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Leanness assessment using multi-grade fuzzy approach

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The manufacturing organisations have been witnessing a transition from mass manufacturing to lean manufacturing. Lean operations are characterised by the elimination of obvious wastes occurring in the manufacturing process, thereby facilitating cost reduction. This paper reports a research carried out to assess the leanness of an organisation using multi-grade fuzzy approach. During this research, a leanness measurement model incorporated with multi-grade fuzzy approach was designed. This is followed by the substitution of the data gathered from a manufacturing organisation. After the computation of leanness index, the areas for leanness improvement have been identified. The approach contributed in this project could be used as a test kit for periodically evaluating an organisation's leanness.

Keywords: lean manufacturing; leanness assessment; fuzzy methods; leanness index

1. Introduction

The contemporary manufacturing organisations have been witnessing a transformation in the manufacturing paradigm (Chen *et al.* 2006). The manufacturing era started with craft manufacturing. Then emerged the mass manufacturing era where manufacturing systems repetitively produced same components in large quantities. This is followed by the emergence of lean manufacturing where the focus is on waste elimination thereby achieving cost reduction (Muda and Hendry 2002, Lummus *et al.* 2006). Lean operations are characterised by the elimination of wastes occurring in the manufacturing process, thereby facilitating cost reduction (Serrano *et al.* 2008). There are seven types of wastes prone to occur in any manufacturing process. The seven wastes include overproduction, waiting, transport, inappropriate processing, unnecessary inventory, unnecessary motion and defects (Hines and Rich 1997, Modarress *et al.* 2005). More recently the underutilisation of employees is considered as the eighth waste. Lean manufacturing has been defined as an integrated manufacturing system intended to maximise capacity, reutilisation and minimise buffer inventories through the minimisation of system variability. Some of the enabling techniques of lean manufacturing include total quality management (TQM), total productive maintenance (TPM), Kaizen, Kanban, single minute exchange of dies (SMED) and value stream mapping (VSM) (Doolen and Hacker 2005, Abdulmalek and Rajgopal 2007, Lian and Van Landeghem 2007).

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The performance measure of lean practices is leanness. Leanness is a measure that is focused on re-utilising lesser input to better achieve the goals of organisation so as to achieve better output (Bayou and De-korvin 2008). Input refers to the physical quantity of resources used and their costs. Output refers to the quality and quantity of products sold and the corresponding customer services. The measurement of leanness gains importance as it is an indicator of lean performance of the organisation. Few researchers have contributed the approaches for measuring leanness. A conceptual model for leanness measurement has been developed from the literature review. The ratings of the experts have been gathered for performing the leanness measurement. Multi-grade fuzzy approach has been used for computation of leanness (Yang and Li 2002). After the computation of leanness, improvement areas have been identified. The results of validation indicated that the multi-grade fuzzy approach for measuring leanness is practically feasible.

2. Literature review

The literature has been reviewed from the perspective of lean manufacturing and its assessment and fuzzy logic.

2.1 *Literature review on lean manufacturing and assessment*

Lean principles have been originated from Toyota's production system known as just in time (JIT) production (Tang *et al.* 2005, Pil and Fujimoto 2007). The term lean has become widespread after the publication of a book titled *The machine that changed the world*. Then the term lean production was widely used. Mason-Jones *et al.* (2000) have matched various strategies of supply chain with product type. They have introduced a 'leagile' approach which determines the decoupling point between lean and agile paradigms in a supply chain. Sullivan *et al.* (2002) have presented the performance of equipment replacement decision problems within the context of lean manufacturing. They utilised VSM as a road map for providing necessary information for the analysis of equipment replacement decision problem in lean manufacturing implementation. Muda and Hendry (2002) have proposed a world class manufacturing concept incorporated with lean principles for the make-to-order sector. Pavnaskar *et al.* (2003) have presented a classification scheme for lean manufacturing tools. They have suggested that their classifications scheme enables companies to become lean and serve as a foundation for research into lean concepts. Many researchers have contributed to the definition of lean manufacturing. Shah and Ward (2003) have provided a comprehensive definition of lean production which is an integrated socio-technical system whose objective is to eliminate waste by reducing and minimising the supplier, customer and internal variability. The tools and techniques of lean manufacturing include TQM, TPM, Kanban, Kaizen, SMED, Poka-Yoke, and visual control, etc. Houshmand and Jamshidnezhad (2006) have presented an extended model of design process of lean production system by means of process variables. They have used axiomatic design theory for developing hierarchical structure to model a design process of lean production system composed of functional requirements, design parameters and process variables. Braglia *et al.* (2006) have presented a new approach for a complex production system based on seven iterative steps associated with typical industrial engineering tools including VSM. Shah and Ward (2007) have defined the measures of lean production. They have mapped the various conceptual measures of lean manufacturing. Some of the measures of lean production include; setup time reduction, simplicity in product design, adherence to daily schedule, customer focus, work force management, etc. Detty and Yingling (2000) have attempted to quantify the benefits of implementing lean manufacturing at an assembly operation using simulation based approach. Lander and Liker (2007) have presented a case example of a low volume, highly customised artistic clay tile company which has utilised a Toyota Production System (TPS) approach for creating highly customised products. Black (2007) has presented design rules for implementing the principles of TPS.

Rivera and Chen (2007) have measured the impact of lean tools on the cost-time investment of a product using a cost-time profile. They have proposed a cost-time profile as a useful tool for the evaluation of improvements achieved by the implementation of lean tools and techniques. Narasimhan *et al.* (2006) have presented the empirical investigation of disentangling leanness and agility. Some of the performance dimensions of leanness include: conformance quality, delivery reliability, low buffering cost, efficiency, product mix flexibility, etc. Bayou and De-korvin (2008) have shown that manufacturing leanness has seven characteristics, such as relative, dynamic, long term, fuzzy logical, objective, integrating and comprehensive. They have used fuzzy logic approach for measuring leanness. They have compared the production leanness of the Ford Motor Company and General Motors, selecting Honda Motor Company as a benchmarking firm. They have proved that the Ford Motor system is 17% leaner than the General Motors system through the benchmarked system.

2.2 *Literature review on fuzzy logic*

The fuzzy logic approach is based on human logic and takes advantage of conceptual knowledge without boundaries. Some of the concepts of fuzzy logic include fuzzy set, linguistic variables, probability distribution and fuzzy if then rules. Most of the researches in qualitative environment suffer from vagueness, in which case data may not be expressed as exact numbers (Yang and Li 2002). Linguistic assessment is recommended instead of numerical values (Beach *et al.* 2000). The proper selection of linguistic variables is more important. The expression of the experts needs to be determined using fuzzy numbers and membership functions. In order to overcome the ambiguity associated with this assessment, triangular and trapezoidal membership functions are recommended (Delgado *et al.* 1993). The membership functions are used for transforming the linguistic variables into fuzzy numbers (Singh *et al.* 2006). Some of the applications include supplier selection, decision making in complex situations, etc.

Based on the literature review, it has been found that few researchers have contributed certain approaches for leanness assessment. Many of the approaches have not been validated in the industrial scenario. The models used in those projects have not been fully supported with literature. In this context, the objective of this paper is to report a project in which the conceptual model has been derived from literature and the model has to be practically validated in the industry scenario.

3. Research methodology

The methodology followed during this research project is shown in Figure 1.

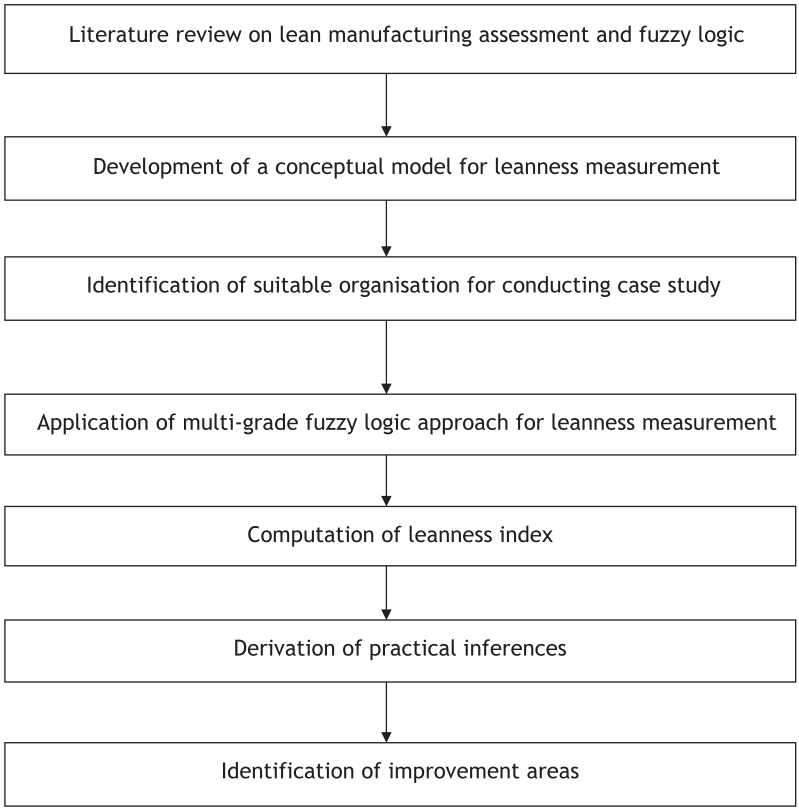

Figure 1. Research methodology.

The project begins with the literature review on lean manufacturing assessment and fuzzy logic. Then a conceptual model for leanness measurement has been developed. This is followed by the identification of a suitable manufacturing organisation for the conduct of case study. Then a multi-grade fuzzy approach for leanness measurement was applied, the leanness index was computed and the practical inferences were derived. The results were then validated. This was followed by the identification of areas for leanness improvement.

4. Development of conceptual model

The leanness measurement system has been designed by referring to the literature. The measurement system is shown in Table 1.

The system consists of three levels. The first level consists of five leanness enablers; the second level consists of 20 lean criteria; and the third level consists of several lean attributes. The leanness measurement system is comprehensive as it reviews leanness from various perspectives. As a sample, the management responsibility enabler has been explained. The two major perspectives of management responsibility are organisational structure and nature of management which forms the criteria. The organisational structure

Table 1. Conceptual model for leanness measurement.

S. no.	Enabler	Criteria	Attributes
1	Management responsibility leanness	Organisational structure	• Smooth information flow • Team management for decision making • Interchange-ability of personnel
		Nature of management	• Clearly known management goal • Management involvement • Transparency in information sharing
2	Manufacturing management leanness	Customer response adoption	• Prevalence of continuous improvement culture • Empowerment of personnel to resolve customer problems
		Change in business and technical processes	• Employee's attitude tuned to accept the changes • Conduct of pilot study on new • Production/business processes
		JIT flow	• Pull production system • Produce small lot sizes • JIT delivery to customers • Optimisation of processing sequence and flow in shop floor
		Supplier development	• Providing technological assistance to the suppliers • Providing training in quality issues to the supplier personnel • Providing financial assistance to the suppliers
		Streamlining of processes	• Adoption of value stream mapping • Quantification of seven deadly wastes
		Cellular manufacturing	• Focused factory production system • Organisation of manufacturing operations around similar product families • Utilisation of manufacturing cells
3	Workforce leanness	Employee status	• Flexible workforce to accept the adoption of new technologies • Multi-skilled personnel • Implementation of job rotation system
		Employee involvement	• Strong employee spirit and cooperation • Employee empowerment
4	Technology leanness	Manufacturing set-ups	• Flexible set-ups • Less time for changing the machine set-ups • Usage of automated tools used to enhance the production • Active policy to help keep work areas clean, tidy and uncluttered

(*continued*)

Table 1. Continued.

S. no.	Enabler	Criteria	Attributes
		Product service	• Products designed for easy serviceability • Service centres well equipped with spares
		Integrated product design	• Usage of DFMA principles • Practice job rotation between design and manufacturing engineering • Usage of product data management (PDM) systems • New ways of coordination of design and manufacturing issues
		In-house technology	• Design and development of proprietary items for own use • Improve present equipment before considering new equipment • Develop dedicated technologies for specific product use
		Production methodology	• Management's interest towards investment on FMS concepts • Application of lean manufacturing principles for waste elimination • IT application to exercise better vendor and supplier management
		Manufacturing planning	• Utilisation of advanced MRPII systems • Usage of ERP systems • Execution of short range planning; • Company's procurement policy based on time schedule • Strategic network in SCM to exercise zero inventory system.
5	Manufacturing strategy leanness	Status of quality	• Products exceeding the customers expectations • Conduct of survey/studies to ensure quality status • Usage of TQM tools
		Status of productivity	• Productivity linked to the personnel prosperity • Reduction of non value-adding costs • Quality is not infused at the cost of productivity; • Application of totality concepts in achieving productivity
		Cost management	• Kaizen method of product pricing • Costing system focusing on the identification of value adding and non-value adding activities
		Time management	• Scheduled activities • IT based communication system

criteria consist of attributes such as smooth information flow, team management for decision making and inter-changeability of personnel. The nature of management criteria consists of clearly known management objectives, management involvement, and transparent information sharing.

5. Case study

5.1 *About case company*

The case study has been carried out in an Indian electronics manufacturer located in Coimbatore, India (hereafter referred to as ABC). ABC manufactures cam-operated rotary switches, relays, starters and modular switches. ABC has implemented ISO 9001:2000 Quality Management System, ISO 14001 Environmental Management System, and is an organisation aspiring to attain world class status.

5.2 *Assessment of leanness using fuzzy logic*

The leanness index of an organisation is represented by I. It is the product of overall assessment factor R and overall weight W. The equation for leanness index is given by

$$I = W \times R.$$

The assessment has been divided into five grades since every leanness factor involves fuzzy determination. $I = \{10, 8, 6, 4, 2\}$ (8–10 represents 'extremely lean', 6–8 represents 'lean', 4–6 represents 'generally lean', 2–4 represents 'not lean' and less than 2 represents 'extremely not lean'). Five experts participated in a discussion session for leanness assessment. Table 2 shows the single factor assessment and weights provided by experts.

5.2.1 *Primary assessment calculation*

The calculation pertaining to 'organisational structure' criterion is shown as follows:

Weights pertaining to 'organisational structure' criterion $W_{11} = (0.3, 0.4, 0.3)$
Assessment vector pertaining to 'organisational structure' criterion is given by

$$R_{11} = \begin{bmatrix} 8 & 7 & 8 & 7 \\ 9 & 8 & 8 & 9 \\ 7 & 8 & 6 & 7 \end{bmatrix}$$

Index pertaining to 'organisational structure' criterion is given by

$$I_{11} = W_{11} \times R_{11}$$
$$I_{11} = (8.1, 7.7, 7.4, 7.8).$$

Using the same principle, the index pertaining to various lean criteria have been derived

$$I_{12} = (7.4, 7, 6.9, 7.6)$$
$$I_{21} = (7, 8, 8.5, 7.5)$$
$$I_{22} = (6.5, 6.5, 6.5, 7.5)$$
$$I_{23} = (5.9, 6.1, 5.8, 6.2)$$

Table 2. Single factor assessment and weights provided by experts.

I_i	I_{ij}	I_{ijk}	E_1	E_2	E_3	E_4	W_{ij}	W_i	W
I_1	I_{11}	I_{111}	8	7	8	7	0.3	0.5	0.3
		I_{112}	9	8	8	9	0.4		
		I_{113}	7	8	6	7	0.3		
	I_{12}	I_{121}	8	7	8	8	0.3	0.5	
		I_{122}	8	7	6	7	0.4		
		I_{123}	6	7	7	8	0.3		
I_2	I_{21}	I_{211}	7	8	8	7	0.5	0.15	0.3
		I_{212}	7	8	9	8	0.5		
	I_{22}	I_{221}	6	7	7	8	0.5	0.3	
		I_{222}	7	6	6	7	0.5		
	I_{23}	I_{231}	6	7	7	6	0.3	0.1	
		I_{232}	7	6	6	7	0.2		
		I_{233}	5	6	5	6	0.3		
		I_{234}	6	5	5	6	0.2		
	I_{24}	I_{241}	7	8	8	7	0.3	0.1	
		I_{242}	8	6	7	6	0.3		
		I_{243}	7	6	7	6	0.4		
	I_{25}	I_{251}	5	5	6	5	0.6	0.2	
		I_{252}	4	5	5	4	0.4		
	I_{26}	I_{261}	6	5	4	5	0.4	0.15	
		I_{262}	5	6	6	5	0.3		
		I_{263}	6	7	6	7	0.3		
I_3	I_{31}	I_{311}	5	6	6	5	0.4	0.5	0.15
		I_{312}	6	5	5	6	0.3		
		I_{313}	5	6	6	5	0.3		
	I_{32}	I_{321}	8	9	9	8	0.5	0.5	
		I_{322}	7	8	8	7	0.5		
I_4	I_{41}	I_{411}	6	7	7	6	0.4	0.2	0.1
		I_{412}	8	7	7	8	0.2		
		I_{413}	8	7	7	9	0.2		
		I_{414}	7	6	6	5	0.2		
	I_{42}	I_{421}	7	6	5	6	0.4	0.1	
		I_{422}	8	7	6	5	0.6		
	I_{43}	I_{431}	7	8	8	7	0.3	0.2	
		I_{432}	8	7	6	5	0.2		
		I_{433}	5	4	4	5	0.3		
		I_{434}	6	7	7	6	0.2		
	I_{44}	I_{441}	6	7	7	6	0.3	0.1	
		I_{442}	8	7	7	9	0.4		
		I_{443}	5	6	8	7	0.3		
	I_{45}	I_{451}	5	6	6	5	0.2	0.2	
		I_{452}	7	6	6	7	0.5		
		I_{453}	8	7	6	7	0.3		
	I_{46}	I_{461}	8	8	7	6	0.2	0.2	
		I_{462}	6	5	5	6	0.2		
		I_{463}	5	7	7	6	0.2		
		I_{464}	6	7	7	8	0.2		
		I_{465}	8	7	7	6	0.2		

(*continued*)

Table 2. Continued.

I_i	I_{ij}	I_{ijk}	E_1	E_2	E_3	E_4	W_{ij}	W_i	W
I_5	I_{51}	I_{511}	7	6	6	7	0.3	0.3	0.15
		I_{512}	8	7	7	6	0.4		
		I_{513}	8	8	9	8	0.3		
	I_{52}	I_{521}	6	7	7	6	0.3	0.3	
		I_{522}	6	5	5	6	0.3		
		I_{523}	6	6	6	5	0.2		
		I_{524}	7	6	6	5	0.2		
	I_{53}	I_{531}	5	4	4	5	0.4	0.2	
		I_{532}	5	6	6	4	0.6		
	I_{54}	I_{541}	6	5	5	6	0.5	0.2	
		I_{542}	5	4	4	6	0.5		

$$I_{24} = (7.3, 6.6, 7.3, 6.3)$$
$$I_{25} = (4.6, 5.0, 5.6, 4.6)$$
$$I_{26} = (5.7, 5.9, 5.2, 5.6)$$
$$I_{31} = (5.3, 5.7, 5.7, 5.3)$$
$$I_{32} = (7.5, 8.5, 8.5, 7.5)$$
$$I_{41} = (7.2, 6.8, 6.8, 6.8)$$
$$I_{42} = (7.6, 6.6, 5.6, 5.4)$$
$$I_{43} = (6.4, 6.4, 6.2, 5.8)$$
$$I_{44} = (6.5, 6.7, 7.3, 7.5)$$
$$I_{45} = (6.9, 6.3, 6, 6.6)$$
$$I_{46} = (6.6, 6.8, 6.6, 6.4)$$
$$I_{51} = (7.7, 7, 7.3, 6.9)$$
$$I_{52} = (6.2, 6, 6, 5.6)$$
$$I_{53} = (5, 6, 5.2, 4.4)$$
$$I_{54} = (5.5, 4.5, 4.5, 6)$$

5.2.2 *Secondary assessment calculation*

The calculation pertaining to 'management responsibility leanness' enabler is given by:

$$I_1 = W_1 \times R_1$$

Weight pertaining to 'management responsibility leanness' enabler is given by:

$$W_1 = (0.5, 0.5).$$

Assessment vector pertaining to 'management responsibility leanness' enabler is given by:

$$R_1 = \begin{bmatrix} 8.1 & 7.7 & 7.4 & 7.8 \\ 7.4 & 7 & 6.9 & 7.6 \end{bmatrix}.$$

Index pertaining to 'management responsibility leanness' enabler is given by:

$$I_1 = W_1 \times R_1$$
$$I_1 = (7.75, 7.35, 7.15, 7.7).$$

Using the same principle, the following indices have been derived for remaining lean enablers.

$$I_2 = (6.095, 6.305, 6.435, 6.385)$$
$$I_3 = (6.4, 7.1, 7.1, 6.4)$$
$$I_4 = (6.83, 6.59, 6.41, 6.41)$$
$$I_5 = (6.27, 6, 5.93, 5.83).$$

5.2.3 *Tertiary assessment calculation*

The value of leanness index of ABC has been computed as follows:

Overall weight $W =$ (0.3, 0.3, 0.15, 0.1, 0.15).

$$\text{Overall assessment vector } R = \begin{bmatrix} 7.75 & 7.35 & 7.25 & 7.7 \\ 6.095 & 6.305 & 6.435 & 6.385 \\ 6.4 & 7.1 & 7.1 & 6.4 \\ 6.83 & 6.59 & 6.41 & 6.41 \\ 6.27 & 6 & 5.93 & 5.83 \end{bmatrix}$$

Leanness index $I = W \times R$

$$I = (12.2165, 6.7205, 6.671, 6.701)$$
$$I = \frac{1}{4}(12.2165 + 6.7205 + 6.671 + 6.701)$$
$$I = 8.07725 \in (8, 10).$$

6. Results and discussions

Based on the assessment of leanness, leanness index computed using multi-grade fuzzy approach for ABC is found to be 8.07. This indicates that ABC is a lean manufacturing organisation. The results very much coincided with practical environment as ABC has implemented strategies such as ISO 9001 QMS, ISO 14001 EMS and 5S; ABC is the process of Kaisen. To make ABC a world class organisation, scope still exists for improving the leanness of the organisation. Some of the areas identified for leanness improvement.

- Optimisation of processing sequence and flow in shop floor.
- JIT delivery to customers.
- Quantification of seven deadly wastes.
- Adoption of value stream mapping (VSM).
- Focused factory production system.
- Organisation of manufacturing operations around similar product families.

- Flexible workforce to accept the adoption of new technologies.
- Multi-skilled personnel.
- Usage of product data management (PDM) systems.
- Management's interest towards investment on FMS concepts.
- Usage of ERP systems.
- Reduction of non value-adding costs.
- Kaisen method of product pricing.
- Costing system focusing on the identification of value adding and non-value adding activities.
- IT based communication system.

After the conduct of the case study, the following changes have taken place in the organisation.

- The process sequence used for manufacturing electronic switches has been analysed for optimisation.
- Delivery to the customers has been incorporated with JIT principles.
- Efforts have been taken to quantify seven deadly wastes.
- The VSM has been adopted for streamlining the processes.
- Principles of group technology have been used for organisation of product families.
- Workforce has been trained to become flexible and multi-skilled.
- The installation of PDM systems is in progress.
- The material requirements planning process has been infused with ERP principles.
- Non value adding activities have been identified.
- Product pricing method has been modified using the Kaisen method.
- Manual communication has been transferred to IT driven systems.

6.1 *Practical validation of leanness assessment*

In order to practically explore the feasibility of multi-grade fuzzy approach for leanness measurement, a questionnaire has been designed for performing validation. The format of the questionnaire is shown in Figure 2.

The experts who participated in the validation section consisted of the department heads of design, manufacturing, quality control, machine shop and research and development. They possess rich expertise regarding the working culture of ABC.

The responses of the experts are presented in Table 3.

The analysis of responses of the experts indicated that the assessment of leanness using multi-grade fuzzy logic approach is practically feasible and adoptable.

6.2 *Statistical validation*

In order to further statistically analyse the feedback of the competent personnel, one sample *t*-test has been conducted to examine the acceptance of 'assessment of leanness using multi-grade fuzzy approach'. In the first case, the test value was given as 10 which mean that '100% of the opinions are in favour of successful assessment of leanness using multi-grade fuzzy approach in practice at 95% confidence interval'. The null hypothesis has not been satisfied in this case.

1. To what extent do you believe that the leanness measurement using multi-grade fuzzy logic approach is practically feasible in your organisation?

0	1	2	3	4	5	6	7	8	9	10

Not at all Partially Completely

2. To what extent do you believe that leanness measurement using multi-grade fuzzy logic approach is understandable by the employees of the organisation?

0	1	2	3	4	5	6	7	8	9	10

Not at all Partially Completely

3. To what extent do you believe that the leanness measurement using multi-grade fuzzy logic approach represents reality?

0	1	2	3	4	5	6	7	8	9	10

Not at all Partially Completely

Figure 2. Format of the questionnaire used for validation.

Table 3. Consolidated responses of the experts.

	Expert response					Average rating in Likert's scale of range 0–10
Question	E_1	E_2	E_3	E_4	E_5	
To what extent do you believe that the leanness measurement using multi-grade fuzzy logic approach is practically feasible in your organisation?	8	9	8	9	8	8.4
To what extent do you believe that leanness measurement using multi-grade fuzzy logic approach is understandable by the employees of the organisation?	7	8	9	9	8	8.2
To what extent do you believe that the leanness measurement using multi-grade fuzzy logic approach represents reality?	8	9	7	9	8	8.2

In the second case, the null hypothesis was set as '90% of the opinions are in favour of successful assessment of leanness using multi-grade fuzzy approach in practice at 95% confidence interval'. In this case, null hypothesis has been accepted. On the whole, this validation study indicated the feasibility assessment of leanness using multi-grade fuzzy approach in practice with the success rate of 90%.

6.3 *Managerial implications*

The managerial implications have been shown in Figure 3.

First, the exposure programme has to be shown to top management regarding leanness assessment. Then the management's approval has to be obtained to apply leanness

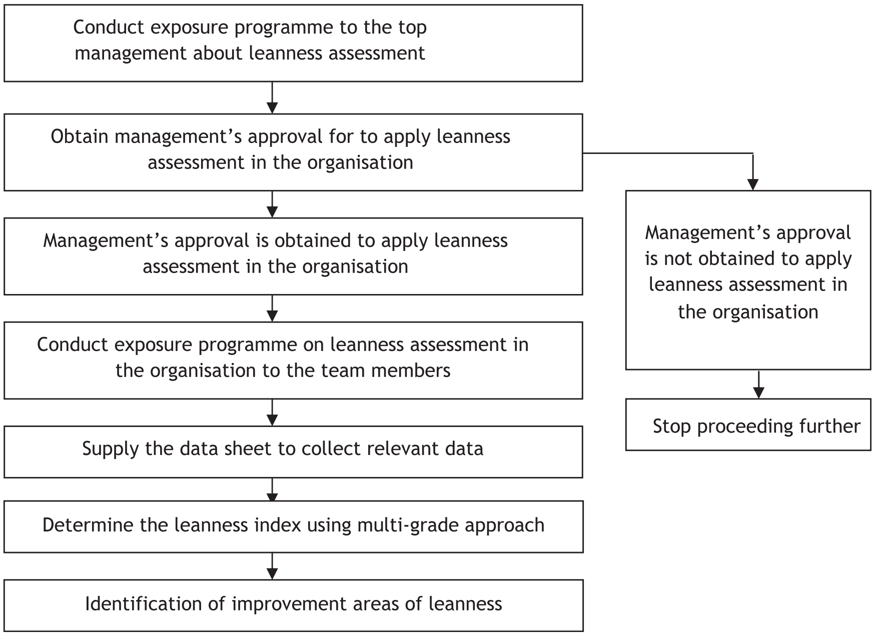

Figure 3. Managerial implications.

assessment in the organisation. If the management's approval is not obtained, the procedure has to be stopped. Then the exposure programme needs to be conducted to the team members. The data sheet has to be supplied to the team members to collect their ratings and weights. Then the leanness index needs to be computed using multi-grade fuzzy approach. This is followed by the identification of improvement areas of leanness.

7. Conclusions

Product complexity and market dynamism are the two decision variables responsible for the transformation of manufacturing paradigm. The manufacturing paradigm has been witnessing a shift from craft manufacturing to lean manufacturing. Lean manufacturing is characterised by low buffering cost, minimum processing time and high delivery speed (Barber and Tietje 2008). The assessment of manufacturing leanness gains vital importance. In this context, this paper reports a case study in which the leanness of a manufacturing organisation has been assessed using the developed conceptual model. The assessment results indicated that the organisation is lean. In order to still improve the leanness of the organisation, improvement areas have been identified. On improvement of the identified weak areas, the leanness of organisation could be improved which enables the organisation to attain world class status.

7.1 *Limitations and future research direction*

The case study has been carried out in a single manufacturing organisation using a multi-grade fuzzy approach for assessing leanness. In future, more case studies could be carried out for different manufacturing organisations across varied sectors thus improving the practical validity of the model.

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