply chain of the automotive industry on the basis of four performance indicators which are cost, quality, flexibility and delivery and flexibility. K.E.K. Vimal and Sekar Vinodh [16] used ANN method to calculate leanness of transformer manufacturing company using fuzzy logic approach to increase the efficiency of calculation. M.A. Alemi and R. Akram [17] presented an inventive method to calculate the leanness of manufacturing organization with fuzzy TOPSIS. Chhabi Ram Matawale, Saurav Datta and et al.

Revised Manuscript Received on October 30, 2019.
* Correspondence Author
Narender Kumar*, Department of Mechanical Engineering of Deenbandhu Chhotu Ram University of science and technology, Murthal, India. Email: narenbhankhar@gmail.com.
Dr. S. K. Jarial, Department of Mechanical Engineering of Deenbandhu Chhotu Ram University of science and technology, Murthal, India. Email: s.jarial@rediffmail.com.
Dr. M. S. Narwal, Department of Mechanical Engineering of Deenbandhu Chhotu Ram University of science and technology, Murthal, India. Email: narwalmohi@rediffmail.com.

[18] presented an effective leanness assessment system with the help of trapezoidal fuzzy numbers for Locomotive part manufacturing industry. Fatma Pakdil and Karen Moustafa Leonard [19] developed a tool to measure leanness using quantitative and qualitative methods. T.G.Arul, C. Arumugam and et al. [20] used TOPSIS decision making method to determine the impact of lean concept on manufacturing industry. Ali Azadeh, Mansour Zarrin and et al. [21] presented a method to measure and optimize the leanness level of packing and printing organizations by using DEA, FDEA, FCM, DEMATEL and AHP techniques. Anita Susilawati, John Tan and et al. [22] proposed an approach to deal with the multidimensional theory, absence of benchmarking and vagueness for the measurement of leanness of manufacturing industry. Chhabi Ram Matawale, Saurav Datta and et al. [23] delivered an effective system to calculate the level of leanness of the automobile part manufacturing industry supply chain with the help of generalized trapezoidal fuzzy numbers.

S. M Seyedhosseini and A. E Taleghani [24] suggested a new methodology to calculate leanness of automobile body part manufacturing industries based on BSC theory. Omogbai Oleghe and Konstantinos Salonitis [25] made an appraisal on methodologies which are used for measuring qualitative lean metrics for print packaging manufacturing industry. Mohammad Ali Maasouman and Kudret Demirli [26] developed a lean model to calculate the maturity level of manufacturing division. R. Vidyadhar R. Sudeep Kumar and et al. [27] presented a theoretical model for calculation of leanness level of manufacturing SME using fuzzy logic. Rohit Agrawal, Asokan P and et al. [28] proposed a model on the basis of five enablers, thirty criteria, and ninety attributes for the calculation of lean index using fuzzy logic and ANFIS techniques for SME. Gopalakrishnan Narayanamurthy and Anand Gurumurthy [29] developed a mathematical model to calculate leanness of a hospital using fuzzy logic. Saleeshya P.G. and Binu M [30] presented a model which is used to calculate the level of leanness of a manufacturing industry by using neuro-fuzzy method.

III. RESEARCH MEHTODOLOGY

The research work flow throughout this work is shown in fig. 1. According to previous research articles there is less work on leanness calculation in this type of industry. After it enablers, criteria were selected. These enablers and criteria have been chosen from the research of S. Vinodh and K. E. K. Vimal [13] according to suitability of FMCG industry and data collection. And some criteria were merged. The enablers and criteria are shown in fig. 2.Questionnaire was developed on the basis of five enablers, thirteen criteria and fifty three attributes on five likert scale. The whole organization is considered as a system and divided into five parts. The questionnaire covers several views of leanness assessment. The experts are the different designation persons in the industry. Experts assigned importance weightage of enablers, criteria and attributes and assigned the performance rating to all attributes. To approximate linguistic terms Triangular fuzzy numbers is used. Three assessments have been done with the help of fuzzy (submission, subtraction, multiplication and division) operations for calculation of ILI (Industrial leanness Index). Industrial leanness Index has been compared with the natural expression linguistic levels to calculate the level of leanness of the case industry using Euclidean distance approach. To find weak areas or hurdles FPIS (Fuzzy performance importance score) has been calculated to improve these areas.

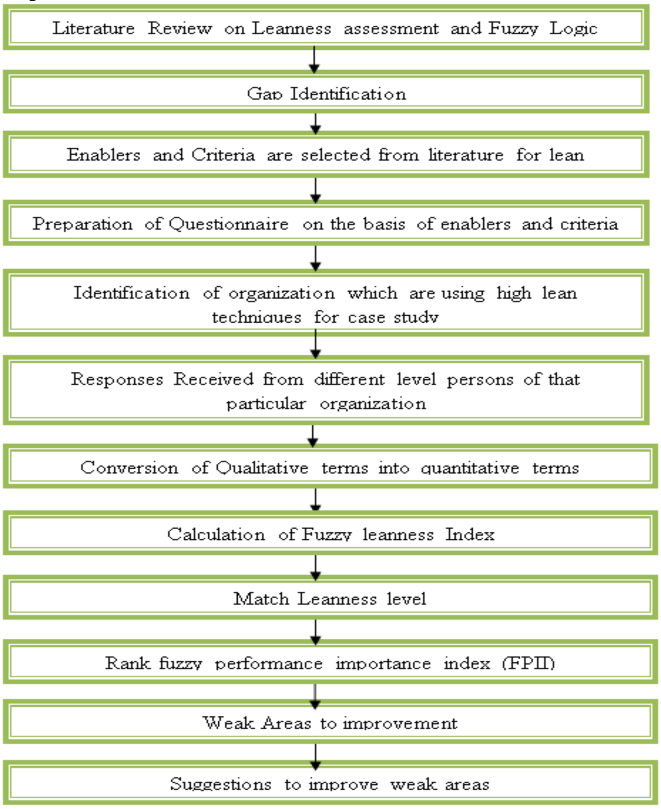

Fig. 1 Research Methodology

IV. CASE STUDY

A. Brief of case industry

The present work has been conducted in a well-known bakery product making organization located in sonepat, Haryana, India. The organization is medium scale enterprises. This organization makes Rusk, suzi rusk, Toast, noodles. The organization exports their products to foreign countries also. The organization has been certified with ISO, (food safety and standards authority of India), US FDA (United State Food and Drug Administration), HALAL (accredited by JAKIM Malaysia), and BRC. The organization has been used Lean concept strategies like TPM, 5S, Kaizen, TQM, TEI (Total employee involvement, Statistical process control and Six Sigma since three year and six months.

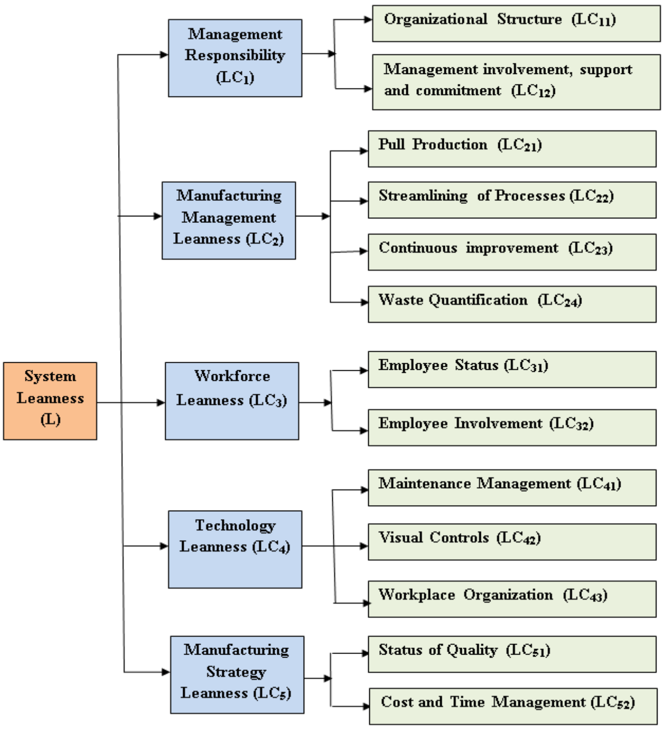

Fig. 2 Research Methodology

B. Measurement of Leanness with fuzzy logic approach

$$LI = \sum_{i=1}^{N} \frac{(R_i \times W_i)}{R_i} \qquad (1)$$

R_i = Index of Performance for enablers
W_i = Weight of Importance for enablers
Rating of enablers is calculated by above equation. Weightage of the enablers, critera and attributes are obtained after discussion with expert. Seven experts (Manager Admin, Production Manager, Sale and purchase manger, Quality officer, Engineers and lab Incharge) joined the conversation on leanness measurement separately. Experts assigned rating and weightage to all attributes. For this small sample median operation is used for aggregate the responses of seven experts. The responses received in the qualitative form after discussion with experts with the help of questionnaire is shown in table III. All received responses changed into triangular fuzzy numbers with the help of table I.

Table-I: Triangular fuzzy numbers for linguistic terms

Rating of Performance		Weightage of Importance	
Linguistic terms and symbols	Triangular Fuzzy Number	Linguistic terms and symbols	Triangular Fuzzy Number
Poor (p)	(0, 0, 2.5)	Very Low (vl)	(0, 0, 0.25)
Fair (f)	(0, 2.5, 5)	Low (l)	(0, 0.25, 0.50)
Good (g)	(2.5, 5, 7.5)	Medium (m)	(0.25, 0.50, 0.75)
Very Good (vg)	(5, 7.5, 10)	High (h)	(0.50, 0.75, 1)
Excellent (e)	(7.5, 10, 10)	Very High (vh)	(0.75, 1, 1)

C. Calculation of Criteria's leanness

Leanness of criteria LI_{ij} is calculated by using Eq. 2

$$LI_{ij} = \frac{\sum_{k=1}^{n} (R_{ijk} \times W_{ijk})}{\sum_{k=1}^{n} W_{ijk}} \qquad (2)$$

LI_{ij}= Lean index of criteria
W_{ijk} = Weight of importance of attribute
R_{ijk} = Rate of performance of attribute

The lean index for "Streamlining of processes" criteria is shown as follows
LI_{22} = Lean index of 2nd criterion on 2nd enabler

$$LI_{22} = \frac{\begin{bmatrix} (0.25,0.50,0.75) \otimes (5,7.5,10) \oplus \\ (0.50,0.75,1) \otimes (5,7.5,10) \oplus \\ (0.50,0.75,1) \otimes (5,7.5,10) \oplus \end{bmatrix}}{\begin{bmatrix} (0.25,0.50,0.75) \oplus \\ (0.50,0.75,1) \oplus \\ (0.50,0.75,1) \end{bmatrix}}$$

$$LI_{22} = [5,7.5,10]$$

Leanness index of all criterions is calculated as shown in table IV.

D. Calculation of Enabler's leanness

Calculation of lean index for "Management Responsibilities" enabler are shown as follows

$$LI_1 = \frac{\begin{bmatrix} (0.50,0.75,1) \otimes (5,7.37,9.64) \oplus \\ (0.50,0.75,1) \otimes (5,7.5,10) \end{bmatrix}}{\begin{bmatrix} (0.50,0.75,1) \oplus \\ (0.50,0.75,1) \end{bmatrix}}$$

$$LI_1 = [5,7.4,9.82]$$

Leanness index of all enablers is calculated as shown in table IV.

E. Calculation of system's leanness

ILI (Industrial leanness index) of the industry

$$ILI = \frac{\begin{bmatrix} (0.50,0.75,1) \otimes (5,7.4,9.82) \oplus \\ (0.50,0.75,1) \otimes (5,7.5,10) \oplus \\ (0.50,0.75,1) \otimes (5,7.5,10) \oplus \\ (0.50,0.75,1) \otimes (5,7.5,10) \oplus \\ (0.50,0.75,1) \otimes (5,7.5,10) \end{bmatrix}}{\begin{bmatrix} (0.50,0.75,1) \oplus \\ (0.50,0.75,1) \oplus \\ (0.50,0.75,1) \oplus \\ (0.50,0.75,1) \oplus \\ (0.50,0.75,1) \end{bmatrix}}$$

$$ILI = [5,7.5,9.96]$$

There is a need to compare ILI (Industrial leanness index) with standard leanness level. There are some methods to compare the ILI and standard leanness level. Frequently preferred distance method is Euclidean distance method. The plus point of this method is the distance between any two items remains unchanged when we add new items in the analysis as compare to other methods. In this method, the natural language notation LLi (Equivalent fuzzy number for natural language notation table II) = {poor lean (PL), fair lean (FL), lean (L), high lean (HL), extreme lean (EL)} is chosen for tagging. The linguistics levels and equivalent numbers are shown in fig. 3. Distance D from the ILI to each standard level is calculated with the help of the Euclidean distance method Eq. 3.

$$D(ILI, LL_i) = \sqrt{\left\{ \sum_{xep} \left(f_{ILI}(x) - f_{LLi}(x) \right)^2 \right\}} \quad (3)$$

D (ILI, LL_i) = Euclidean distance between ILI and LL_i
ILI = Industrial leanness index
LL_i =Corresponding fuzzy number for natural language notation
f_{ILI} (x) = fuzzy numbers of ILI
f_{LLi} (x) = fuzzy numbers of LL_i
Here x is lower, middle and upper triangular numbers

$$D(ILI, EL) = \sqrt{\left\{ (4.94 - 7)^2 + (7.4 - 8.5)^2 + (9.9 - 10)^2 \right\}} = 2.34$$

Similarly
D (ILI, HL) = 1.56
D (ILI, L) = 4.4
D (ILI, FL) = 7.77
D (ILI, PL) = 10.34

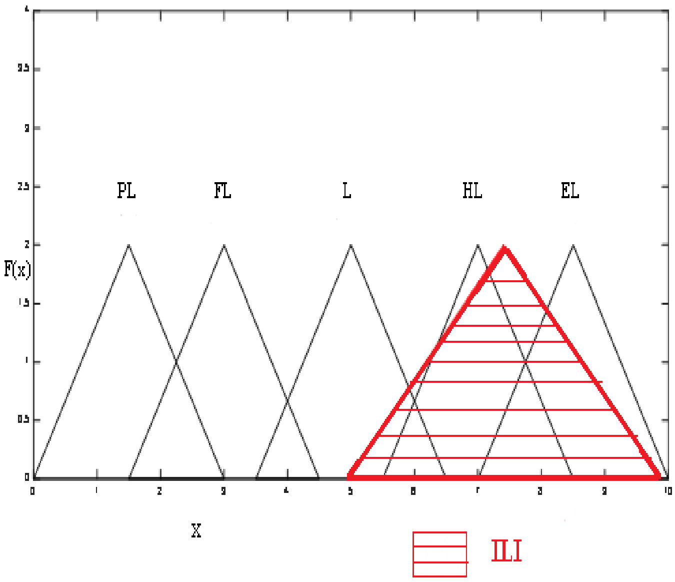

Fig. 3 Comparison of ILI with Linguistic levels

Table Equivalent fuzzy number for natural language notation

PL	0	1.5	3
FL	1.5	3	4.5
L	3.5	5	6.5
HL	5.5	7	8.5
EL	7	8.5	10

V. RESULT AND DISCUSSION

The case industry is found "high lean" after comparing the linguistic levels with ILI. Red triangle shows the leanness level of case industry which is nearer to the HL as shown in fig. 3. It is also confirmed with mathematical calculation. Leanness level is 1.5 distance away from HL which is minimum. It is also useful to find the weak areas/ hurdles. FPIS is combination of rating of performance and weightage of every attributes. It denotes an effect which will show the level of leanness of FMCG industry. If the value of FPIS of a factor is low it means the contribution of this factor is less. [31] The value of transformation (W'_{ijk}) is low because the value of W_{ijk} is high. So, for every attribute ijk, $FPIS_{ijk}$ is defined as

$$FPIS_{ijk} = W'_{ijk} \otimes R_{ijk} \quad (4)$$

$FPIS_{ijk}$ = FPIS for ijkth attribute
W'_{ijk} = Complement of ijkth attribute$^{'s}$ weightage
Where $W'_{ijk} = \left[(1,1,1) - W_{ijk} \right]$, W_{ijk} is the weightage of attribute ijk [31]. Then FPISs of every attributes are calculated by using eq. 4. For example, the calculation of $FPIS_{116}$ attribute is shown below

$$FPIS_{116} = (0.25, 0.5, 0.75) \otimes (2.5, 5, 7.5)$$

$$FPIS_{116} = (0.63, 2.5, 5.63)$$

FPIS of all attributes are calculated using this formula as shown in table V. The ranking index of all attributes has been calculated by using eq. 5. Where a, is lower fuzzy number, b is middle fuzzy number, and c is upper fuzzy number.

$$\text{Ranking Index} = \frac{a + 4b + c}{6} \quad (5)$$

For example the calculation for the $FPIS_{116}$ attribute is shown below

$$\text{Ranking Index} = \frac{0.63 + 4 \times 2.5 + 5.63}{6} = 2.71$$

The ranking index of all attributes is shown in table VI. Scale three was set after the discussion with experts to identify the few critical weak areas. It is found that only four attributes have low performance. Appropriate actions have been suggested to the concern industry to improve the weak areas. There are only four weaker attributes (* mark in table VI) which have need for improvements which are as shown in table V with improvement methods.

VI. CONCLUSION

Lean concept is a combined manufacturing approach which is useful to maximize the capacity and minimize the variability. [32] Leanness is the measurement of performance of lean strategies [1]. Some authors have introduced certain methodologies for calculation of leanness. In this study leanness of FMCG is calculated with the help of fuzzy logic approach. Leanness level of the FMCG industry is found high lean is found by using Euclidean distance method. ILI and FPIS are calculated. FPIS is useful to find the weaker areas. Four attributes are found weak from 53 attributes.

FUTURE SCOPE

The leanness has been calculated in a single FMCG industry. In future we can calculate leanness of many FMCG industries of different products. There are possibilities of comparison of global FMCG industries leanness.

Table-III: Received responses after discussion.

LI_i	LI_{ij}	LI_{ijk}	W_i	W_{ij}	W_{ijk}	R_{ijk}	LI_i	LI_{ij}	LI_{ijk}	W_i	W_{ij}	W_{ijk}	R_{ijk}
LI_1	LI_{11}	LI_{111}	h	h	h	g	LI_3	LI_{31}	LI_{311}	h	h	h	g
		LI_{112}			h	vg			LI_{312}			h	g
		LI_{113}			h	vg			LI_{313}			h	g
		LI_{114}			h	vg			LI_{314}			h	g
		LI_{115}			h	vg			LI_{315}			h	g
		LI_{116}			m	g			LI_{316}			h	g
		LI_{117}			h	vg			LI_{317}			h	g
		LI_{118}			m	g		LI_{32}	LI_{321}		h	h	g
	LI_{12}	LI_{121}		h	h	vg			LI_{322}			h	g
		LI_{122}			h	vg			LI_{323}			m	g
		LI_{123}			h	vg			LI_{324}			h	g
		LI_{124}			vh	vg			LI_{325}			h	g
		LI_{125}			h	vg			LI_{326}			h	g
		LI_{126}			h	vg			LI_{327}			h	g
		LI_{127}			h	vg			LI_{328}			m	g
		LI_{128}			h	vg			LI_{329}			h	g
		LI_{129}			h	vg	LI_4	LI_{41}	LI_{411}	h	h	h	g
LI_2	LI_{21}	LI_{211}	h	h	h	vg			LI_{412}			h	g
	LI_{22}	LI_{221}		h	h	vg		LI_{42}	LI_{421}		h	h	g
		LI_{222}			h	vg		LI_{43}	LI_{431}		h	h	g
		LI_{223}			h	vg			LI_{432}			vh	g
	LI_{23}	LI_{231}		vh	vh	vg			LI_{433}			m	g
	LI_{24}	LI_{241}		h	h	vg	LI_5	LI_{51}	LI_{511}	h	h	h	g
		LI_{242}			h	vg			LI_{512}			h	g
		LI_{243}			h	vg		LI_{52}	LI_{521}		h	h	g
		LI_{244}			m	vg							
		LI_{245}			m	vg							
		LI_{246}			h	vg							

Table-IV: Fuzzy index of all Criterions and all Enablers.

LI_{ij}	R_{ij}	LI_{ij}	R_{ij}	LI_i	R_i
LI_{11}	(4.64, 7.05,9.5)	LI_{32}	(5, 7.5, 10)	LI_1	(4.82, 7.28, 9.75)
LI_{12}	(5, 7.5, 10)	LI_{41}	(5, 7.5, 10)	LI_2	(5, 7.5, 10)
LI_{21}	(5, 7.5, 10)	LI_{42}	(5, 7.5, 10)	LI_3	(5, 7.5, 10)
LI_{22}	(5, 7.5, 10)	LI_{43}	(4.58, 6.88, 9.32)	LI_4	(4.86, 7.29, 9.77)
LI_{23}	(5, 7.5, 10)	LI_{51}	(5, 7.5, 10)	LI_5	(5, 7.5, 10)
LI_{24}	(5, 7.5, 10)	LI_{52}	(5, 7.5, 10)		
LI_{31}	(5, 7.5, 10)				

Table-V: Weak areas with improvement methods.

Attribute	Weaker attributes	Improvement methods
LI_{244}	Wastes reduced after Lean implementation in industry.	Use of Leanness measurement techniques.
LI_{245}	Effect of Lean tool/techniques on Industrial wastes.	Use of Leanness measurement techniques.
LI_{323}	Employees drive suggestion programs time to time in industry.	Rewarding scheme.
LI_{328}	Authority distributed to employees to correct problems.	Training to correct problems.

Table-VI: Fuzzy performance importance Score and Ranking Index of all lean capability

LI_{ijk}	FPIS	Ranking Index	LI_{ijk}	FPIS	Ranking Index
LI_{111}	(0, 1.88, 5)	2.09	LI_{311}	(0, 1.88, 5)	2.09
LI_{112}	(0, 1.88, 5)	2.09	LI_{312}	(0, 1.88, 5)	2.09
LI_{113}	(0, 1.88, 5)	2.09	LI_{313}	(0, 1.88, 5)	2.09
LI_{114}	(0, 1.88, 5)	2.09	LI_{314}	(0, 1.88, 5)	2.09
LI_{115}	(0, 1.88, 5)	2.09	LI_{315}	(0, 1.88, 5)	2.09
LI_{116}	(0.63, 2.5, 5.63)	2.71	LI_{316}	(0, 1.88, 5)	2.09
LI_{117}	(0, 1.88, 5)	2.09	LI_{317}	(0, 1.88, 5)	2.09
LI_{118}	(0.63, 2.5, 5.63)	2.71	LI_{321}	(0, 1.88, 5)	2.09
LI_{121}	(0, 1.88, 5)	2.09	LI_{322}	(0, 1.88, 5)	2.09
LI_{122}	(0, 1.88, 5)	2.09	LI_{323}^{*}	(1.25, 3.75, 7.5)	3.96
LI_{123}	(0, 1.88, 5)	2.09	LI_{324}	(0, 1.88, 5)	2.09
LI_{124}	(0, 0, 2.5)	0.42	LI_{325}	(0, 1.88, 5)	2.09
LI_{125}	(0, 1.88, 5)	2.09	LI_{326}	(0, 1.88, 5)	2.09
LI_{126}	(0, 1.88, 5)	2.09	LI_{327}	(0, 1.88, 5)	2.09
LI_{127}	(0, 1.88, 5)	2.09	LI_{328}^{*}	(1.25, 3.75, 7.5)	3.96
LI_{128}	(0, 1.88, 5)	2.09	LI_{329}	(0, 1.88, 5)	2.09
LI_{129}	(0, 1.88, 5)	2.09	LI_{411}	(0, 1.88, 5)	2.09
LI_{211}	(0, 1.88, 5)	2.09	LI_{412}	(0, 1.88, 5)	2.09
LI_{221}	(0, 1.88, 5)	2.09	LI_{421}	(0, 1.88, 5)	2.09
LI_{222}	(0, 1.88, 5)	2.09	LI_{431}	(0, 1.88, 5)	2.09
LI_{223}	(0, 1.88, 5)	2.09	LI_{432}	(0, 0, 2.5)	0.41
LI_{231}	(0, 0, 2.5)	0.42	LI_{433}	(0.63, 2.5, 5.63)	2.71
LI_{241}	(0, 1.88, 5)	2.09	LI_{511}	(0, 1.88, 5)	2.09
LI_{242}	(0, 1.88, 5)	2.09	LI_{512}	(0, 1.88, 5)	2.09
LI_{243}	(0, 1.88, 5)	2.09	LI_{521}	(0, 1.88, 5)	2.09
LI_{244}^{*}	(1.25, 3.75, 7.5)	3.96			
LI_{245}^{*}	(1.25, 3.75, 7.5)	3.96			
LI_{246}	(0, 1.88, 5)	2.09			

REFERENCES

1. Bayou, Me E., and A. De Korvin. "Measuring the leanness of manufacturing systems—a case study of Ford Motor Company and General Motors." *Journal of Engineering and Technology Management* 25, no. 4 (2008): 287-304. https://doi.org/10.1016/j.jengtecman.2008.10.003
2. Singh, Bhim, S. K. Garg, and S. K. Sharma. "Development of index for measuring leanness: study of an Indian auto component industry." *Measuring Business Excellence* 14, no. 2 (2010): 46-53. https://doi.org/10.1108/13683041011047858
3. Behrouzi, Farzad, Kuan Yew Wong, and Chuen Tse Kuah. "A fuzzy-based model to measure supplier performance with lean attributes." In *2010 Fourth Asia International Conference on Mathematical/Analytical Modelling and Computer Simulation*, pp. 372-377. IEEE, 2010. https://ieeexplore.ieee.org/abstract/document/5489165
4. Zanjirchi, Seyed Mahmod, Hossein Sayyadi Tooranlo, and Leili Zeidabadi Nejad. "Measuring organizational leanness using fuzzy approach." In *Proceedings of the 2010 International Conference on Industrial Engineering and Operations Management*, pp. 144-156. 2010. http://www.iieom.org/paper/145%20Zanjirchi.pdf
5. Behrouzi, Farzad, and Kuan Yew Wong. "Lean performance evaluation of manufacturing systems: A dynamic and innovative approach." *Procedia Computer Science* 3 (2011): 388-395. https://doi.org/10.1016/j.procs.2010.12.065
6. Vinodh, S., and S. R. Balaji. "Fuzzy logic based leanness assessment and its decision support system." *International Journal of Production Research* 49, no. 13 (2011): 4027-4041. https://doi.org/10.1080/00207543.2010.492408
7. Vinodh, S., N. Hari Prakash, and K. Eazhil Selvan. "Evaluation of leanness using fuzzy association rules mining." *The International Journal of Advanced Manufacturing Technology*57, no. 1-4 (2011): 343-352. https://doi.org/10.1007/s00170-011-3260-3
8. Vinodh, S., and Suresh Kumar Chintha. "Leanness assessment using multi-grade fuzzy approach." *International Journal of Production Research* 49, no. 2 (2011): 431-445. https://doi.org/10.1080/00207540903471494
9. Vinodh, S., and Suresh Kumar Chintha. "Application of fuzzy QFD for enabling leanness in a manufacturing organisation." *International Journal of Production Research* 49, no. 6 (2011): 1627-1644. https://doi.org/10.1080/00207540903568729
10. Anvari, Alireza, Norzima Zulkifli, and Rosnah Mohd Yusuff. "A dynamic modeling to measure lean performance within lean attributes." *The International Journal of Advanced Manufacturing Technology* 66, no. 5-8 (2013): 663-677. https://link.springer.com/article/10.1007/s00170-012-4356-0
11. Vimal, K. E. K., and S. Vinodh. "Leanness evaluation using IF–THEN rules." *The International Journal of Advanced Manufacturing Technology* 63, no. 1-4 (2012): 407-413. https://link.springer.com/article/10.1007/s00170-012-3919-4

12. Achanga, Pius, Essam Shehab, Rajkumar Roy, and Geoff Nelder. "A fuzzy-logic advisory system for lean manufacturing within SMEs." *International Journal of Computer Integrated Manufacturing* 25, no. 9 (2012): 839-852. https://doi.org/10.1080/0951192X.2012.665180
13. Vinodh, S., and K. E. K. Vimal. "Thirty criteria based leanness assessment using fuzzy logic approach." *The International Journal of Advanced Manufacturing Technology* 60, no. 9-12 (2012): 1185-1195. https://link.springer.com/article/10.1007/s00170-011-3658-y
14. Vinodh, S., and Suresh Kumar Chintha. "Leanness assessment using multi-grade fuzzy approach." *International Journal of Production Research* 49, no. 2 (2011): 431-445. https://doi.org/10.1080/00207540903471494
15. Behrouzi, Farzad, and Kuan Yew Wong. "An integrated stochastic-fuzzy modeling approach for supply chain leanness evaluation." *The International Journal of Advanced Manufacturing Technology* 68, no. 5-8 (2013): 1677-1696. https://link.springer.com/article/10.1007/s00170-013-4966-1
16. Vimal, K. E. K., and Sekar Vinodh. "Application of artificial neural network for fuzzy logic based leanness assessment." *Journal of Manufacturing Technology Management* 24, no. 2 (2013): 274-292. https://doi.org/10.1108/17410381311292340
17. Alemi, M. A., and R. Akram. "Measuring the leanness of manufacturing systems by using fuzzy TOPSIS: A case study of the'Parizan Sanat'company." *South African Journal of Industrial Engineering* 24, no. 3 (2013): 166-174. http://www.scielo.org.za/scielo.php?pid=S2224-78902013000300014&script=sci_abstract&tlng=af
18. Ram Matawale, Chhabi, Saurav Datta, and Siba Sankar Mahapatra. "Leanness estimation procedural hierarchy using interval-valued fuzzy sets (IVFS)." *Benchmarking: An International Journal* 21, no. 2 (2014): 150-183. https://doi.org/10.1108/BIJ-03-2012-0020
19. Pakdil, Fatma, and Karen Moustafa Leonard. "Criteria for a lean organisation: development of a lean assessment tool." *International Journal of Production Research* 52, no. 15 (2014): 4587-4607. https://doi.org/10.1080/00207543.2013.879614
20. Arul, T. G., C. Arumugam, and P. Parthiban. "Evaluation of lean manufacturing systems using MADM and Fuzzy TOPSIS." In *Applied Mechanics and Materials*, vol. 592, pp. 2628-2638. Trans Tech Publications, 2014. https://doi.org/10.4028/www.scientific.net/AMM.592-594.2628
21. Azadeh, Ali, Mansour Zarrin, Mohammad Abdollahi, Saeid Noury, and Shabnam Farahmand. "Leanness assessment and optimization by fuzzy cognitive map and multivariate analysis." *Expert Systems with Applications* 42, no. 15-16 (2015): 6050-6064. https://doi.org/10.1016/j.eswa.2015.04.007
22. Susilawati, Anita, John Tan, David Bell, and Mohammed Sarwar. "Fuzzy logic based method to measure degree of lean activity in manufacturing industry." *Journal of Manufacturing Systems* 34 (2015): 1-11. https://doi.org/10.1016/j.jmsy.2014.09.007
23. Matawale, Chhabi Ram, Saurav Datta, and Siba Sankar Mahapatra. "Leanness metric evaluation platform in fuzzy context." *Journal of Modelling in Management* 10, no. 2 (2015): 238-267. https://doi.org/10.1108/JM2-10-2013-0057
24. Seyedhosseini, Seyed Mohammad, and Ahmad Ebrahimi-Taleghani. "Group fuzzy ANP procedure development for leanness assessment in auto part manufacturing companies." *Journal for Global Business Advancement* 8, no. 2 (2015): 157-175. https://doi.org/10.1504/JGBA.2015.069528
25. Oleghe, Omogbai, and Konstantinos Salonitis. "Improving the efficacy of the lean index through the quantification of qualitative lean metrics." *Procedia CIRP* 37 (2015): 42-47. https://doi.org/10.1016/j.procir.2015.08.079
26. Maasouman, Mohammad Ali, and Kudret Demirli. "Assessment of lean maturity level in manufacturing cells." *IFAC-PapersOnLine* 48, no. 3 (2015): 1876-1881. https://doi.org/10.1016/j.ifacol.2015.06.360
27. Vidyadhar, R., R. Sudeep Kumar, S. Vinodh, and Jiju Antony. "Application of fuzzy logic for leanness assessment in SMEs: a case study." *Journal of Engineering, Design and Technology*14, no. 1 (2016): 78-103. https://doi.org/10.1108/JEDT-05-2014-0029
28. Agrawal, Rohit, P. Asokan, and S. Vinodh. "Benchmarking fuzzy logic and ANFIS approaches for leanness evaluation in an Indian SME: a case study." *Benchmarking: An International Journal* 24, no. 4 (2017): 973-993. https://doi.org/10.1108/BIJ-06-2016-0083
29. Narayanamurthy, Gopalakrishnan, and Anand Gurumurthy. "Is the hospital lean? A mathematical model for assessing the implementation of lean thinking in healthcare institutions." *Operations Research for Health Care* 18 (2018): 84-98. https://doi.org/10.1016/j.orhc.2017.05.002
30. Saleeshya, P. G., and M. Binu. "A neuro-fuzzy hybrid model for assessing leanness of manufacturing systems." *International Journal of Lean Six Sigma* (2019). https://doi.org/10.1108/IJLSS-05-2017-0040
31. Lin, Ching-Torng, Hero Chiu, and Yi-Hong Tseng. "Agility evaluation using fuzzy logic." *International Journal of Production Economics* 101, no. 2 (2006): 353-368. https://doi.org/10.1016/j.ijpe.2005.01.011
32. Chahal, Virender, and M. S. Narwal. "A Theoretical Analysis for Prioritization of Lean Strategies: A Survey of Indian Manufacturing Industries." In *Advances in Industrial and Production Engineering*, pp. 365-373. Springer, Singapore, 2019. https://doi.org/10.1007/978-981-13-6412-9_35
33. Shah, Rachna, and Peter T. Ward. "Lean manufacturing: context, practice bundles, and performance." *Journal of operations management* 21, no. 2 (2003): 129-149. https://doi.org/10.1016/S0272-6963(02)00108-0

AUTHORS PROFILE

Narender Kumar is pursuing PhD in Mechanical Engineering Department of Deen Bandhu Chhotu Ram University of Science and Technology, Murthal. His research interst is lean manufacturing, Just in Time. He has published 1 research paper in International journal and present 1 review paper in international conference.

Dr. S. K Jarial (Professor) is working in Mechanical Engineering Department of Deen Bandhu Chhotu Ram University of Science and Technology, Murthal. Industrial Engineering/ Rotodynamic Machines/ MCDM Techniques are the research areas of him. He has 31 year teaching experience. He has published 18 research papers in International journals, 1 in International conference, and 6 in national conference. He is member of ASHRAE India Chapter. He has been received Certificate of Excellence from India – International Friendship Society. Fourteen M. Tech has been awarded under the guidance of him.

Dr. M. S Narwal (Professor) is working in Mechanical Engineering Department of Deen Bandhu Chhotu Ram University of Science and Technology, Murthal. Manufacturing Strategy, Operations Management and Project Management are the research areas of him. He has 21 year teaching experience. He has published 22 research papers in International journals, 3 in national journals, 1 in International conference, and 2 in national conference. He is life time member of ISTE, member of Institute of Engineers (India), senior member of IIIE. Two PhD and 12 M. Tech have been awarded under the guidance of him.