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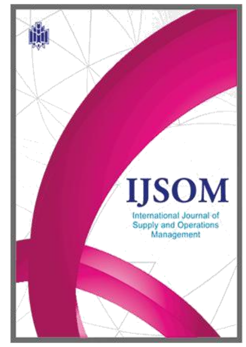

Assessment Lean Level in Manufacturing Enterprises Based on Fuzzy Multi-Criteria Decision Making (FMCDM) - Literature Review

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Abstract

In the current competitive environment and globalization, every organization is trying continuously to get better to stay competitive with their global rivals. So, most Manufacturing companies pursue to improve their productivity to meet the highly demanding business market by using effectively the resources, eliminating wastes, enhancement of process flow, and continuous improvement. There are many tools and strategies to improve productivity. Therefore, selecting appropriate strategies is an essential problem that faces most companies. Lean Manufacturing (LM) is a powerful system that improves efficiency, productivity, quality and reduces costs in any company. One of the reasons to fail the lean program's implementation is the lack of a clear understanding about what are lean performance and its evaluation. Lean level assessment can be considered a guide for the organization through their lean journey where it is the first step that led to the control and finally to improve the enterprise performances. Nowadays fuzzy Multicriteria Decision Making (FMCDM) can be considered one of the most efficient approaches to assess the lean performance level for any manufacturing enterprise to identify if the enterprise is near or far from the ideal implementation of the lean principles. The contributions of this review paper are; highlighting on Fuzzy Technique of order preferences by similarity to ideal solution(Fuzzy TOPSIS) and Fuzzy Multi criteria Optimization and compromise solution (FuzzyVIKOR) as distance-based methods for assessment the current lean performance for manufacturing enterprises and help them to improve continuously their performance ; review the most common lean assessment methods; highlighting lean dimensions and criteria that can be used in lean assessment by Fuzzy TOPSIS and Fuzzy VIKOR with illustrate the various criteria weighting methods. This review paper can be considered as a guide for researchers who interest in lean performance assessment that will fill some gaps in field of lean assessment level.

Keywords: Lean Assessment Methods; Lean Level; FMCDM; Fuzzy TOPSIS; Fuzzy VIKOR.

1. Introduction

Every organization is trying continuously to get better to stay competitive with their global rivals. The global competition has forced many manufacturing enterprises to corporate new productivity improvement strategies so; the manufacturing organizations pursue hard to improve their productivity to meet the highly demanding business market (Rajpurohit et al. 2017). The lean manufacturing (LM) philosophy and its various tools have been applied by many enterprises with different forms and names for improving the performance by reducing or if possible eliminating the various eight wastes and efficiently managing the resources(Leksic et al. 2020)(Al-baldawi et al. 2023).LM is a manufacturing system pioneered by Japanese engineers Taiichi Ohno and Shigeo Shingo as an alternative to the existing mass production system (Kumar et al. 2021). LM is 'lean' because compared with mass production; it uses less of everything - half the investment tools, half of human effort, half the manufacturing space, half the engineering

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hours to develop a new product in half time. Also, it requires maintaining less than half the needed inventory so this will produce a high quantity and variety of products with fewer defects (Wahab et al. 2013). lean can be defined as a continuous improvement philosophy that persuade to make enterprise more competitive and enhance their market position to stay competitive with the global rivals in the global markets by focusing on involvement all levels of enterprise in improvement practices for reducing or eliminating the eight types of wastes (the eight non –added value activities) throughout it by working as a team in improvement suggestions, problems solving, decisions making and other improvement practices to improve productivity, quality ,work environment and reduce cost in addition to lean polices that related to suppliers and customers that help to achieve these improvements. The idea of LM is to eliminate the most critical eight types of waste; Motion, Transportation, Inventory, Overproduction, Waiting, Over-processing, Defects and finally Skills (The underutilization of people and facilities) through the continuous improvements by involve all levels of enterprise in decision making and problem solving through implementation effectively lean practices and policies(also called lean tools, techniques or lean criteria) that represented the core of lean philosophy for improvement the performance of enterprise, lean practices and policies can be illustrated as follow(Scherrer-Rathje et al. 2009):-

- Lean practices is set of operational lean practices and tools that if it effectively used will eliminate the eight wastes, these practices are; Standardized work, Just-in-Time, Takt-time, Heijunka, 5S, Kanban (visual signal), Jidoka (autonomation/stop system), Total productive maintenance (TPM), Poka-Yoke (mistake proofing), Visual Control.
- Lean policies are a set of supporting activities that support lean practices in continuous improvement, these lean polices like; long-term relationship with customer, , co-operation and transparency across the supply chain, , , enhanced employee participation and enhanced problem-solving ability of employees,

Lean practices and policies both ar important for continuous eliminating waste throughout organization for increasing quality, improvements in productivity, reducing time and cost by eradicating non value added activities (Saini & Singh 2020) whereas evaluation of policies and practices on an ongoing basis helps organizations identify the potential opportunities for improvement. Lean production is described as manufacturing without waste where Waste is Processes or anything that does not add value to the final product or customer but adds cost to enterprise.

Lean Philosophy concept indicate to Lean Manufacturing, Lean Management, Lean Production or Lean Enterprise and it expressed as; a philosophy, a way, a set of principles, a set of techniques and tools, a practice, an approach, a concept, a program, a system, a manufacturing paradigm, or a model or effort to prevent and eliminate waste. Narpat Ram Sangwa(2015 indicate that lean manufacturing combines the best features of both mass and craft production(Narpat Ram Sangwa, Kailash Choudhary 2015). (Scherrer-Rathje et al. 2009), (Manea 2013)and (Alkhoraif et al. 2019) defined lean as an integrated socio-technical system that has the major objective is to eliminate waste by concurrently minimizing or reducing customer, supplier, and internal variability and it is adopted by many major enterprises around the world in trying to remain competitive in an increasingly globalized market.

The benefits of adopting LM as characterized by (Rajpurohit et al. 2017), reduction the customer complaints, waste reduction, improving quality, productivity and the overall competitiveness of the organization by the introduction of innovative practices, induction of good management practices, well-managed workplace, optimum utilization of resources (manpower, space, energy, material, etc.), continuous improvement culture, delivery improvement, improved knowledge management, increase reliability, and brand/reputation enhancement, Safer work environment, Improved employee morale, Problem elimination, Total company involvement, Faster delivery times.
It is important to assess continuously the progress and effectiveness of lean implementation using comprehensive and reliable performance assessment methods(Pakdil & Leonard 2014). Distance -based Methods Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (Fuzzy TOPSIS) and Fuzzy Multi criteria Optimization and compromise solution (FuzzyVIKOR) (fuzzy VIKOR) can be considered efficient methods to assess the current lean performance level to identify if the enterprise is near or far from the ideal implementation of the lean philosophy.

The motivation behind the use of Fuzzy TOPSIS and Fuzzy VIKOR to assess the lean performance level are their ability to handle the subjectivity and imprecision inherent in evaluating production systems and provide robust and reliable evaluation methods and provide a structured framework for decision-making.

The primary objectives to utilize Fuzzy TOPSIS and Fuzzy VIKOR are to provide a comprehensive and systematic assessment framework that addresses the complexities and uncertainties associated with performance assessment. This review serves many objectives by Highlighting on;

1- Efficient the distance based methods, Fuzzy TOPSIS and Fuzzy VIKOR to assess the current lean performance level where both methods provide a fuzzy-based decision-making framework that models and captures the subjectivity and uncertainty that associate with lean performance assessment.
2- The most common lean assessment methods with review the papers that addressing these assessment methods.
3- The lean practices or policies associated with each waste type that where it applied will be reduce or eliminate waste.
4- The essential lean dimensions and the most common lean practices and policies that consider as criteria whether subjective or objective criteria that can be used to assess lean level with one level or multi levels of criteria.
5- The most common weighting methods that can use to weight lean criteria to use it in assessment process using fuzzy TOPSIS or FuzzyVIKOR.

6- The differences and similarities in procedure of fuzzy TOPSIS and fuzzy VIKOR.

This review paper will fill a gap related using only Fuzzy TOPSIS only in lean assessment, possibility using various lean dimensions, criteria and weighting methods to weight lean criteria.

2. Criticism of Lean Concept

The implementation of lean is still lacking in developing a systematic approach. Many companies have failed in implementing lean successfully due to many reasons some of these related to lack understand and awareness of the benefits of lean, absence of a clear vision and plan about what the company want to achieve by lean, What is the problem that trying to solve it, absence or lack knowledge about steps of implementation lean program, do not have sufficient knowledge about the strength and weakness of the all company area, what the company of the strategic goal are trying to achieve, trying to get immediate success result from implementation lean, should involvement all company levels in lean implementation program, lack the planning how to start or where to start implementation lean in addition to the company culture that prevents lean transformation and also absence support the leadership in lean transformation all these consider barriers that could fail the successful implementation and transformation to lean(Timothy McLean 2015)(Lodgaard et al. 2016). At the same time, companies that have been applying lean practices and tools face deficiency in the evaluation of their improved performance. This led to producing a gap in the evaluation of performance improvements resulting from the failed implementation of the lean approach due to the unclear understanding of the concept of lean performance and appropriate models for monitoring, evaluating and comparing the evolution of "lean level" through the corresponding implementation process. So, it is not possible to manage the lean level of the enterprise without measuring its current performance. The measurement is the first step that led to the control and finally to processes improvement. If you do not measure the current enterprise performance, you do not have a clear understanding. If you do not understand it, you cannot control it and if you cannot control it, you cannot improve it (A & J. M. F 2017).

3. Lean Level Assessment

The lack of a clear understanding about what is lean performance and its evaluation is one of the reasons for lean programs implementation have failed. In other words, it is not possible to manage the lean level of an organization without measuring its performance(Calado 2017). Companies have realized the need to effectively measure and monitor the enterprise's performance`s to effective implementation of lean in the enterprise. Assessment of the lean level of the enterprise is a crucial issue that measures the degree of lean adoption in it to effectively identify a more critical area that hinders the performance of the enterprise directly affects the profitability, efficiency, effectiveness of the organization where it refers to the structured approach taken to assess and estimate the level of leanness attained or it is a measure of the degree of lean adoption in the organization (Narayanamurthy, G., Narayanamurthy, G., Gurumurthy 2016). Lean level assessment can be considered a guide for the organization through their lean journey to manage, control and improve their performances.

4. Assessment of the Lean Level by Fuzzy Multi-Criteria Decision Making (FMCDM)

Lean performance level assessment process may include inputs and subjective judgments that can create vagueness in decision-making so, Fuzzy logic is a tool that has able to represent subjective measures and eliminate their associated vagueness effects, it deals with imprecision and uncertainty, lack of information and partial truth in solving problems [13].

After Zadeh and Bellman introduced the fuzzy sets within Multi-Criteria Decision Making (MCDM led to appear a new theory known as fuzzy multi-criteria decision making (FMCDM) where, the conventional MCDM ignore the problem of subjective uncertainty).

FMCDM can be considered an efficient tool to assess the lean level of the enterprise with existence of uncertain and imprecise information related to lean assessment parameters that are based on the expert's subjective judgments.

Fuzzy numbers (FN) mostly triangular Fuzzy numbers TFNs, trapezoidal Fuzzy numbers TrFN and Gaussian Fuzzy numbers are used to express linguistic variables (terms or lingual expression) to describe and translate the subjective judgment of decision-makers quantitatively but TFNs are used more because of their computationally efficient information processing and representation in a fuzzy environment [16]. FMCDM approaches can be classified into four categories [18] (Table 1).

Table 1. Categories of FMCDM Methods

FMCDM Methods Categories	FMCDM Methods	Application
Pairwise Comparison based Methods	F-AHP F-ANP F-MACBETH	Pairwise comparison methods that use for identify the relative importance of alternatives and criteria using pairwise comparison matrices.
Outranking Methods	F- PROMETHE I(partial ranking) F- PROMETHE II (complete ranking) F- ELECTRE	Use outranking relations for evaluating alternatives.
Distance Based Methods	F-VIKOR F-TOPSIS	Used as a distance based methods to assess alternatives according to their distance to ideal solutions
Other Methods	F-AXIOMATIC DESIGN	Use for determining conjunctive or disjunctive behaviours between criteria
	F- DEMATEL	Utilize for determining interrelationships among criteria and identify cause and effect criteria.
	F- CHOQUET INTEGRAL	Utilized for rating criteria and alternatives by expressing semantically and quantitatively.

The current lean manufacturing level for identified enterprises can be assessed by distance-based methods Fuzzy TOPSIS and Fuzzy VIKOR to get the advantages of these distance methods and with using related lean criteria.

5. Fuzzy TOPSIS and Fuzzy VIKOR Distance-Based Methods

Fuzzy TOPSIS and Fuzzy VIKOR are FMCDM distance-based methods that incorporate fuzzy logic to deal with uncertainty and vagueness in lean level assessment process.

5.1. Fuzzy TOPSIS

Fuzzy TOPSIS is one of FMCDM methods that use as a distance based methods that based on choose the alternative that has shortest distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS) using criteria related the problem and their calculations are easy to understand and done . The methodology of Fuzzy TOPSIS is(Nazam et al. 2015):-

1- Identifying, alternatives, criteria, experts and linguistic variables for weighting criteria and rating alternatives.

Let, there are m alternatives Ai = A1, A2 .....Am are alternatives that are to be valuated against the criteria, Cj = C1 , C2 .....Cn, w j) refer to criteria weights where j = 1, 2, ..., n , i = 1, 2,...., m.

Dk refer to the performance ratings of each expert, k = 1, 2,.....K. Linguistic will be used twice first to weight criteria (Table 2) and by expert to get their judgments and rating alternatives according the weighted criteria(Table 3).

Table 2. Linguistic Variables for the importance weight of each criterion for TFN (Yavuz 2016)

Linguistic Variables	Fuzzy Value Corresponding TFN
Very Low(VL)	0,0,0.1
Low(L)	0,0.1,0.3
Medium Low(ML)	0.1,0.3,0.5
Medium(M)	0.3,0.5,0.7
Medium High(MH)	0.5,0.7,0.9
High(H)	0.7,0.9,1
Very High(VH)	0.9,1,1

Table 3. Linguistic variables for Performance ratings by Experts for TFN (Yavuz 2016)

Linguistic Variables	Fuzzy Value Corresponding TFN
Very Poor(VP)	0,0,1
Poor(P)	0,1,3
Medium Poor(MP)	1,3,5
Fair(F)	3,5,7
Medium Good(MG)	5,7,9
Good(G)	7,9,10
Very Good(VG)	9,10,10

2- Calculating the aggregate fuzzy ratings for the alternatives, Let X_{ijk} $:(a_{ijk}, b_{ijk}, c_{ijk})$ is the fuzzy rating of the kth expert $i:1,2,\ldots m,\ j:1,2,\ldots,n$ then the aggregated fuzzy ratings X_{ij} of alternatives with respect to each criteria are $X_{ij}\ (a_{ij}, b_{ij}, c_{ij})$.

$$a = \min_k a_k \ ,\ b = 1/k\left(\sum_{k=1}^{k} bk\right)\ ,\ c = \max_k c_k \tag{1}$$

3-Constructing the fuzzy decision matrix D˜ for the alternatives as follow: -

$$\tilde{D} = \begin{matrix} & \begin{matrix} C1 & \ldots\ldots & Cn \end{matrix} \\ \begin{matrix} A1 \\ \\ A_m \end{matrix} & \begin{bmatrix} X11 & \cdots & X1n \\ \ldots. & \ldots\ldots & \ldots. \\ Xm1 & \cdots & Xmn \end{bmatrix} \end{matrix} \tag{2}$$

3- Constructing the Normalize fuzzy decision matrix ˜R using linear scale transformation as follow: -

$$\tilde{R} = [\tilde{r}_{ij}]_{m*n} \tag{3}$$

$\tilde{r}_{ij} = (a_{ij}/c^*_j, b_{ij}/c^*_j, c_{ij}/c^*_j)$, $c = \max_i c_{ij}$ (benefit criteria)

$\tilde{r}_{ij} = (a^-_j/c_{ij}, a^-_j / b_{ij}, a^-_j / a_{ij})$, $a^-_j = \max_i a_{ij}$ (non-benefit criteria(cost creteria)).

4- Constructing the weighted normalized matrix V˜ by multiplying the weights w_j of evaluation criteria with the normalized fuzzy decision matrix r_{ij} .

$$\tilde{V} = [\tilde{v}_{ij}]_{m*n} \tag{4}$$

where :- $\tilde{v}_{ij} = \tilde{r}_{ij} * w_j$ and $\tilde{v}_{ij}$ is a TFN that represented by $\tilde{a}_{ijk}$, $\tilde{b}_{ijk}$, $\tilde{c}_{ijk}$

5- Determining the fuzzy ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) ,the FPIS and FNIS of the alternatives is calculated as follows:

$A^*=(v\tilde{}_1^*, v\tilde{}_2^*,,...,v\tilde{}_n^*)$, where $v\tilde{}_j^* = (c\tilde{}_j^*, c\tilde{}_j^*, c\tilde{}_j^*)$, $c\tilde{}_j^* = \max_i (c\tilde{}_{ij})$ (5)
$A^-=(v\tilde{}_1^-, v\tilde{}_2^-,,...,v\tilde{}_n^-)$, where $v\tilde{}_j^- = (a\tilde{}_j^-, a\tilde{}_j^-, a\tilde{}_j^-)$, $a^-_j = \min_i (a\tilde{}_{ij})$ (6)

6- Calculating distance of each alternative from FPIS and FNIS, The distance d_i^+, d_i^- for each weighted alternative from the FPIS and the FNIS as follows:

$d_i^+ = \sum_{j=1}^{n} dv(v\tilde{}_{ij}, v\tilde{}^*_j)$ (7)
$d_i^- = \sum_{j=1}^{n} dv(v\tilde{}_{ij}, v\tilde{}^-_j)$ (8)

6- Calculating the closeness coefficient CCi of each alternative that represents the distances to the fuzzy positive ideal solution (A*) and the fuzzy negative ideal solution (A^-) and can be calculated for each alternative as follow:-
$CC_i = d_i^- / (d_i^- + d_i^+)$ (9)

7- Ranking the alternatives where the highest-ranking is the alternative with high closeness coefficient CC_i and it is considered the best solution.

5.2. Fuzzy VIKOR

Fuzzy Multi criteria Optimization and compromise solution (Fuzzy VIKOR) is one of the common FMCDM methods, it is a compromise ranking method. This method establishes a compromise ranking list, a compromise solution and the weight stability intervals for the compromise solution. It then determines the positive-ideal solution and the negative-ideal solution to aid in ranking and selection [26]. The underlying principle of the VIKOR MCDM method is to deal with ranking and selection of alternatives which have multiconflicting or non-commensurable criteria(Afful-Dadzie et al. 2014).Methodology of Fuzzy VIKOR is similar Fuzzy TOPSIS in step1- 3 and differ in rest steps as follow(Ismail & Felix 2022):-

1- Determining the fuzzy best value($f\tilde{}^+_j$) and the fuzzy worst value ($f\tilde{}^-_j$)for all criteria.
$f\tilde{}^+_j = \max_i x\tilde{}_{ij}$, $f\tilde{}^-_j = \min_i x\tilde{}_{ij}$ (10)

2- Calculating the index S~i and R~i by equations 11 and 12.
S~i =∑nj=1 (w~j*(f~+j - f~ -j)) / (f~+j - f~ -j) (11)
R~i =maxj w~j *(f~+j - f~ -j) / (f~+j - f~ -j) (12)

3- Calculating the indexQ~i by equation 13.
Q~i = (v(Si~-Si~+)/(Si~ --Si~+))+ ((1-v)(R i ~ -Ri~+)) /(Ri~ --Ri~+)) (13)

Where:-

Si~+ =min i Si~ , Si~ - = max i Si~ , Ri~+= min i Ri~ , Ri~ -= max i Ri~

4- Defzzifying the index S~i , R~i and Q~i using such Center of Area Method (COA) as follow:-
The Defuzzification of the index S~i , R~i and Q~i for TFN by COA is calculated by equation 14 as follow

$A\tilde{} = a+b+c /3$ (14)

5- Ranking all alternatives based on the index $S\tilde{}_i$, $R\tilde{}_i$ and $Q\tilde{}_i$, thus three ranking lists will be obtained.
6- Proposing that the compromise solution is the alternative (a′)that is ranked the best by the measure Q (minimum)

if the following two conditions are satisfied:

7- C1:- Acceptable advantage, Q(a'') – Q (a') ≥ DQ,

Where:- a'' is alternative in second position in the Q ranking list, DQ = 1/(J − 1); and J is the number of alternatives.
C2:- Acceptable stability in decision making:
Alternative a' must also be the best ranked by S or/and R with v≥ 0.5.
Where v is the weight of the decision-making strategy "the majority of criteria" (or "the maximum group utility").
If one of these conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:
• Alternative a′ and a″ if only condition C2 is not satisfied,
• Alternative a', a'',…, $a(n)$ if condition C1 is not satisfied; and $a(n)$ is determined by the relation $Q(a(n) - Q(a')) < DQ$ for maximum n (the positions of these alternatives are "in closeness").

6. Results and Discussion

Many assessment types can be used to assess the current lean level of any enterprise involving Benchmarking, VSM , Lean Metrics, Fuzzy Logic, MCDM and FMCDM [14] strength and weakness of each the assessment methods (Adel et al. 2020) (Amin 2013)can be illustrate (Table 4),(Table 5) show review that conducted for references from 2009-2023 using Google Scolar,Google engine ,Research Gate that show using these various assessment methods to assess the current lean performance of enterprise.

Comparison between the main features of Fuzzy VIKOR and Fuzzy TOPSIS illustrate that both share some steps and differ in some (Acuña-Soto et al. 2019),(Kizielewicz & Baczkiewicz 2021)as shown in Fig 1.

Establishing the lean criteria (lean practices or policies or also called lean tools and techniques) is the crucial step in lean assessment process where it is used as a basis in assessing the lean performance level of the enterprise. Generally, Five principles must be considered in identifying lean criteria for assessment the current lean performance level: it should be meaningful and available for decision-makers; it must include all the important characteristics of lean level assessment problem; number of criteria is minimum as possible ; focuses on criteria that has a on high influence on lean performance; criteria can be decomposed from a higher level of hierarchy to lower level to simplify the process of evaluation , finally avoiding duplicate the same lean performance criteria(Tzeng & Huang n.d.)(Table 6) illustrate lean criteria or practices and (Table 7) show the most important lean dimensions that represent the main factors or directions for investigating lean level. Two types of criteria can be used in assessment lean level; quantitative criteria and qualitative criteria. Lean criteria are weighted by multiple experts for providing impartiality and avoid the biased decision making (Emrah Onder and Sundus Dag 2013)(Mumani et al. 2021). Various weighting methods can be used to weight lean criteria as shown in fig 2.(Ezell et al. 2021)(Jahan et al. 2012)(Odu 2019).

Table 4. Strength and weakness of lean assessment methods

Lean Assessment Methods	Criteria Type	Description	Strengths	Weaknesses
Benchmarking	Quantitative	Quantitatively measuring the level of lean by comparing the current performance of the system with the benchmarked performance where it can be used for both self-assessment and comparison.	The overall lean performance is measure quantitatively by comparing the systems state with benchmarking performance.	Example of performance benchmark needs to be collected from peers and competitors. The evaluation depends on comparisons of performance between companies, and the correct comparison must be under similar conditions between companies If the comparison process is not subject to this condition, the results are inaccurate and unfair. . It relies on historical data. the outcome is heavily depending on the quality of the benchmark.

Table 4. Strength and weakness of lean assessment methods (Continued)

Lean Assessment Methods	Criteria Type	Description	Strengths	Weaknesses
Value Stream Mapping(VSM)	Qualitative	It is a visual presentation of collection of activities that are required to produce a product or service or a combination of them to a customer where it is developed to streamline the processes continuously where seven value stream mapping tools were developed to help lean practitioners identify the sources of waste and the appropriate steps of improvement as well as it is used to assess the leanness level by developing and comparing a system's current and future state maps.	Effective mapping tool focuses on creating continuous value stream.	• All aspects of Lean level cannot be identified for company due to its limited use. • Limited coverage of wastes. • Missed improvement opportunities. • Complexity of the approach in understanding and implementation. • It has limited capabilities to represent the qualitative performance metrics (e.g. supplier Responsiveness and customer satisfaction) of a manufacturing system.
Lean Metrics	Quantitative	A set of metrics that necessary to outline the comprehensive Lean level that use to quantitatively assess the lean level of each practice and policy based on organizations' actual performance thus each metric participates only partly.	Assessing lean level quantitavily based on the actual performance thus can be considered a more comprehensive evaluation than others.	• Each metric assesses performance of one lean practice and policy. • Difficulty in coordinating the gathering of measurements into merged lean measure due to nature of metrics that differ from each other.
Fuzzy Logic	Qualitative, Quantitative	Fuzzy assessment methods that use fuzzy logic for assessing the enterprises lean level to deal with ambiguity and uncertainty of human evaluation.	More flexible in identifying options available during the design of evaluation tools.	No expansion in studies on the use of the fuzzy concept in improving the design and development of assessment.
Multi Criteria Decision Making MCDM	Qualitative, Quantitative	it can deal with situations with inherent complexities.	• Systematic methods. • Easy to understand and apply. • Can be used to assess the overall lean performance or each practice performance.	It is based on various problem related criteria both qualitative criteria that based on experts judgment that may involve bias and errors or quantitative criteria that need numerical data.
Fuzzy Multi Criteria Decision Making FMCDM	Qualitative, Quantitative	It involves using the fuzzy logic within MCDM to deal with subjective uncertainty and vagueness in data of problem due to that the lean assessment process may include subjective metrics and inputs that can create vagueness in decision-making.	• Systematic methods. • Easy to understand and apply. • Can be used to assess the overall lean performance or each practice performance. • deal with vague and uncertain data	It is based on various problem related criteria qualitative criteria that based on experts judgment that may involve bias and errors.

Table 5. Lean Assessment Methods Literature Review

Lean Assessment Methods / References	Benchmarking	VSM	Lean Metrics	Fuzzy Logic	FMCDM	MCDM
(Sabah et al. 2023)		√				
(Li & Yuan 2022)					√	
(Rodrigues Verçosa & Andrade Coelho 2022)	√					
(Kilic et al. 2021)					√	
(Prasetyawan et al. 2021)		√				
(Harjanto & Karningsih 2021)			√			
(Tayaksi et al. 2020)					√	
(Dahda et al. 2020)				√		
(Amin et al. 2020)				√		
(Bueno et al. 2020)					√	
(Ramos et al. 2018)	√					
(Oliveira 2018)			√			
(Rakhmanhuda & Karningsih 2018)			√			
(Galankashi & Helmi 2017)						√
(Agrawal et al. 2017)				√		
(Rajpurohit 2017c)					√	
(Calado 2017)				√		
(YURDAER 2016)						√
(Ravikumar et al. 2015)						√
(Pakdil & Leonard 2014)			√			
(Manjunath M., Shiva Prasad H. C.,Keerthesh Kumar K. S. 2014)		√				
(Susilawati et al. 2015)				√		
(Garza-reyes et al. 2014)	√					
(Kumar et al. 2013)					√	
(Vimal & Vinodh 2012)				√		
(Vinodh & Chintha 2011)				√		
(Arrieta Posada et al. 2010)	√					
(Gurumurthy & Kodali 2009)	√					

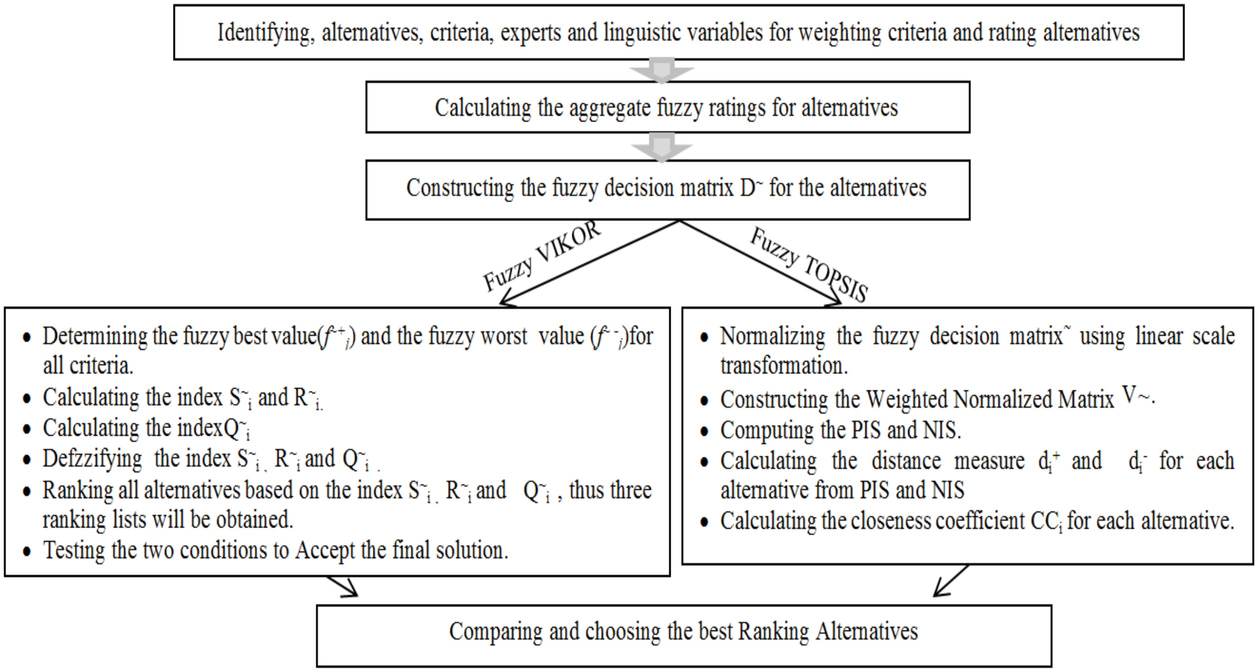

Figure 1. Comparison of Fuzzy TOPSIS and Fuzzy VIKOR

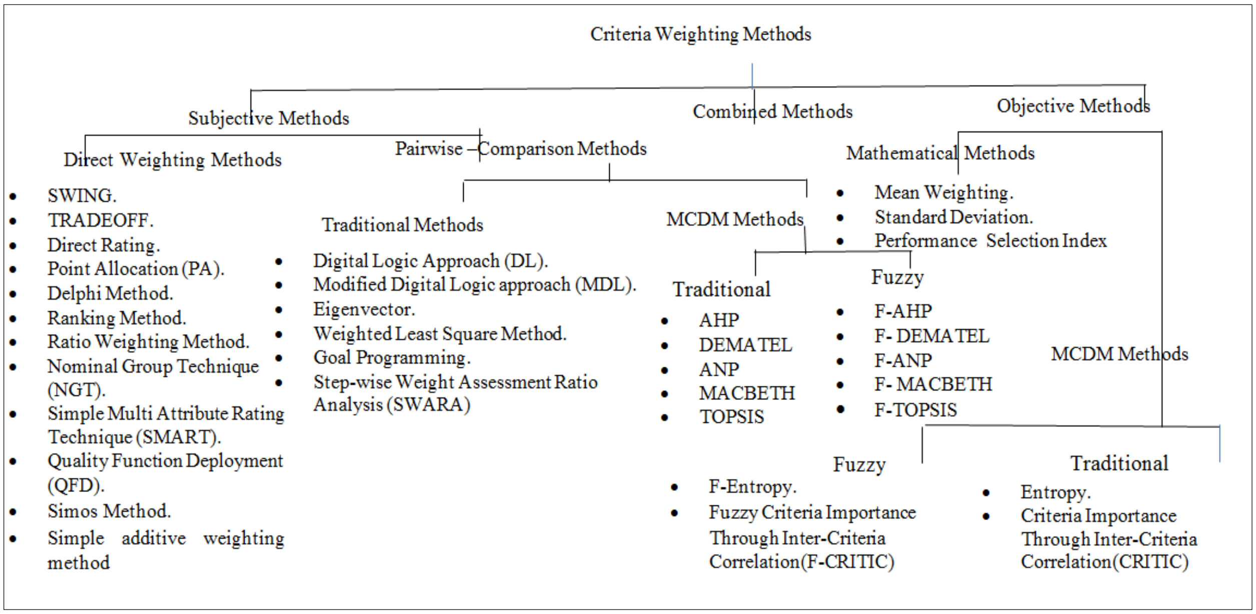

Figure 2. Illustrate the weighting methods

Table 6. SMEs Lean Criteria

Lean Criteria	Harjanto & Karningsih 2021)	Sathiya Narayana et al. 2020)	(Bueno et al. 2020)	(Vishal A Wankhede, Ankur Chaurasia 2019)	(Belhadi et al. 2018a)	(Saini 2019)	(Sahoo & Yadav 2018)	(Cengiz Toklu & Taşkin 2017)	(Abreu & J. M. F. 2017)	(Rajpurohit 2017a)	(Godinho Filho et al. 2016)	(Zhou 2016)	(Balasubramanian & Hemamala 2016)	(Zanjbeel TABASSUM 2016)	(Godinho Filho et al. 2016)	(Thanki et al. 2016)	(R. Vidyadhar R. Sudeep Kumar S. Vinodh Jiju Antony 2016)	(Laoha & Sukto 2015a)	(Laoha & Sukto 2015b)
Efficient Manager				•				•					•				•		
Motivating, and Supporting Employees	•			•				•		•			•				•		
Employee Involvement and empowerment				•				•					•				•		
Smooth information flow and transparency in information sharing	•			•	•	•		•					•				•		
Pull approach (Kanban)						•	•		•	•	•	•	•		•	•	•		
Line Balancing																		•	•
Lot size reduction													•		•				
Awareness the 7 Waste																		•	•
Set up reduction(SMED)				•		•	•			•	•	•	•	•	•	•		•	
Workplace Organization-5S				•		•	•		•	•		•	•	•	•	•		•	•
Preventive Maintenance(PM)			•		•		•		•	•	•	•	•	•	•	•	•	•	•
visual management system (flow charts, safety instruction						•			•			•	•	•		•	•	•	•
Poka Yoke	•			•			•			•		•	•	•	•		•	•	•
Adoption of value stream mapping							•						•		•	•	•		
Standardization and Simplification work							•		•	•			•	•	•				
Kazien suggestions and ideas team, PDCA problem solving)					•		•		•	•				•		•			
Supplier relationship	•	•		•					•	•	•						•		
Suppliers development(providing training in quality issues)				•					•	•							•		
Evaluation Suppliers' performance				•						•									
JIT purchasing deliveries by supplier	•			•	•					•	•								
Incorporation and Execution and the customer suggestions, feedback and requirements										•							•		
Handling and solving customer complaints	•	•		•						•			•				•		
Customer satisfaction		•								•							•		
Team work	•			•	•		•		•	•	•		•		•				•
Flexible/ multiskill workforce	•			•	•				•	•			•				•		•
Employee training	•		•				•			•					•		•		
Job Rotation between employees	•		•	•						•			•				•		
Quality Circle	•	•			•	•			•								•		

Table 7. Lean Dimensions

References	Lean Dimensions
(Harjanto & Karningsih 2021)	Quality, Delivery, Customer, Inventory, Product Value, Supplier,Technology Upgradation, Vertical information system,Time,Continuous Improvement, Management Commitment, Employees.
(Sathiya Narayana et al. 2020)	Purpose of organisation, Structure of organisation, Design of product and process, Logistics Customer satisfaction, Supply relationships, Environmental performance, Willing to admit change, Recycling, Capacity of organisation, Government support, Quality.
(Bueno et al. 2020)	Processes, Inspection, Storage, Capacity, Costs, Management.
(Vishal A Wankhede, Ankur Chaurasia 2019)	Management responsibility, Supplier and customer management, Manufacturing strategy, Workforce, Technology.
(Yadav et al. 2019)	Management, Technology, Workforce, Process, Customer.
(Belhadi et al. 2018b)	Elimination of waste, Continuous improvement, Multifunctional teams, Zero defects, Just-in-time delivery, Information systems.
(2017) (Rajpurohit 2017a)	Shop floor management, Manufacturing Process, Manufacturing Strategy, Workforce Management, Delivery and customer management.
(A. Abreu & J. M. F. 2017)	Costumers, Organization, Suppliers.
(Balasubramanian & Hemamala 2016)	Management responsibility, Manufacturing management, Work force , Technology, Manufacturing strategy.
(R. Vidyadhar R. Sudeep Kumar S. Vinodh Jiju Antony 2016)	Management Responsibility, Technology management, Manufacturing management, Workforce management, Customer and supplier management.
(Arul & Arumugam 2015)	Organisational structure, Resources optimization, Knowledge management, Employee status, Team working, Manufacturing setups, Manufacturing planning, Advances in design, Status of productivity, Time management and Design improvement

Lean practices and policies are used for continuous improvement the lean performance through reduce or eliminate the eight types of waste (Table 8) illustrate waste and the associated lean practices and policies related to it (Rajpurohit 2017b)(Nwanya & Oko 2019) (Arashpour & Karimi 2009) (Caldera et al. 2019).

Table 8. Waste and Associated Lean Practices and policies

Lean Wastes	The Associated Lean Practices and policies
Overproduction	Information system, Pull approach (Kanban), Efficient Manager, Lot size reduction,VSM.
Defects	Information system, Employee Involvement and empowerment , Motivation and Supporting employees, Workplace orgnization (5S), Previntive maintance,Work Standarization, (PM),Pokayoke, Kazien , Supplier relationship, Supplier Development ,Evaluation of suppliers' performance, Incorporation and Execution and the customer suggestions, feedback and requirements, Handling and solving customer complaints, Team work,. Employee skill, training.
Waiting	pull approach (Kanban) ,VSM, Set up reduction, Preventive Maintains(PM), Kazien, Supplier relationship, JIT purchasing deliveries by supplier.
Transportation	Pull approach (Kanban), Lot size reduction.
Extra Processing	Information system ,Workplace orgnization (5S), Flexible/ multitasking workforce, Work Standarization.
Inventory	Information system, Pull approach (Kanban), Set up reduction, Lot size reduction, Kazien, VSM, JIT purchasing deliveries by supplier, Efficient Manager.
Motion	Workplace orgnization (5S), Visual management system, Lot size reduction, Work Standarization .
Non –Utilized Skill	Employee Engagement ,Quality circle, Problem Solving Team, Suggestion Team,Job rotation, Motivating, Empowering and Supporting of employees, Training.

Review papers from 2013-2022 has been conducted to illustrate the various methodologies that based on using distance based methods for assessment the current lean performance level as shown in (Table 9). Fuzzy VIKOR has not used in lean assessment where authors have not found any paper use these methods for lean level assessment thus this can be point for future work

Table 9. Lean Assessment Literature Review

References	MCDM Used	Methodology
(Li & Yuan 2022)	TOPSIS	Developed methodology to assess the lean performance level of three production lines A-B-C of H company where criteria weights have determined by Fuzzy CRITIC, entropy and TOPSIS to identify the objective and subjective weight of criteria.
(Devnath et al. 2020)	TOPSIS	Proposed a methodology to evaluate, and prioritize the lean practices and policies to find and rank the major wastes on a production line using QFD and TOPSIS and also prioritize lean policies and practices to eliminate them. The suggested model consists of House Of Quality to identify the major waste throught identify a significant waste signs by interviews and on-field investigation Then convert these signs into the seven major wastes. The relative weights of the wastes have been determined that then input in TOPSIS method to prioritize the appropriate lean practices and policies.
(Sathiya Narayana et al. 2020)	F- TOPSIS	Suggested a method to assess the lean performance of ten automobile manufacturing industries regarding green and lean implementation to assess near these industries to ideal level of implementation the lean and green concepts.
(Seyed Vahid Mirnoori 2020)	TOPSIS, Simple Additive Weighting (SAW) , VIKOR	Evaluating and ranking 20 Lean practices using three MCDM methods.
(Pérez-Domínguez et al. 2019)	TOPSIS and hesitant fuzzy set (HFLTS)	Proposed methodology to deal with hesitant assessments in lean manufacturing problems using TOPSIS and hesitant fuzzy set to assess the KPI's performance of the LM projects.
(Rajpurohit et al. 2017)	F- TOPSIS	Assessed the lean level of three SMEs by F- TOPSIS where two experts weighted lean criteria and rating performance of these SMEs.
(Arul & Arumugam 2015)	TOPSIS F-TOPSIS	Proposed a methodology that uses TOPSIS and fuzzy TOPSIS to determine lean criteria weights and then evaluation the lean manufacturing in Indian industries by F-TOPSIS.
(Kumar et al. 2013).	F- TOPSIS	Suggested a framework for evaluating and and compare of the lean Performance level of three firms where, Three experts identified weights of criteria and firms' performance rating. Sensitivity analysis is done to verify robustness of the suggested framework.
(M.A. Alemi 2013).	F- TOPSIS	Developed an approach using fuzzy TOPSIS to assess the lean level of company using 11 criteria .criteria weights have identified by experts.
(Hossein Hojjati & Anvary 2013)	TOPSIS	Using SAW and TOPSIS methods for evaluating the lean policies and practices and assess the relative efficiency them under four criteria: lead time, cost, defects and value.

7- Challenges of the Distance Based Methods Fuzzy TOPSIS and Fuzzy VIKOR

1- While fuzzy TOPSIS and fuzzy VIKOR offer valuable approaches for assessing lean performance levels of production enterprises, they have certain challenges and overcoming these challenges requires careful consideration and expertise to ensure accurate and meaningful lean performance assessment. These challenges such;

2- Both methods are FMCDM that based on decision making judgment thus the lean assessment process may involve a potential inconsistency and bias in the assessment results.

3- The subjective nature of assigning linguistic variables and membership functions in fuzzy logic-based models can consider challenge of both methods.

4- Both require identifying criteria weights representing their relative importance and it is considered a challenge. Different weightings can significantly influence the final rankings and may lead to different assessment outcomes.

5- Selecting the appropriate criteria that reflect the problem and complexity of handling large number of criteria and weighting it and dealing and managing a large number of alternatives.

6- Both often treat criteria as independent factors without consider the interdependencies among them while each criterion may influence on other, and neglecting these interdependencies may overlook important factors that affect lean performance.

8- Conclusions

Lean manufacturing is a philosophy that helps manufacturing enterprises to improve their performance aspects by identifying and reducing or if possible, eliminating the eight types of wastes using specific techniques/tools. Currently, most companies pursue to implementation of lean to one degree or another or with various levels to enhance their performance to stay in the market competition through product cost and quality. Lean level assessment can be considered as a guide for the organization throught their lean journey to manage, control and improve their performances where it provides a baseline for improvement. Enterprise should assess its current status of lean level to know if it is near or far from the ideal level of lean using suitable and effective assessment methods to deal with any hinder the performance of an organization that directly affects the profitability, efficiency, effectiveness of the organization where Benchmarking, VSM, Lean Metrics, Fuzzy Logic, MCDM and FMCDM are lean assessment methods each one has Strengths and Weaknesses. Nowadays, the interest is increased to use the various FMCDM approaches in various fields to deal with incomplete information and uncertain knowledge. Currently, lean production can be considered one of the important fields that FMCDM approaches are used to investigate whether the company is near or far from the ideal application of the concepts of lean. Two effective distance-based methods namely, Fuzzy TOPSIS and Fuzzy VIKOR can be used for assessing the current lean performance level of the enterprise depending on related lean criteria and the level of lean-to know if it is near or far from the ideal level of lean (the lean level between 0-1, where 1 refer to optimal lean implementation. Various weighting methods can be used wether subjective or objectives or combined to weight a specific lean criteria using particular lean dimensions. Each lean practic and policy is responsible to reduce or eliminate more than one waste. Although this review has focusde on only the manufacturing sector but for future works, it could be used for assessing the lean level of service in addition Fuzzy VIKOR has not used in lean assessment where authors have not found any paper use these methods for lean level assessment thus this can be point for future work and various weighting methods can be used with it to weight criteria with selecting a specific lean dimensions and lean criteria.

References

A. Abreu & J. M. F., C.(2017). A Fuzzy Logic Model to Evaluate the Lean Level of an Organization. *International Journal of Artificial Intelligence & Applications*, 8(5), pp.59–75.

A, A. & J. M. F, C.(2017). Lean Level of an Organization Assessed Based on Fuzzy Logic. , (September), pp.09–21.

Abreu, A. & J. M. F., C.(2017). A Fuzzy Logic Model to Evaluate the Lean Level of an Organization. *International Journal of Artificial Intelligence & Applications*, 8(5), pp.59–75.

Acuña-Soto, C.M., Liern, V. & Pérez-Gladish, B.(2019). A VIKOR-based approach for the ranking of mathematical instructional videos. *Management Decision*, 57(2), pp.501–522.

Adel, A.A., Badiea, A.M. & Albzeirat, M.K.(2020). Techniques and Assessment of Lean Manufacturing Implementation: An Overview. *International Journal of Engineering and Artificial Intelligence*, 1(4), pp.35–43. Available at: http://wwwijeair.com.

Afful-Dadzie, E., Nabareseh, S. & Oplatkova, Z.K.(2014). Fuzzy VIKOR approach: Evaluating quality of internet health information. In *2014 Federated Conference on Computer Science and Information Systems, FedCSIS 2014*. pp. 183–190.

Agrawal, R., Asokan, P. & Vinodh, S.(2017). Benchmarking fuzzy logic and ANFIS approaches for leanness evaluation in an Indian SME: A case study. *Benchmarking*, 24(4), pp.973–993.

Al-baldawi, Z., Kassam, A.E.H. & Al-zubaidi, S.S.A.(2023). Assessment of the Interrelationship and the Influence Degree of Lean Dimensions Based on Fuzzy DEMATEL. , 17(4), pp.215–226.

Alkhoraif, A., Rashid, H. & McLaughlin, P.(2019). Lean implementation in small and medium enterprises: Literature review. *Operations Research Perspectives*, 6(December).

Amin, M.A. et al.(2020). A fuzzy-based leanness evaluation model for manufacturing organisations. *Production Planning and Control*, 0(0), pp.1–16. Available at: https://doi.org/10.1080/09537287.2020.1778113.

Amin, M. Al(2013). *a Systematic Approach for Selecting Lean Strategies and Assessing Leanness in Manufacturing Organizations*.

Arashpour, M.R. & Karimi, M.(2009). The Relationship between Lean and TPM. , (11).

Arrieta Posada, J.G., Botero Herrera, V.E. & Romano Martinez, M.J.(2010). Benchmarking about lean manufacturing in the textile sector in Medellin. *Journal of Economics, Finance and Administrative Science*, 15(28), pp.141–170.

Arul, T.G. & Arumugam, C.(2015). Implementation of Lean Manufacturing Technique in Indian Manufacturing Industries. *International Journal of Innovative Research in Science, Engineering and Technology*, 4(Special Issue 6), pp.1847–1853.

Balasubramanian, P.K. & Hemamala, K.(2016). Leanness Assessment using Fuzzy Logic Approach: A Case of Indian Horn Manufacturing Company. *International Journal of Data Mining Techniques and Applications*, 5(2), pp.102–109.

Belhadi, A., Touriki, F.E. & El fezazi, S.(2018a). Development of a Lean Assessment Tool for Small and Medium Sized-Enterprises. , (September), pp.361–369.

Belhadi, A., Touriki, F.E. & El fezazi, S.(2018b). Development of a Lean Assessment Tool for Small and Medium Sized-Enterprises. In *Springer International Publishing AG 2018*. pp. 361–369.

Bueno, W.P. et al.(2020). Fuzzy in Lean To Evaluate the Decision Degree. *Revista Gestão e Desenvolvimento*, 17(1), p.4.

Calado, A.A. and J.M.F.(2017). LEAN LEVEL OF AN ORGANIZATION ASSESSED BASED ON FUZZY LOGIC. In *Computer Science & Information Technology (CS & IT)*. pp. 9– 21.

Caldera, H.T.S., Desha, C. & Dawes, L.(2019). Evaluating the enablers and barriers for successful implementation of sustainable business practice in "lean" SMEs. *Journal of Cleaner Production*, 218, pp.575–590. Available at: https://doi.org/10.1016/j.jclepro.2019.01.239.

Cengiz Toklu, M. & Taşkin, H.(2017). Performance evaluation of small-medium enterprises based on management and organization. *Acta Physica Polonica A*, 132(3), pp.994–998.

Dahda, S.S., Andesta, D. & Wicaksono, A.S.(2020). Measuring leanness index using fuzzy logic approach. *Journal of Physics: Conference Series*, 1469(1), pp.0–8.

Devnath, A. et al.(2020). An integrated QFD-TOPSIS method for prioritization of major lean tools: a case study. *International Journal of …*, 9(1), pp.65–76. Available at: http://www.riejournal.com/article_105447.html.

Emrah Onder and Sundus Dag(2013). Combining Analytical Hierarchy Process and Topsis Approaches for Supplier Selection in a Cable Company. *Journal of Business, Economics and Finance*, 2(2), pp.56–74.

Ezell, B., Lynch, C.J. & Hester, P.T.(2021). Methods for Weighting Decisions to Assist Modelers and Decision Analysts : A Review of Ratio Assignment and Approximate Techniques. *Applied Sciences (Switzerland)*, 11(10397).

Galankashi, M.R. & Helmi, S.A.(2017). Assessment of lean manufacturing practices: An operational perspective. *International Journal of Services and Operations Management*, 28(2), pp.163–184.

Garza-reyes, J.A., Er, A. & Kumar, V.(2014). A VSM improvement-based approach for lean operations in an Indian manufacturing SME. *International Journal of Lean Enterprise Research*, 1(1), pp.41–58.

Godinho Filho, M., Ganga, G.M.D. & Gunasekaran, A.(2016). Lean manufacturing in Brazilian small and medium enterprises: implementation and effect on performance. *International Journal of Production Research*, 54(24), pp.7523–7545.

Gurumurthy, A. & Kodali, R.(2009). Application of benchmarking for assessing the lean manufacturing implementation. *Benchmarking*, 16(2), pp.274–308.

Harjanto, D.D. & Karningsih, P.D.(2021). Development of Lean Assessment Tools Dimensions and Indicators for MSMEs in Indonesia. *Prozima*, 5(1), pp.21–29.

Hossein Hojjati, S.M. & Anvary, A.(2013). An integrated SAW, TOPSIS method for ranking the major lean practices based on four attributes. *World Applied Sciences Journal*, 28(11), pp.1862–1871.

Ismail, M.S. & Felix, A.(2022). Integrated fuzzy VIKOR and TOPSIS system for the sustainable development in Islam. In *AIP Conference Proceedings*.

Jahan, A. et al.(2012). A framework for weighting of criteria in ranking stage of material selection process. *International Journal of Advanced Manufacturing Technology*, 58(1–4), pp.411–420.

Kilic, H.S., Yurdaer, P. & Aglan, C.(2021). A leanness assessment methodology based on neutrosophic DEMATEL. *Journal of Manufacturing Systems*, 59(June 2019), pp.320–344. Available at: https://doi.org/10.1016/j.jmsy.2021.03.003.

Kizielewicz, B. & Baczkiewicz, A.(2021). Comparison of Fuzzy TOPSIS, Fuzzy VIKOR, Fuzzy WASPAS and Fuzzy MMOORA methods in the housing selection problem. *Procedia Computer Science*, 192(October), pp.4578–4591.

Kumar, M.B. et al.(2021). Framework for Lean Implementation Through Fuzzy AHP-COPRAS Integrated Approach. In *IEEE Transactions on Engineering Management*. IEEE, pp. 1–12.

Kumar, S. et al.(2013). A framework for comparative evaluation of lean performance of firms using fuzzy TOPSIS. *International Journal of Productivity and Quality Management*, 11(4), pp.371–392.

Laoha, C. & Sukto, S.(2015a). Lean assessment for manufacturing of small and medium enterprises: A case study of 2 industrial groups in Northeast of Thailand. *International Business Management*, 9(4), pp.590–595.

Laoha, C. & Sukto, S.(2015b). Lean assessment for manufacturing of small and medium enterprises (SMEs): A case study of electronics industry in the Northeast of Thailand. *KKU ENGINEERING JOURNAL*, 42(3), pp.258–262.

Leksic, I., Stefanic, N. & Veza, I.(2020). The impact of using different lean manufacturing tools on waste reduction. *Advances in Production Engineering And Management*, 15(1), pp.81–92.

Li, Y. & Yuan, P.(2022). Evaluation of Enterprise Lean Level Based on Fuzzy Multiple Subjective and Objective Weights. *Open Journal of Business and Management*, 10(3), pp.1290–1309.

Lodgaard, E. et al.(2016). Barriers to Lean Implementation: Perceptions of Top Managers, Middle Managers and Workers. *Procedia CIRP*, 57, pp.595–600. Available at: http://dx.doi.org/10.1016/j.procir.2016.11.103.

M.A. Alemi, R.A.(2013). 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(3), pp.166–174.

Manea, D.(2013). Lean Production – Concept and Benefits. *Review of General Management*, 17(1), pp.164–171.

Manjunath M., Shiva Prasad H. C.,Keerthesh Kumar K. S., D.P., 2014. Value Stream Mapping : A Lean Tool. *THE INTERNATIONAL JOURNAL OF BUSINESS & MANAGEMENT*, 2(4), pp.100–104.

Mumani, A.A., Magableh, G.M. & Mistarihi, M.Z.(2021). *Decision making process in lean assessment and implementation: a review*, Springer International Publishing. Available at: https://doi.org/10.1007/s11301-021-00222-z.

Narayanamurthy, G., Narayanamurthy, G., Gurumurthy, A. and G..(2016). Leanness assessment: a literature review.

Journal of Operations & Production Management, Vol. 36 Iss 10, 36(10).

Narpat Ram Sangwa, Kailash Choudhary, K.S.S.(2015). Performance Evaluation Framework for Lean Manufacturing- A Review. *National Conference on Sustainable Manufacturing*, (January), pp.61–68.

Nazam, M. et al.(2015). A fuzzy AHP-TOPSIS framework for the risk assessment of green supply chain implementation in the textile industry. *[GS],International Journal of Supply and Operations Management*, 2(1), pp.548–568.

Nwanya, S.C. & Oko, A.(2019). The limitations and opportunities to use lean based continuous process management techniques in Nigerian manufacturing industries - A review. *Journal of Physics: Conference Series*, 1378(2).

Odu, G.O.(2019). Weighting methods for multi-criteria decision making technique. *Journal of Applied Sciences and Environmental Management*, 23(8), p.1449.

Oliveira, R.(2018). *Lean and performance measuring: Developing a new performance measurement framework to fit lean*.

Pakdil, F. & Leonard, K.M.(2014). Criteria for a lean organisation: Development of a lean assessment tool. *International Journal of Production Research*, 52(15), pp.4587–4607.

Pérez-Domínguez, L. et al.(2019). Hesitant fuzzy linguistic term and TOPSIS to assess lean performance. *Applied Sciences (Switzerland)*, 9(873).

Prasetyawan, Y., Ramadhan, B.A. & Salsabila, L.(2021). Lean manufacturing with multilevel Value Stream Mapping. In *IOP Conference Series: Materials Science and Engineering*. p. 12030.

R. Vidyadhar R. Sudeep Kumar S. Vinodh Jiju Antony(2016). Application of fuzzy logic for leanness assessment in SMEs: a case study. *Journal of Engineering, Design and Technology*, 14(1).

Rajpurohit, L.(2017a). *A Study of Leanness Assessment of Manufacturing Organizations*.

Rajpurohit, L.(2017b). A Study of Selection of Lean Tools In Manufacturing Sector. , (November), pp.0–74.

Rajpurohit, L.(2017c). Leanness Assessment of Manufacturing Organizations Using Fuzzy Topsis: a Case Study. *International Journal of Advance Engineering and Research Development*, 4(11), pp.2–7.

Rajpurohit, L., Verma, A. & Singh, M.(2017). Comparative Study of Leanness Index Methods for Manufacturing Organizations. *International Journal of Advance Engineering and Research Development*, 4(11), pp.600–606.

Rakhmanhuda, I. & Karningsih, P.D.(2018). Development lean assessment indicator: A case study. In *MATEC Web of Conferences*. pp. 1–6.

Ramos, A.R. et al.(2018). A lean and cleaner production benchmarking method for sustainability assessment: A study of manufacturing companies in Brazil. *Journal of Cleaner Production*, 177, pp.218–231.

Ravikumar, M.M., Marimuthu, K. & Parthiban, P.(2015). Evaluating lean implementation performance in Indian MSMEs using ISM and AHP models. *International Journal of Services and Operations Management*, 22(1), pp.21–39.

Rodrigues Verçosa, W. & Andrade Coelho, M.(2022). Evaluation of Lean Manufacturing Practices in an Automotive Component Manufacturer. *Revista Gestão da Produção Operações e Sistemas*, 17(2), pp.29–56.

Sabah, A., Al-Kindi, L. & Al-Baldawi, Z.(2023). Adopting Value Stream Mapping as a Lean Tool to Improve Production Performance. *Engineering and Technology Journal*, 41(6), pp.1–14.

Sahoo, S. & Yadav, S.(2018). Lean implementation in small- and medium-sized enterprises: An empirical study of Indian manufacturing firms. *Benchmarking*, 25(4), pp.1121–1147.

Saini, S., 2019. Impact of implementing lean practices on fi rm performance : a study of Northern India SMEs.

Saini, S. & Singh, D.(2020). Investigating the perceptions of Lean manufacturing practices in Northern India SMEs: an empirical study. *Industrial Engineering Journal*, 13(3).

Sathiya Narayana, S.N. et al.(2020). Assessment and implementation of lean and green supply chain in medium scale automobile industries using AHP and Fuzzy TOPSIS. *Journal of Scientific and Industrial Research*, 79(8), pp.720–726.

Scherrer-Rathje, M., Boyle, T.A. & Deflorin, P.(2009). Lean, take two! Reflections from the second attempt at lean implementation. *Business Horizons*, 52(1), pp.79–88.

Seyed Vahid Mirnoori(2020). *Prioritizing Lean Techniques by Employing Multi- Criteria Decision-Making (MCDM): The Case of MCoutinho*.

Susilawati, A. et al.(2015). Fuzzy logic based method to measure degree of lean activity in manufacturing industry. *Journal of Manufacturing Systems*, 34(C), pp.1–11.

Tayaksi, C., Sagnak, M. & Kazancoglu, Y.(2020). A new holistic conceptual framework for leanness assessment. *International Journal of Mathematical, Engineering and Management Sciences*, 5(4), pp.567–590.

Thanki, S., Govindan, K. & Thakkar, J.(2016). An investigation on lean-green implementation practices in Indian SMEs using analytical hierarchy process (AHP) approach. *Journal of Cleaner Production*, 135, pp.284–298. Available at: http://dx.doi.org/10.1016/j.jclepro.2016.06.105.

Timothy McLean(2015). *Grow your Factory Grow your Profits, Lean for Small and medium Manufacturing Entrprises*,

Tzeng, G.-H. & Huang, J.-J., *Multiple Attribute Decision Making Methods and applications*, United States of America: Taylor & Francis Group. Available at: 978-1-4398-6157-8.

Vimal, K.E.K. & Vinodh, S.(2012). Leanness evaluation using IF-THEN rules. *International Journal of Advanced Manufacturing Technology*, 63(1–4), pp.407–413.

Vinodh, S. & Chintha, S.K.(2011). Leanness assessment using multi-grade fuzzy approach. *International Journal of Production Research*, 49(2), pp.431–445.

Vishal A Wankhede, Ankur Chaurasia, N.K.(2019). Leanness assessment of an organization using fuzzy logic approach. *Journal of engineering practice and futuristic technologies*, 2(1), pp.1–6.

Wahab, A.N.A., Mukhtar, M. & Sulaiman, R.(2013). A Conceptual Model of Lean Manufacturing Dimensions. In *Procedia Technology*. pp. 1292–1298.

Yadav, V. et al.(2019). Development of leanness index for SMEs. *International Journal of Lean Six Sigma*, 10(1), pp.397–410.

Yavuz, M.(2016). Equipment Selection by using Fuzzy TOPSIS Method. In *IOP Conference Series: Earth and Environmental Science*.

YURDAER, P.(2016). *A Leanness Assessment Model and An Application*.

Zanjbeel TABASSUM(2016). *A STATISTICAL ANALYSIS OF LEAN PRACTICES, AND IMPACTS ON SMALL AND MEDİUM-SIZED ENTERPRISES (SMEs) IN PAKISTAN*. Available at: file:///Users/andreataquez/Downloads/guia-plan-de-mejora-institucional.pdf%0Ahttp://salud.tabasco.gob.mx/content/revista%0Ahttp://www.revistaalad.com/pdfs/Guias_ALAD_11_Nov_2013.pdf%0Ahttp://dx.doi.org/10.15446/revfacmed.v66n3.60060.%0Ahttp://www.cenetec.

Zhou, B.(2016). Lean principles, practices, and impacts: a study on small and medium-sized enterprises (SMEs). *Annals of Operations Research*, 241(1–2), pp.457–474.