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Leanness Assessment using Fuzzy Logic Approach: A Case of Indian Horn Manufacturing Company

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Abstract— Lean principles are being implemented by many industries today that focus on improving the efficiency of the operations for reducing the waste, efforts and consumption. Organizations implementing lean principles can be assessed using the some tools. This paper attempts to assess the lean implementation in a leading Horn manufacturing industry in South India. The twofold objectives are set to be achieved through this paper. First is to find the leanness level of a manufacturing organization for which a horn manufacturing company has been selected as the case company. Second is to find the critical obstacles for the lean implementation. The fuzzy logic computation method is used to extract the perceptions about the particular variables by using linguistic values and then match it with fuzzy numbers to compute the precise value of the leanness level of the organization. Based on the results obtained from this analysis, it was found that the case study company has performed in the lean to vey lean range and the weaker areas have been identified to improve the performance further.

Keywords— Horn manufacturing, operations, leanness assessment, process improvement, fuzzy logic.

I. INTRODUCTION

In today's competitive business world, lean techniques predominantly used in manufacturing companies. They are being used as a cost effective tool for process improvement to achieve significant organization performance. Lean Manufacturing aims in providing with elimination of wastes from the process by making use of the lean manufacturing concepts to improve the value delivered to the customer. Lean is a continuous process for improvement, hence there forth, it requires developing a framework to assess and monitor the performance against the standards continuously to achieve the end objective over a particular period of span. Manufacturing companies today face many challenges and a particularly difficult one is resource optimization.

Improper planning leads to the issue of over-inventory and also the problem of waste *(muda)*. Wastes start right from the raw material acquisition. Placing the order of improper quantities leads either to excess inventory or shortage. These wastes get accumulated as excessive work-in-process and finished goods inventory. Lean manufacturing helps in overcoming these obstacles.There are many researches undertaken and contributions were made in the case of leanness assessment in the manufacturing industries.

In this research fuzzy logic approach has been used to compute the leanness level and identifying the obstacles. This computation method eliminates vagueness and impreciseness of the input data as they make use of the linguistic variables to measure qualitatively the subjective attributes that formed in the conceptual model and match it with the fuzzy set numbers to acquire the result quantitatively.

II. LITERATURE REVIEW

Vinodh and Vimal [1] has designed a leanness assessment method for the evaluation of the lean practices in the manufacturing organization. In this journal they discuss about the usage of 30 criteria based methodology for the evaluation of the leanness in the organization using the fuzzy logic computation method. Using this method they not only found the leanness level of organization, but also the weaker capabilities where the improvement is needed and measured them before and after the improvements were implemented and proved it to have significant results. Customer's pay only for the value added in manufacturing a product, and not for the non-value added time and materials [2]. The activities that are required to manufacture a product are a value added ones, the rest of the activities are known as waste [3]. Lean principles identifies the non-value add activities and are either removed or reduced there by improving the quality and delivery time, [4]. Lean adds value by eliminating waste, focusing on quality and enhancing the effectiveness of the workforce, [5]. Value added steps can be improved and wasteful steps can be eliminated in the process using Lean. Organizations focusing on customer needs via lean methodology will achieve high customer satisfaction.

Vinodh [6] has designed a model to measure the sustainability of the organization. In this research they made use of the multi grade fuzzy approach to measure the sustainability of the organization of the data gathered from the manufacturing company and the gap analysis was carried out to find the weak areas to improve. Then the results were validated for the practical compatibility using a feedback method then through statistical validation. Vinodh and Vimal [7] have extended their previous research work of leanness assessment for evaluation of lean practice in the organization. They made use of the 30 criteria based methodology for evaluation of the leanness in the organization, and instead of going for the fuzzy logic computation method in this research they have made use of the IF - THEN rules based interface method an advanced fuzzy logic technique for analysis. Seyedhosseini et all., [8] has developed a model for leanness assessment, in this research first the various methods for performance measurement were analyzed, then balance scorecard was selected and based on that balanced score card model perspective, lean criteria's and objectives were extracted which were analyzed using DEMATEL technique and lean strategy map was developed. This method helps in selecting the higher-level criteria's and objectives to improve the leanness of the organization.

III. Methodology

The methodology adopted in carrying out in this research work is shown in Figure 1. The literature review was first carried out. We found that Vinodh [1] has already developed a conceptual model for the leanness assessment for the manufacturing organization and that model has been taken as the basis for the development of the conceptual model in this research. The conceptual model is developed using literature review and expert opinions suiting the assessment of manufacturing organization. Three stages of assessment namely enabler, criteria and attributes are used in this paper. The case organization has been identified and data being collected for the developed conceptual model. Initially, the complete operation of the organization is studied. Based on that we found that there is an immense scope for our research work.

First, there should be weightage given to each of the variables. For that, series of discussions are held with the experts in the company. Experts are mainly from the top management team. Then each of the variables should be given a rating. Experts from middle and low management team set the performance rating. Experts provides with the importance weightage and the rating of the organization using the linguistic variables.

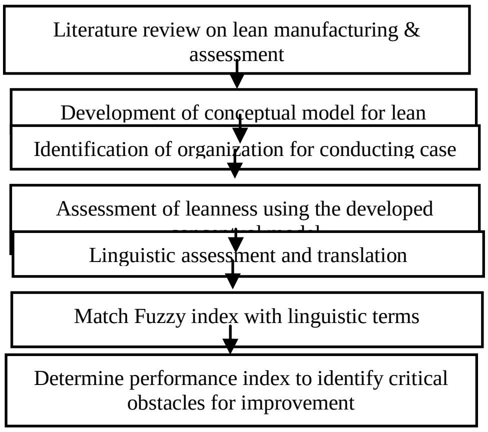

Figure 1. Research Methodology

Then the weightage and rating has been approximated from the linguistic terms to the triangular fuzzy numbers and fuzzy logic operation has been carried out to find the Fuzzy Lean Index (FLI), which denotes the leanness level of the organization. Fuzzy Performance Index is calculated which helps in identifying the obstacles that helps in identifying areas of performance improvement.

IV. Development of conceptual model

The leanness assessment and conceptual model were developed using the literature review and appropriate enablers, criteria and attributes are formulated and captured in Table 2. The developed model has 3 stages. The first stage consists of 5 lean enablers. Second stage consists of 30 lean criteria and the third stage consists of 55 lean attributes. Referring to literature review and considering the experts' opinion has developed the model. The leanness assessment model is developed by considering the 4 major perspectives of the organization viz. process, employee, customer and organization culture. Twenty criteria leanness assessment [9] doesn't capture some important attributes. The 30 criteria overcome these drawbacks.Some changes have been done to Vinodh's [1] model based on the discussions with the experts in the company. Product service criteria have been removed because it is not being done inside the company.

V. Case company

The case study has been conducted in the XYZ Horn Industries limited, Coimbatore city of India. The company is leading horn manufacturer in India. It produces 16 major varieties of horns. The company has one press shop and two assembling units. Each of the assembling unit has separate dedicated QA team. All the required parts like Diaphragm, Tone disc, point plate, clamp etc are produced within the company. The company has already started implementing the lean manufacturing techniques like 5S, Kaizen, TQM. We are assessing how far the implementation is successful.

VI. Selection of the Linguistic variable scale to measure the importance weight and performance rate of the attributes developed

The linguistic variables have been used to measure the importance weight and performance rate of the attributes, as they get rid of vagueness and impreciseness of the data captured from the experts as these attributes are difficult to measure them qualitatively. The linguistic scale which used by Vinodh [1] has been made use in this research. For acquiring the importance weight by experts the linguistic variables {very low (VL), low (L), fairly low (FL), medium (M), fairly high (FH), high (H), very high (VH)} are used, and in the case of performance rating the linguistic variables {excellent (E), very good (VG), good (G), fair (F), poor (P), very poor (VP), worst (W)} are used. Many literature reviews showed the advantageof using fuzzy models for expressing precise data. [10-12]

VII. Measurement of the performance rating and importance weightage of lean attributes using linguistic terms

After the importance weightage scale and rating scale has been chosen, the experts and the mid-level managers of the branches provided with their ratings for the attributes developed in the conceptual model. The fuzzy set theory is made used to approximate the linguistic values to their respective fuzzy numbers. Then the relation of the linguistic terms and fuzzy numbers has been established and they are translated and depicts in Table 1.

Table 1. Fuzzy number used to approximate the linguistic variable

Linguistic variable for weightage	Fuzzy number	Linguistic variable for performance rate	Fuzzy number
Very low (VL)	(0, 0.05, 0.15)	Worst (W)	(0, 0.5, 1.5)
Low (L)	(0.1, 0.2, 0.3)	Very poor (VP)	(1, 2, 3)

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Fairly Low (FL)	(0.2, 0.35, 0.5)	Poor (P)	(2, 3.5, 5)
Medium (M)	(0.3, 0.5, 0.7)	Fair (F)	(3, 5, 7)
Fairly High (FH)	(0.5, 0.65, 0.8)	Good (G)	(5, 6.5, 8)
High (H)	(0.7, 0.8, 0.9)	Very good (VG)	(7, 8, 9)
Very high (VH)	(0.85, 0.95, 1)	Excellent (E)	(8.5, 9.5, 10)

Table 2. Conceptual model for leanness assessment

Leanness Enabler	**Leanness Criteria**	**Leanness Attributes**
Management responsibility (LC1)	Organizational structure (LC11)	Smooth informational flow (LC111)
		Team management for decision making (LC112)
		Interchange-ability of personnel (LC113)
	Nature of management (LC12)	Clearly known management goals (LC121)
		Management involvement (LC122)
		Transparency in information sharing (LC123)
Manufacturing management leanness (LC2)	Customer response adaptation (LC21)	Prevalence of continuous improvement culture (LC211)
		Empowerment of personnel to resolve customer problem (LC212)
	Change in business and technical processes (LC22)	Employee's attitude tuned to accept the changes (LC221)
	JIT flow (LC23)	Conduct of pilot study on new (LC222)
		Produce small lot size (LC231)
		JIT delivery to customers (LC232)
	Pull production (LC24)a	Optimization of processing sequence and flow in shop floor (LC233)
		Demand driven production (LC241)
		Limited WIP inventory (LC242)
	Supplier Development (LC25)	Minimal equipment idle time (LC243)
		Providing technological assistance to the suppliers (LC251)
		Providing training in quality issues to the supplier personnel (LC252)
	Streamlining of processes (LC26)	Providing financial assistance to the suppliers (LC253)
		Adoption of value stream mapping (LC261)
	Cellular Manufacturing (LC27)	Quantification of seven deadly wastes (LC262)
		Focused factory production system (LC271)
		Organization of manufacturing operation around similar product (LC272)
	Continuous improvement (LC28)	Utilization of manufacturing cells (LC273)
		Mission driven strategy (LC281)
		Positive attitude of employees (LC281)
	Waste quantification (LC29)	Inclusion of employees suggestion scheme (LC283)
		Identification of wastes (LC291)
	Activity categorization (LC210)	Scope for waste elimination (LC292)
		Classification of activities (LC2101) Conversion of non-value added (NVA) non-value added (NNVA) (LC2102)
Work force leanness (LC3)	Employee status (LC31)	Flexible workforce to adapt the adaptation of new technologies (LC311)
		Multi-skilled personnel (LC312)

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	Employee status (LC31)	Implementation of job rotation system (LC313)
		Strong employee sprit and cooperation (LC321)
		Employee empowerment (LC322)
Technology leanness (LC4)	Manufacturing set-ups (LC41)	Flexible set-ups (LC411)
		Less time to changing machine set-ups (LC412)
		Usage of automated tools used to enhance the production (LC413)
	Maintenance management (LC42)	Activity policy to help and keep work areas clean and uncluttered (LC414)
		Identification and prioritization of critical machines (LC421)a [22]
		Implementation of TPM techniques (LC422)
	Visual controls (LC43)	Maintenance of installed machine (LC423)
		Implementation of Poka-Yoke (LC431)
		Using ANDON device (LC432)
		Usage of DFMA principles (LC441)
		Practice job rotation between design and manufacturing engineering (LC442)
	In-house technology (LC44)	New way of coordination of design and manufacturing issues (LC444)
		Design and development of proprietary items for own use (LC451)
		Improve present equipment before considering new equipment (LC452)
	Production methodology (LC45)	Develop dedicated technologies for specific product use (LC453)
		Management interest towards investment on FMS concepts (LC461)
		Application of lean manufacturing principles for waste elimination (LC462)
	Workplace organization (LC46)	It application to exercise better vendor and supplier management (LC463)
		Elimination of unnecessary tools (LC464)
		Sustainability of improvements (LC465)
	Manufacturing planning (LC47)	Proper allocation of tools (LC66)
		Utilization of advanced MRP II systems (LC471)
		Execution of short range planning (LC472)
		Company procurement policy based on time schedule (LC473) Strategic network in SCM to exercise zero inventory system (LC474)
Manufacturing strategy leanness (LC)	Standardization, systematization and simplification (LC51)a	
		Standardization of components (LC511)
		Systematization of processes (LC512)
	Status of quality (LC52)	Simplification of processes (LC513)
	Status of productivity (LC53)	Products exceeding the customers expectation (LC521)
		Productivity linked to the personnel prosperity (LC531)
		Reduction of non-value adding cost (LC532)
		Quality in not infused at the cost of productivity (LC533)
	Cost management (LC54)	Application of totality concepts in achieving productivity (LC534)
		Kaizen method of product pricing (LC541)

	Time management (LC55)	Costing system focusing on the identification of value adding and Non-value adding activities (LC542)
		Scheduled activities (LC551)
	Resource utilization (LC56)	IT-based communication system (LC552)
		Planning of resources (LC561)
	Flexible business practices (LC57)	Utilization of optimization tools (LC562)
		Retrofitting of machine tools (LC571)
		Exploration of machine tool automationa (LC572)
		Flexibility in layout (LC573)

VIII. Determination of FLI

The fuzzy lean index (FLI) represents the leanness level of the organization. The calculation for the fuzzy index starts at the attributes level and end at the enabler level thus scaling down to the triangular fuzzy value which helps in finding the precise leanness value. At the attributes level there are several lean attributes and from it which the primary assessment is done. The weightages set by the management for first 2 enablers is depicted in Table 3.

Primary assessment:
The formula used for the primary assessment calculation is as follows.

$$LC_{ij} = \sum_{k=1}^{n}\left(W_{ijk} \times R_{ijk}\right) \Big/ \sum_{k=1}^{n} W_{ijk} \qquad (1)$$

LC_{ij} Lean capabilities of jth criterion in ith enabler
W_{ijk} Importance weight of k^{th} attribute in j^{th} criterion in ith enabler
R_{ijk} Performance rating of k^{th} attribute in j^{th} criterion in ith enabler
Using this primary assessment calculation the fuzzy index for the second stage criteria has been found. Then they have been extended to find fuzzy index for all the developed criteria in the second stage. For the corressponding ratings in Table 3, fuzzy number is set for assessment. Table 4 captures the fuzzy numbers for the first 2 enablers for both weightages and performance ratings.

The model calculation for the criteria one 'Organizational Structure' is been calculated and shown below:
LC_{11} – Lean level of first criteria of the first enabler

$$CS_{11} = \begin{bmatrix} (5,6.5,8)\otimes(0.42,0.59,0.76)\oplus \\ (5.4,6.2,8.4)\otimes(0.32,0.5,0.68)\oplus \\ (3.8,5.6,7.4)\otimes(0.24,0.41,0.58) \end{bmatrix} \Big/ \begin{bmatrix} (0.42,0.59,0.76)\oplus \\ (0.32,0.5,0.68)\oplus \\ (0.24,0.41,0.58) \end{bmatrix}$$

LC_{11} = (4.8, 6.3, 7.8)
Secondary assessment:
In the case of the secondary assessment by making use of the equation (2):

$$LS_i = \sum_{j=1}^{n}\left(W_{ij} \times R_{ij}\right) \Big/ \sum_{j=1}^{n} W_{ij} \qquad (2)$$

LS_i Lean capabilities of i^{th} enabler
W_{ij} Importance weight of j^{th} criterion in i^{th} enabler
R_{ij} Performance rating of j^{th} criterion in i^{th} enabler
The model calculation for the criteria one 'Management Responsibility' is been calculated and shown below:
LC_1 – Lean level of the first enabler

$$CS_1 = \begin{bmatrix} (4.8,6.3,7.8)\otimes(0.58,0.71,0.84)\oplus \\ (3.7,4.8,5.9)\otimes(0.5,0.65,0.8) \end{bmatrix} \Big/ \begin{bmatrix} (0.58,0.71,0.84)\oplus \\ (0.5,0.65,0.8) \end{bmatrix}$$

LC_1 = (4.3, 5.6, 6.9)

Table 3: Aggregated weights and performance rating of leanness attributes of first two enabler

LC_i	***LC_{ij}***	***LC_{ijk}***	***W_i***	***W_{ij}***	***W_{ijk}***	***R_{ijk}***
LC1	LC_{11}	LC_{111}	FH	FH	FH	F
		LC_{112}			M	G
		LC_{113}			FL	F
	LC_{12}	LC_{121}		M	FH	F
		LC_{122}			H	VG
		LC_{123}			FL	G
	LC_{21}	LC_{211}		FH	H	G
		LC_{212}			M	F
LC2	LC_{22}	LC_{221}	H	M	FH	P
		LC_{222}			FH	F
	LC_{23}	LC_{231}		H	M	G
		LC_{232}			M	F

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		LC_{233}			FH	F
	LC_{24}	LC_{241}		M	M	F
		LC_{242}			FH	F
		LC_{243}			FH	F
	LC_{25}	LC_{251}		FH	FH	F
		LC_{252}			FH	F
		LC_{253}			FL	P

Table 4: Fuzzy Numbers Matched With Linguistic Variables For First Two Enablers

LC_i	***LC_{ij}***	***LC_{ijk}***	***W_i***			***W_{ij}***			***W_{ijk}***			***R_{ijk}***		
LC1	*LC_{11}*	LC_{111}	0.5	0.65	0.8	0.5	0.65	0.8	0.5	0.65	0.8	3	5	7
		LC_{112}							0.3	0.5	0.7	5	6.5	8
		LC_{113}							0.2	0.35	0.5	3	5	7
	LC_{12}	LC_{121}				0.3	0.5	0.7	0.5	0.65	0.8	3	5	7
		LC_{122}							0.7	0.8	0.9	7	8	9
		LC_{123}							0.2	0.35	0.5	5	6.5	8
	LC_{21}	LC_{211}				0.5	0.65	0.8	0.7	0.8	0.9	5	6.5	8
		LC_{212}							0.3	0.5	0.7	3	5	7
LC2	LC_{22}	LC_{221}	0.7	0.8	0.9	0.3	0.5	0.7	0.5	0.65	0.8	2	3.5	5
		LC_{222}							0.5	0.65	0.8	3	5	7
	LC_{23}	LC_{231}				0.7	0.8	0.9	0.3	0.5	0.7	5	6.5	8
		LC_{232}							0.3	0.5	0.7	3	5	7
		LC_{233}							0.5	0.65	0.8	3	5	7
	LC_{24}	LC_{241}				0.3	0.5	0.7	0.3	0.5	0.7	3	5	7
		LC_{242}							0.5	0.65	0.8	3	5	7
		LC_{243}							0.7	0.5	0.65	5	6.5	8
	LC_{25}	LC_{251}				0.5	0.65	0.8	0.5	0.65	0.8	3	5	7

Tertiary assessment:

Since the lean capabilities of the attributes, criteria and enablers has been found in the previous calculations, with that data the Fuzzy Lean Index has been calculated by making use of the formula (3), which states the overall leanness level of the organization.

$$FLI = \sum_{i=1}^{N} \frac{R_i \times W_i}{W_i} \qquad (3)$$

R_i Performance index of lean capabilities
W_i Importance weightage of lean capabilities
The calculation is as follows:

$$FLI = \begin{bmatrix} (4.3,5.6,6.9) \otimes (0.48,\ 0.58,\ 0.68) \oplus \\ (3.7,5.4,7.2) \otimes (0.5,\ 0.65,\ 0.8) \oplus \\ (3.4,5.3,7.1) \otimes (0.58,\ 0.71, 0.84) \oplus \\ (4.8,6.3,7.8) \otimes (0.5,\ 0.65,\ 0.8) \oplus \\ (4.4,6.0,7.7) \otimes (0.38,\ 0.56,\ 0.74) \end{bmatrix} \Bigg/ \begin{bmatrix} (0.48,\ 0.58,\ 0.68)) \oplus \\ (0.5,\ 0.65,\ 0.8) \oplus \\ (0.58,\ 0.71, 0.84) \oplus \\ (0.5,\ 0.65,\ 0.8) \oplus \\ (0.38,\ 0.56,\ 0.74) \end{bmatrix}$$

FLI = (4.1, 5.7, 7.3)

Figure 2 explains where the company that is under study fits in the leanness curve. The company is currently fits in Lean to Very Lean stage, which is typically good for a manufacturing company. Still, the company should work towards in moving towards the Enhanced Lean stage.

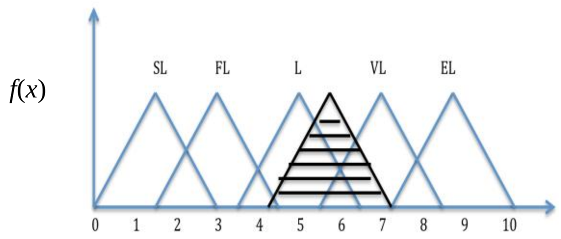

Figure 2. Leanness Index Curve

Ranking Score – (a+4b+c)/6

Ranking score (4.1+4(5.7)+7.3)/6

The ranking score for the reaming attributes are calculated using above principle. To identify the few critical obstacles, scale three was set as the management threshold to distinguish which critical obstacles need to be improved.

After the calculation some of the weaker attributes are captured and analyzed. The attributes are shown to the experts for further discussions. Some of the suggestions are also made for improving the weaker attributes. The weaker attributes and corresponding improvement methods are shown in Table 5.

Table 5. Identified weaker attributes and improvement methods

Weaker attributes	Improvement methods
Nature of Management	Move towards
Providing technological assistance to the suppliers	Conduct of regular meetings
Employee involvement	Encourage inputs from employees
Classification of activities	Activity management
Conversion of NVA into NNVA	Activity analysis
Products exceeding the customers expectation	New Product Development Analysis

IX. Results and Discussion

Here the minimum distance has been taken and matched with the linguistic label, found that the leanness index is Fairly Lean. Since the leanness level of the organization has been found now the obstacles for the lean performance is to be found through the fuzzy performance index.

Identification of obstacle for improvement

The fuzzy performance index (FPI) is helps to finding and evaluating the obstacles through this analysis. The FPI combines the performance rating and importance weights of the each attributes that helps in finding the leanness capability that affect the overall leanness level of the organization and the performance are found. The higher the FPI the higher the contribution to the leanness level of the organization. The following formulae is used to find the FPI for each attribute.

$$FPI_{ijk} = W'_{ijk} \otimes R_{ijk} \qquad (5)$$

FPI_{ijk} FPI for ijkth attribute

W'_{ijk} Complement of ijkth attribute's importance weight

Where $W'_{ijk} = [(1,1,1) - W_{ijk}]$, W_{ijk} is the fuzzy importance weight of the leanness element capability *ijk*.

Since the obtained FPI value is composed of the fuzzy number and that doesn't define the real number so the FPI must be ranked to find the obstacles. The centroid method which has the membership function (x,y,z) is used to rank the fuzzy number obtained. The formula for this ranking score is provided below.

$$\text{Ranking score} = (x+4y+z)/6 \qquad (6)$$

The ranking score for the all the attributes developed is found using the formula (6). The management threshold is set as 0.8 in the scale and we found that 10 attributes are performing below the management threshold and these are identified as the critical obstacles that need improvement. The identified attributes that shows lower performance and needs improvement are listed below

1. Capturing and sharing tacit knowledge
2. Empowerment of personnel to resolve customer problem
3. Promote idea of continuous improvement in the organizational culture
4. Usage of formal improvement project teams for organization wide issues
5. Best practices through benchmarking
6. Planning of resources
7. Utilization of optimization tools
8. Conduct of survey/studies to ensure quality status

Managerial Implications

From the undertaken analysis leanness level, stronger areas in which the company has been performing good and weaker areas for improvement has been found. The weaker areas are the obstacles that are deteriorating the leanness level of the organization. Therefore efforts and actions ought to be taken to boost these weaker areas, as an example to manage the organization performance efficiently the resources should be planned to perfection and the very low score yield of all the weaker areas, 'capturing and sharing tacit knowledge' issue ought to be addressed with most importance has its helps in improving the process and disseminating implied process information to the new worker or novice. Since this lean measurement is simple, straightforward and provides efficient result they are to be made use to get the periodic assessment done for improvement, also this enables the decision makers to make appropriate decisions to boost the organization performance and sustain the competition.

X. Conclusion

Lean manufacturing helps in implementing the lean practices in an organization to boost the efficiency in the company. This research helped in identifying the leanness level of the horn manufacturing organization by incorporating the concept of lean enablers as an instrument for assessment. To abide the traditional measurement techniques here during this analysis, fuzzy logic based computation method is used to keep away

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vagueness and impreciseness of the ratings obtained. The ratings were obtained from the executives and mid-level managers of the company for which analysis was carried out and found that the company was performing in the range of 'lean to very lean'. Besides that the fuzzy performance index was calculated which helped in identifying the obstacles for improvement, thus the measures should to be taken to boost this weaker areas to improve the performance of the company. In case of this research the developed conceptual model is limited to the major perspectives of the production, which can be further extended to have more practical relevance. The research objective was restricted to a selected manufacturing organization, they can be further extended for comparison of the similar organization to enhance the effectiveness of the model to direct to further tweaking of limitations.

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