

Assessment of the Interrelationship and the Influence Degree of Lean Dimensions Based on Fuzzy DEMATEL

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ABSTRACT

Lean manufacturing is a world class philosophy and a well-approved strategy for improving quality, productivity and reduce cost to makes the organization more competitive in the changing global markets, where every organization pursues continuously to improve their lean performance by reducing or eliminating all types of waste. Fuzzy DEMATEL has been utilizes to develop assessment model to help focusing more on the most influence lean dimensions for driving the improvement process. Five essential lean dimensions have been studied that extracted by a survey to assess degree of relation, importance, and category the lean dimensions and determine the interrelationships among them. The assessment model has been developed using MICROSOFT EXCEL and applied by surveying five companies for soft drink and healthy water by a questionnaire to get their opinion about importance and the influence each lean dimension on another. Interrelationship diagram show top management has highest effect on all lean dimensions so it is considered as driving lean dimension.

Keywords: Cause-effect-Importance Diagram, F-DEMATEL Interrelationship diagram, Lean Dimensions.

INTRODUCTION

Increased customer expectations and competition in the global markets require companies to gain powerful competitive advantages [1] and face global challenges like cost, product quality, delivery, and so on by changing the existing working ways by using effective manufacturing philosophies and technologies, such as Computer Integration Manufacturing CIM, Flexible manufacturing System FMS, Lean Manufacturing LM, agile manufacturing, etc. [2]. Nowadays, lean manufacturing is widely used as a continuous improvement philosophy for improving quality, productivity, performance and the overall competitiveness of the organization by the introduction of innovative practices. LM is a manufacturing system that develop in 1949 by Taiichi Ohno to be an alternative to the existing mass production system [3], Ohno has concluded that different kinds of wastes (non-value added works) are the main cause of low productivity and inefficiency. While

analyzed the problems inside the manufacturing environment [4] where he defined LM as capture and hunting all types of waste [5]. Scherrer-Rathje [6], Manea [7] and Alkhoraif [8] defined LM 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. Ghushe et al. [9] defined LM as internal tools for creating a streamlined and high quality system which actually deals with the optimum use of resources and increasing the value of a product by reducing the waste in every aspect of production right from customer relations (sales, delivery, billing, service and product satisfaction) to product design, supplier networks, production flow, maintenance, engineering, quality assurance and factory management, where it use of everything in very less in comparison with mass production in, the production space, the

financial investment in devices, design hours to develop a new item and human initiative in enterprise. Lean philosophy can be concluded as a continuous improvement philosophy that pursued 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.

Several of Multi Criteria Decision Making MCDM methods have been used for studying various lean philosophy aspects and one of the most efficient subjective methods is Fuzzy Decision MAKing Trial and Evaluation Laboratory (F-DEMATEL).

DEMATEL was introduced in 1973 by Geneva; it is a useful tool to solve complicated and unclear issues where it is used to evaluate the relationships between criteria for determination the type of relation, interrelationship and importance of the evaluation criteria. In DEMATEL method the criteria are classified into two groups; the cause group and the effect group. The cause group has an influence on the effect group where improvement for the cause criteria will directly influence on the effect criteria where such influence is used to estimate the criteria weights [10], where the final result of the DEMATEL procedure is a visual representation of digraphs, which separates components into cause and effect groups in addition it is used for decreasing the number of evaluation criteria by focusing on the influence criteria more than the influenced criteria thus this is beneficial for organizations in performance improvement by focusing on particular criteria in view of the effect diograph and criteria importance. In reality, crisp values are not effective because human judgments are largely indistinct and difficult to assess by exact crisp values, due to the imperfection of some assessment criteria and even uncertain factors thus fuzzy theory is used in the DEMATEL method to overcome this type of MCDM problem. The Fuzzy DEMATEL method is applied in different areas of research to solve different MCDM problems [11, 12].

Zhu et al. (2023) [13] used DEMATEL to calculate the degree of influence, the degree of influenced, and the centrality and causes for the Brittleness Factors for the Lean–Green and The causal relationships between these factors in Manufacturing System in a Manufacturing Company.

Kilic et al. (2021) [14] proposed methodology based on neutrosophic DEMATEL for assessing the importance weight of five lean dimensions such; performance, process, inventory, supplier and human resources management.

Kang et al. (2022) [15] used DEMATEL to identify the interactions and important level of the eight key factors that Increasing the Free Cash Flow for Manufacturers Utilizing Lean Production namely; new product planning, quality is built into the process, strategic planning, PD matrix management, strategic deployment, leadership, goal orientation and quality first.

Tayaksi et al. (2020) [16] proposed a holistic leanness assessment framework based on fuzzy DEMATEL to identify the importance and causal relationships between lean practices related supplier issues, manufacturing activities, marketing, JIT, cost and financial management, employees, management responsibility and quality management in the plastics industry of Turkey.

Sharma et al. (2016) [17] used DEMATEL to assess the causal relationships among 17 lean practices in machine tool manufacturing company such JIT, 5S, VSM, information technology, SMED, visual control, CIM, ERP, job scheduling, standardized work, training, fixed position layout, cellular manufacturing, poka-yoke, smart process and automation, TQM and concurrent engineering.

Zadeh et al. (2015) [18] evaluated the influence degree of 20 leanness factors on each other namely; The structure of organization, management nature, adaptation of customer reaction, changing technical and business processes, JIT flow, supplier development, streamlining procedures cellular manufacturing, worker status, worker involvement, manufacturing setups, product service, integrated product design, in-house technology, production procedure, manufacturing planning, quality status, productivity status, cost management and management of time.

In this research, a survey has been conducted for references related lean from 2016 to 2021 using Google engine and research gate based on keywords; lean dimensions, lean assessment, lean activities to extract lean dimensions by focused

Table 1. Survey the lean dimensions

References	Lean dimensions				
	Top management	Processes	Suppliers	Customers	Employees
Harjanto (2021) [19]	√		√	√	√
Moustafa Elnadi et al. (2021) [20]	√	√	√	√	√
Bueno et al.(2020) [21]	√	√			
Dahda et al. (2020) [22]		√	√	√	√
Cansu Tayaksi et al. (2020) [16]	√	√	√		√
Vishal A Wankhede et al. (2019) [23]	√	√	√	√	√
Vinod Yadav et al. (2018) [24]	√	√		√	√
Agrawal, P. Asokan et al. (2017) [25]	√	√	√	√	√
Abreu et al. (2017) [26]		√	√	√	
Lalit Rajpurohit (2017) [27]			√	√	√
Pradeep Kumar Balasubramanian et al. (2016) [28]	√	√			√
Vidyadhar et al. (2016) [29]	√		√	√	√

on the most important lean dimensions that have influence on lean performance of organization where the final result of survey shown in Table 1 the selected dimensions are top management, processes, suppliers, customers and employees thus Fuzzy DEMATEL has used as an efficient FMCDM method to assess the relationship and Influence degree of lean dimensions.

THE PROPOSED LEAN DIMENSIONS ASSESSMENT MODEL

F-DEMATEL is one of subjective and efficient MCDM method that help decision makers for; identifying weight of influence (importance) of lean dimensions, identifying the cause dimensions (the influencing dimensions) and effect

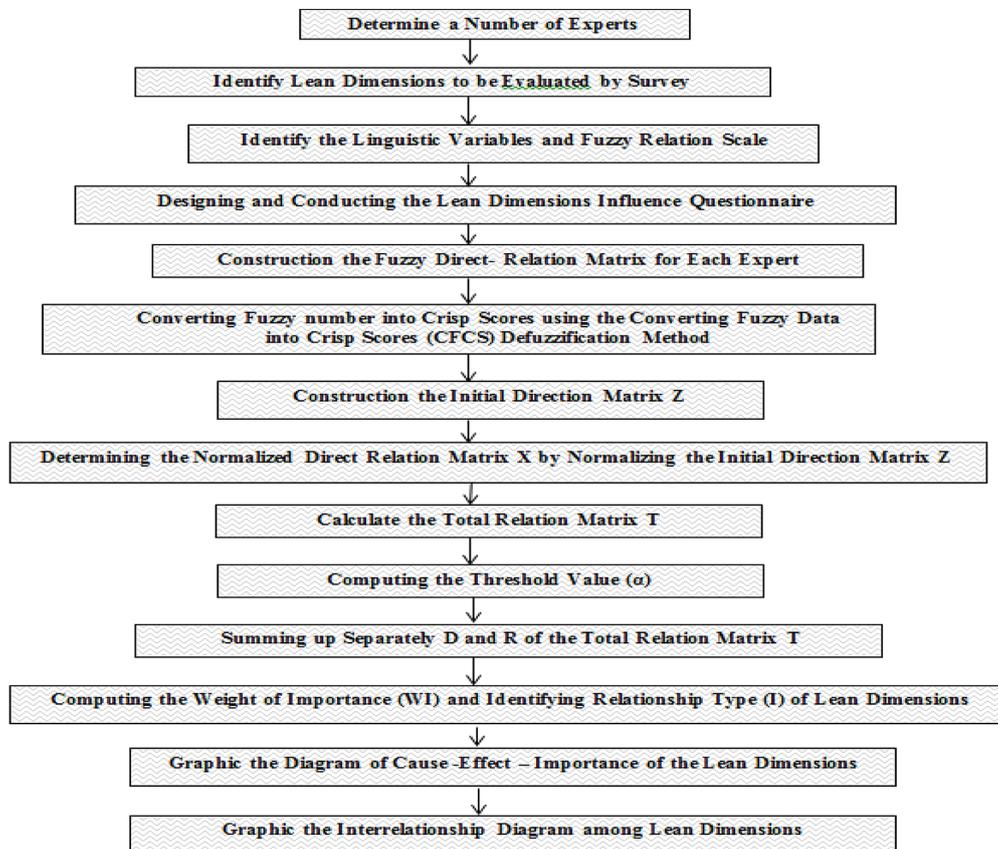


Fig. 1. Assessment model of relationship and importance of lean dimensions

dimensions (the influenced dimensions) where the influencing dimensions will impact directly on influenced dimensions, determine the receiver’s dimensions and dispatcher’s dimensions by interrelationships diagram. Identifying weights of lean dimensions influence (dimension importance) and degree of relation are important to distinguish and categorize lean dimensions through cause-effect diagram. Importance and degree of relation of lean dimensions can be calculated through sequential steps as illustrate in Figure 1.

- Step 1 – determine a number of experts.
Experts from five various companies in same type of industry who have experience about company processes and activities will be consulted to get their opinion about level of influence of lean dimension on each other by scoring the influence using fuzzy influence scale in order to obtain consistent assessments.
- Step 2 – identify lean dimensions to be evaluated.

The lean dimensions namely; top management, processes, supplier, customer and

employees are extracted by survey and it will be evaluated only by experts.

- Step 3 – identify the linguistic variables and fuzzy scale.
Linguistic variables and its corresponding fuzzy scale, Table 2 has been used by experts to evaluate influence of lean dimensions on each other.
- Step 4 – designing and conducting the criteria influence questionnaire.
Questionnaire has been designing then conducted by asking experts to evaluate and identify their opinion about influence the lean five dimensions on each other by tick the right influence score. Figure 3 illustrate the Influence Questionnaire sheet of lean dimensions.
- Step 5 – construction the fuzzy direct-relation matrix.

Constructing the fuzzy direct-relation matrix that identify influences of lean dimensions on each other based on results of questionnaire, where the no influence linguistic variable and fuzzy scale (0,

Table 2. Degree and explanation of the influence score for TFNs [30, 31]

Degree of Influence	TFNs	Symbol	Explanation
No influence	(0, 0, 0.25)	NI	The two evaluation criteria are not related to each other
Low influence	(0, 0.25, 0.5)	LI	Low correlation between the two evaluation criteria
Medium influence	(0.25, 0.5, 0.75)	MI	A moderate correlation between the two evaluation criteria
High influence	(0.5, 0.75, 1)	HI	A high degree of correlation between the two evaluation criteria
Very high influence	(0.75, 1, 1)	VHI	A very high degree of correlation between the two evaluation criteria

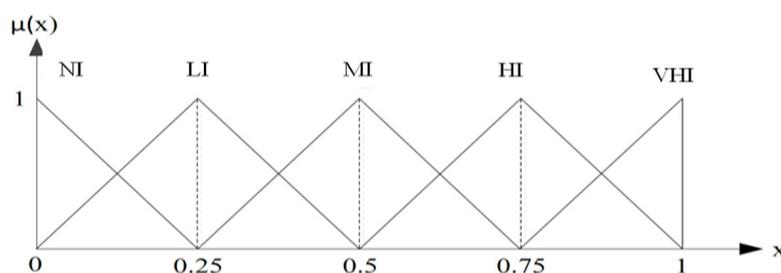


Fig. 2. The Fuzzy TFNs Memberships for criteria influence [30]

Lean criteria	According to your experience, how dose each criteria in the left influence on criteria in the right					Lean criteria
	No influence on	Low influence on	Medium influence on	High influence on	Very high influence on	
Top management (C1) has						C2 - processes
Top management (C1) has						C3 - supplier
Top management (C1) has						C4 - customer
Top management (C1) has						C5 - employees

Fig. 3. Questionnaire sheet the influencing of lean dimensions

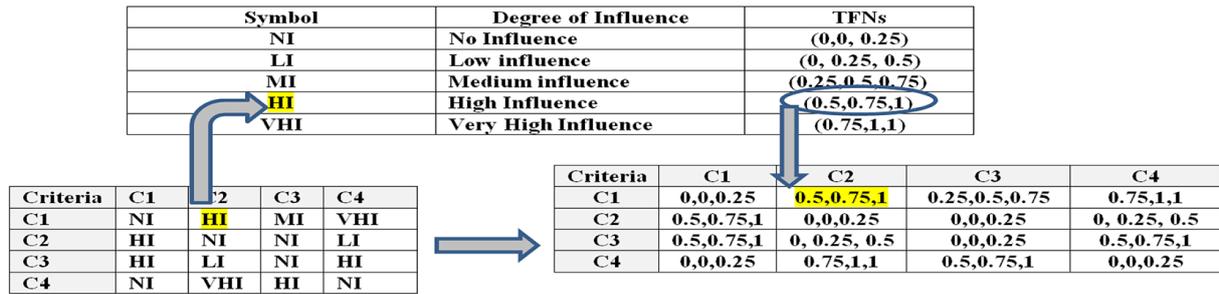


Fig. 4. Example of transferring the linguistic variables to fuzzy numbers

0, 0.25) will be used for the diagonal of matrix to refer to the comparison of the same dimensions. Then, judgment of experts about assess influence of each dimension on the other using linguistic variables will be transformed into their corresponding of triangular fuzzy numbers (TFNs) as shown in Figure 4.

- Step 6 – converting the fuzzy experts judgments into crisp judgment by CFCS method.

Fuzzy number will be converted into crisp scores using the converting fuzzy data into crisp scores (CFCS) defuzzification method [12, 32]: $Z_{ij}^k = (l_{ij}^k, m_{ij}^k, u_{ij}^k)$ refer to the fuzzy score based on opinion of the K experts based on Table 2, where: $k = 1, 2, \dots, p$.

1. Normalization:

$$X l_{ij}^k = (l_{ij}^k - \min l_{ij}^k) / \Delta_{min}^{max} \quad (1)$$

$$X m_{ij}^k = (m_{ij}^k - \min l_{ij}^k) / \Delta_{min}^{max} \quad (2)$$

$$X u_{ij}^k = (u_{ij}^k - \min l_{ij}^k) / \Delta_{min}^{max} \quad (3)$$

$$\Delta_{min}^{max} = \max u_{ij}^k - \min l_{ij}^k \quad (4)$$

where: $X l_{ij}^k$ – normalized value of the lower fuzzy score;

$X m_{ij}^k$ – normalized value of the middle fuzzy score;

$X u_{ij}^k$ – normalized value of the upper fuzzy score;

$\min l_{ij}^k$ – min. value of the lower fuzzyscore;

Δ_{min}^{max} – max. fuzzy score value minus min. fuzzy score value.

Computing the left (ls) and the right (us) normalized values as follow:

$$xls_{ij}^k = xm_{ij}^k / (1 + xm_{ij}^k - X l_{ij}^k) \quad (5)$$

$$xus_{ij}^k = xu_{ij}^k / (1 + xu_{ij}^k - X m_{ij}^k) \quad (6)$$

2. Computing the total normalized crisp value as follow:

$$x^k_{ij} = [xls_{ij}^k (1 - xls_{ij}^k) + xus_{ij}^k * xus_{ij}^k] / [1 - xls_{ij}^k + xus_{ij}^k] \quad (7)$$

Computing the crisp values as follow:

$$Z^k_{ij} = \min l_{ij}^k + z^k_{ij} * \Delta_{min}^{max} \quad (8)$$

3. Integrating the crisp value by aggregate the opinion of all experts in one opinion for each cells of matrix as follow:

$$Z_{ij} = 1/p (z^1_{ij} + z^2_{ij} + \dots + z^p_{ij}) \quad (9)$$

Or can write as

$$Z = 1/p \sum_{p=1}^k z^p_{ij} \quad (10)$$

where: z_{ij} – represents the level of lean dimensions influence with each other.

Thus, the Initial direction matrix $Z = [z_{ij}]_{n \times n}$ that identify the influences between the five lean dimensions has been constructed

- Step 7 – normalizing the Initial direction matrix Z for determining the normalized direct relation matrix X where $X = [x_{ij}]_{n \times n}$, and $0 \leq x_{ij} \leq 1$ as follow [33].

$$X = r \cdot Z \quad (11)$$

$$r = 1 / \max \sum_{j=1}^n z_{ij} \quad 1 \leq i \leq n \quad (12)$$

where: $i, j = 1, 2, \dots, n$.

- Step 8 – calculate the Total relation matrix T as follow [33]:

$$T = X(I - X)^{-1} \quad (13)$$

where: I – the identity matrix.

- Step 9 – computing the threshold value (α) using Eq. 14 where it is represented the average of values in the Total Direction Matrix (T) as follow:

$$\alpha = (\sum_{i=1}^n \sum_{j=1}^n X_{ij}) / n \quad (14)$$

where: i – dimensions in rows;

j – dimensions in columns;

X_{ij} – values of cells of the total direction matrix;

n – Cells No.

- Step 10 – sum up separately the rows and columns of the total relation matrix T as follow [33]:

$$T = \sum t_{ij} \quad (15)$$

$$D = \sum_{j=1}^n t_{ij} \quad (16)$$

$$R = \sum_{i=1}^n t_{ij} \quad (17)$$

where: D – the sum of rows cells for the total relation matrix T ;
 R – the sum of columns cells for the total relation matrix T .

- Step 11 – computing the Influence Weight (W_i), degree of relation (I_i) and Importance Weights (WI_i) of the lean dimensions.

$$W = D + R \quad (18)$$

$$I = D - R \quad (19)$$

Where two types of influence relations are existed; cause dimensions that represent the decisive dimension that influence on the effect dimensions and it is so important dimension. The second type of relation is the effect dimension where the degree of influence is depending on the value of ($R-D$) where the highest positive value of influence relation ($D-R$) has the greatest direct influence on other dimensions contrastly, when the influence relation ($D-R$) is negative, so this dimension will be influence by other dimensions and it cannot improve through itself which need to take cause dimensions to effect the improvements [34].

Importance Weights (WI_i) can be computed using Equation 20 [14]:

$$WI_i = W_i / \sum W_i \quad (20)$$

where: WI_i – the Importance Weights of lean dimension where $i = 1, 2, 3, \dots, n$.

- Step 12 – Categorizing the five lean dimensions into four categories using the cause-effect-Importance diagram based on the degree of relation ($D-R$) and Influence Weight ($D+R$) of the lean dimensions as follow:

1. High influencing (cause dimension) & High importance dimension: refers to lean dimensions in this sector are driving dimensions for solving problems.
2. High influencing (cause dimension) & Low importance: indicates that lean dimensions in this sector are independent and can influence only a few other lean dimensions.
3. Low influence (effect dimensions) & High importance: refer that the lean dimensions are core problem that must be solved due to it is an effect dimensions that cannot be directly improved.
4. Low influence (effect dimensions) & Low importance: indicate that these lean dimensions are independent and effect dimensions that can be influenced by only a few other lean dimensions.

Where High influence is represent the cause dimension whereas Low influence represent the effect dimensions.

- Step 13 – identifying the interrelationship of influence among the lean dimensions using Interrelationship diagram based on the threshold value (α) where it is considered as reference value that used to identify the interrelationship among lean dimensions by identifying which values of this matrix has a higher than

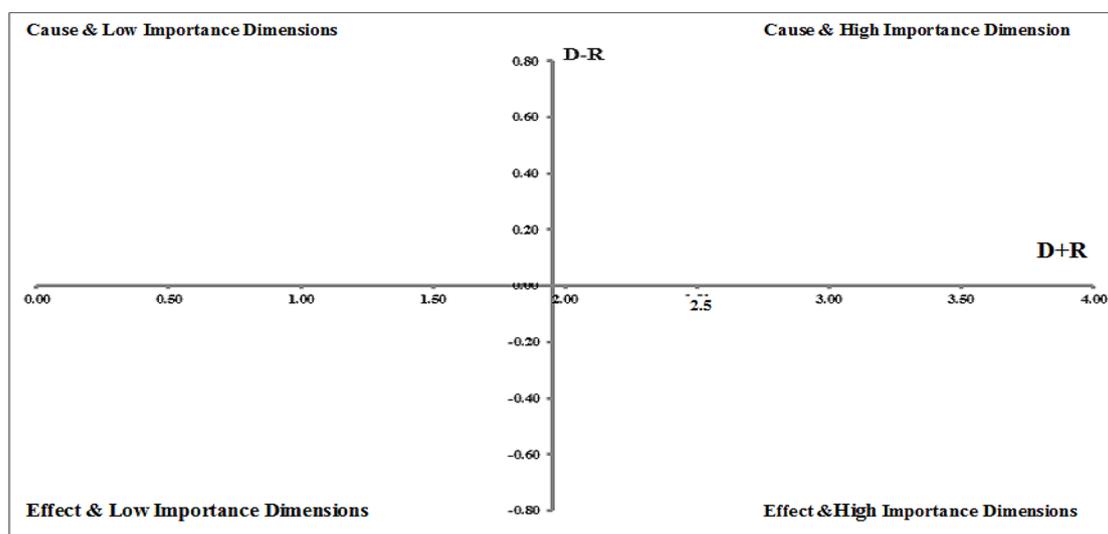


Fig. 5. Cause-effect-importance diagram of lean dimensions

the threshold value (α) where dimension in row with value up (α) will be considered dispatcher dimension to the dimension in column in that intersect with it (the bold value in matrix) and the below value will be considered a receiver's dimension.

THE APPLICATION THE PROPOSED MODEL

The calculations of the proposed model has established by MICROSOFT EXCEL and all calculations have done using fuzzy DEMATEL. Five companies for soft drink and healthy water have been surveyed to get opinion of their experts by performed pairwise comparisons by tick their opinions in the questionnaire sheet of the lean dimensions thus determining degrees of influence between lean dimensions Figure 6. Opinions of

the five experts have been converted from linguistic variables to triangular fuzzy numbers TFNs using Table 2 to construct the five fuzzy initial direct relation matrix, then conduct Equations from 1-8 to converted these fuzzy matrix to crisp matrix and finally these crisp matrices have been aggregated using Equation 9 to established the crisp aggregated initial direct relation matrix as shown in Figure 6.

Values of Total Relation Matrix 'T' have been computed sequentially by equation from 9-13. The threshold value (α) has been calculated by average of values of Total Relation Matrix 'T' using Equations 14. Influence weight (W) that represent dimension importance and degree of relation (I) of the five Lean dimensions have been identified sequentially using equations from 15-19 thus The cause and effect dimensions have been identified as shown in Table 3.

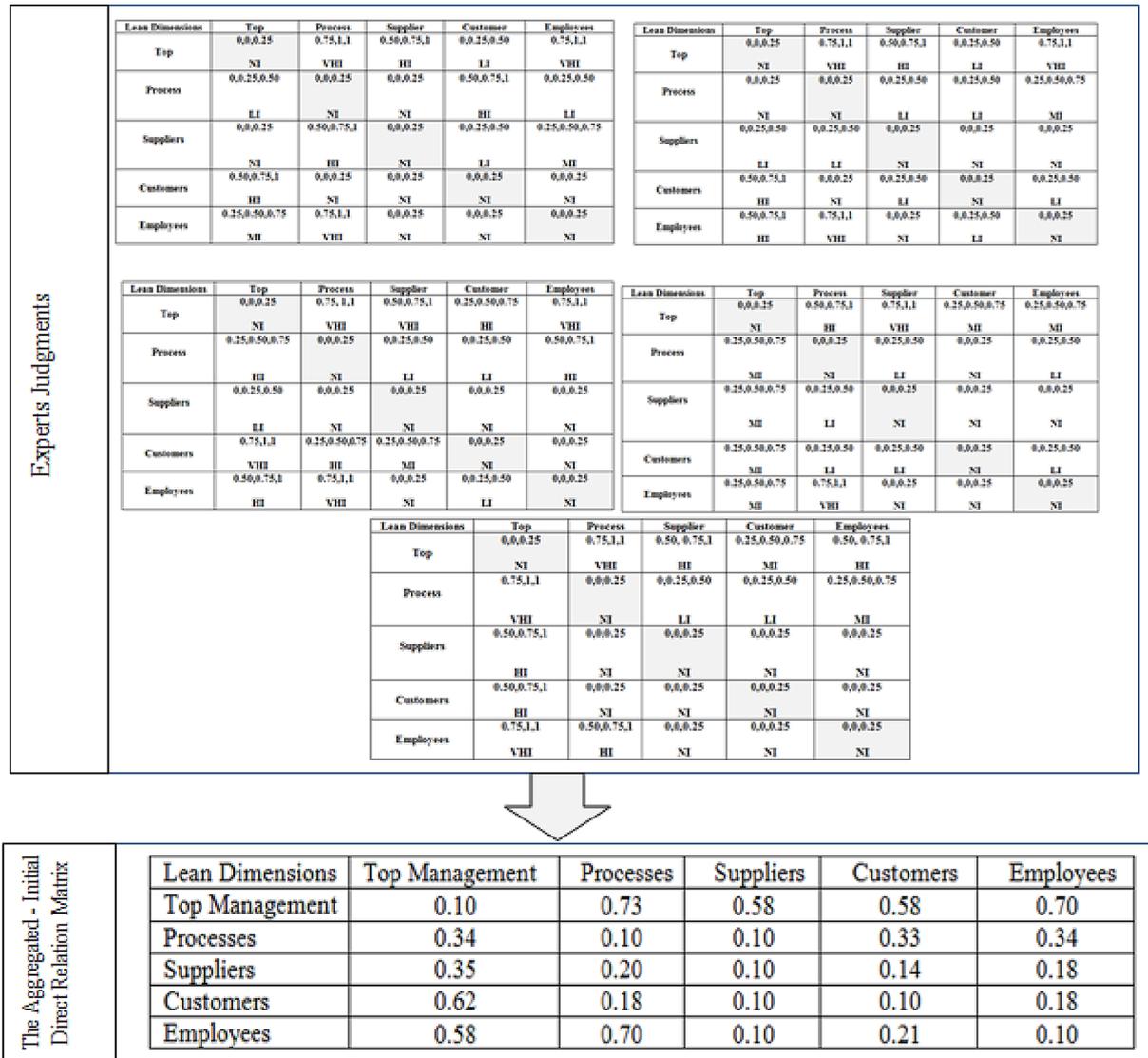


Fig. 6. Five expert's judgments and the aggregated-initial direct relation matrix

RESULTS AND DISCUSSION

Influence weights (D+R) of the five lean dimensions and degree of relation (D-R) have been calculated as illustrate in Table 3 using equations 18 and 19 and the calculations have conducted by fuzzy DEMENTAL and MICROSOFT EXCEL. Top management has high influence weight followed employees then processes,customers and finally suppliers with less influence. The Degree of

relation is varied among the five lean dimensions where top management,suppliers and employees with positive value of relation represent cause dimensions that represent as driving dimensions where any improvement in these dimensions will influence directly on the effect dimensions name-ly processes and customers with negative value of relation as illustrate in Table 3 where any improvements on the cause dimensions (the positive value of relation) using lean philosophy practices

Table 3. Illustrate lean dimensions influence level and influence relation

Equations used	16	17	18	20	Ranking	19	Relation type	Ranking according relation type
Lean dimensions	D	R	Influence weight (D+R)	Importance weights %		Degree of relation D-R		
Top management	2.234	1.587	3.822	27.379	1	0.646	Cause	1
Processes	1.035	1.740	2.776	19.886	3	-0.705	Effect	5
Suppliers	0.935	0.907	1.843	13.205	5	0.027	Cause	3
Customer	1.208	1.268	2.477	17.746	4	-0.060	Effect	4
Employees	1.566	1.474	3.040	21.782	2	0.092	Cause	2

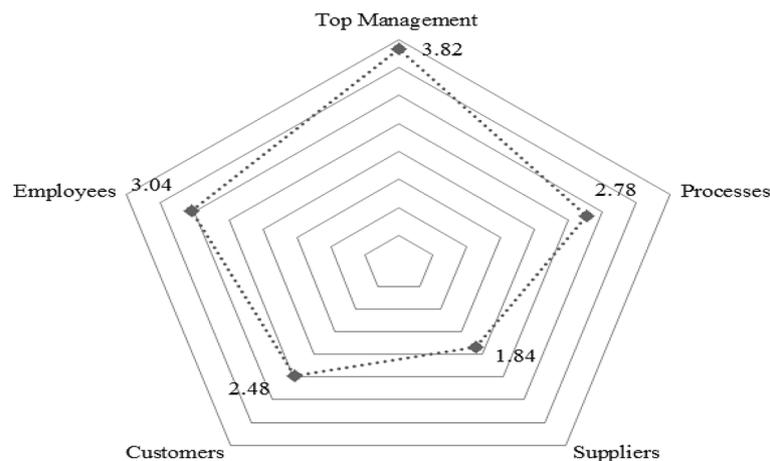


Fig. 7. Radar chart illustrate influence weight of the five lean dimensions

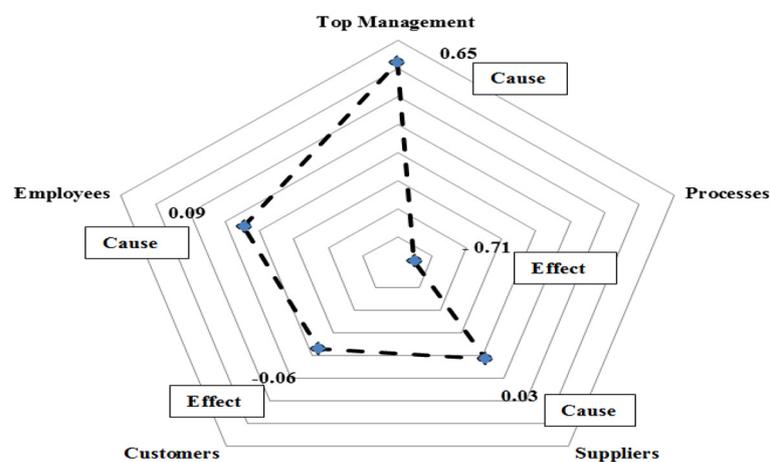


Fig. 8. Radar chart of the degree of relation for each lean dimension

and policies will be dramatically effect on the effect dimensions (the negative value of relation).

The radar chart illustrates top management has the highest influence So it consider the most important dimension for improvement than other, contrastly suppliers is less important dimension compared with other lean dimensions as shown in Figure 7 and Table 3 at the same time top management has a highest positive degree of relation among the rest dimensions where it is a cause dimension with suppliers and employees whereas processes and customers are an effect dimensions as shown in Figure 8.

The degree of relation and level of importance of the five lean dimensions have been positioned by the four sectors of Cause-effect-Importance diagram based on importance (D+R) and degree of relation (D-R) of the five lean dimensions as shown in Figure 9, where:

1. Lean dimensions with high degree of relation influence and high importance: this category involved top management and employees and these dimensions are characterized as a cause dimensions, are the essential dimensions influencing on other dimensions, and are as driving dimensions for resolving problems
2. Lean dimensions with high degree of relation influence and low importance:-this category comprised suppliers dimension and it is a cause dimension that has a minor influence on the other lean dimensions with low degree of influence.
3. Lean dimensions with low relation influence and high importance: this category included customers and processes dimensions and these lean dimensions are characterized as an effect

dimensions, are influence by other lean dimensions and cannot be directly improved where it need the cause dimensions to effect the improvements.

4. Lean dimensions with low relation influence and low importance: this category is influenced by other dimension and no lean dimension is existence in this part of diagram where it is an effect dimensions and relatively independent and the degree of influence is extremely low.

So, Cause-effect-Importance Diagram is important tool to distinguish firstly the type of dimensions whether cause or effect dimensions in addition identify the degree of importance of each dimensions of both cause and effect dimensions.

The total relation matrix (T) has been developed as shown in Table 4 through sequential calculating steps 10-13 and threshold (α) of the total relation matrix has computed using Equation 14 and it is 0.28 where it is considered as reference value that used to identify the interrelationship among lean dimensions by identifying which values of this matrix has a higher than the threshold value (α) where dimension in row with value up (α) will be considered dispatcher dimension to the dimension in column in that intersect with it(the bold value in matrix) and the below value will be considered a receiver's dimension as shown in Figure 10.

A comparison will be done between each two dimensions in the total-relation matrix T to represent visually the direction of influence of them using arrows, for example, the interrelation between top management and processes can be identified as follow:

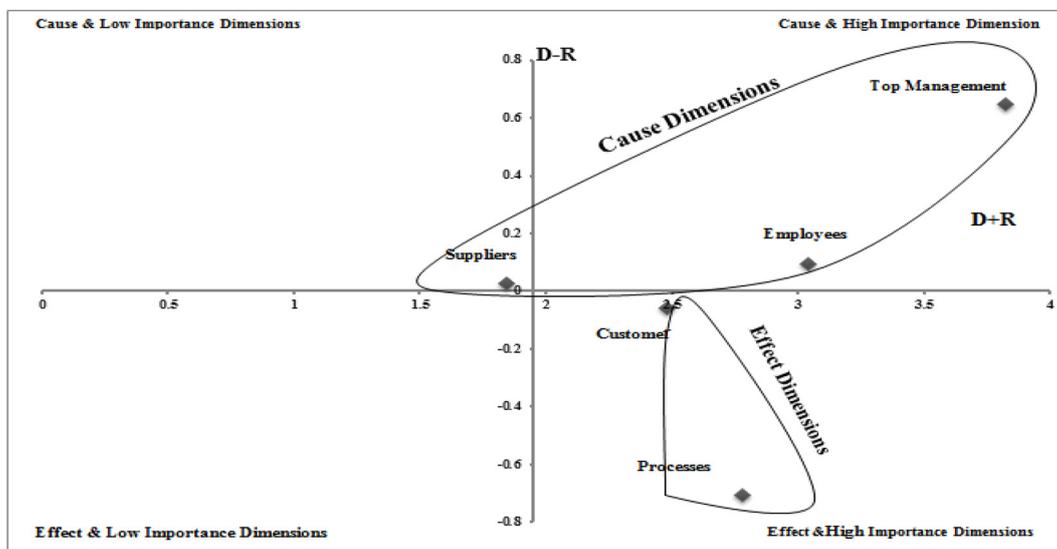


Fig. 9. Cause-effect-importance diagram of lean dimensions

Table 4. The total relation matrix

Lean dimensions	Top management	Processes	Suppliers	Customers	Employees
Top management (T)	<u>0.35</u>	<u>0.58</u>	<u>0.36</u>	<u>0.44</u>	<u>0.51</u>
Processes (P)	0.22	0.20	0.11	0.23	0.27
Suppliers (S)	0.25	0.22	0.12	0.16	0.19
Customers (C)	<u>0.38</u>	0.26	0.15	0.18	0.24
Employees (E)	<u>0.40</u>	<u>0.48</u>	0.17	0.26	0.26

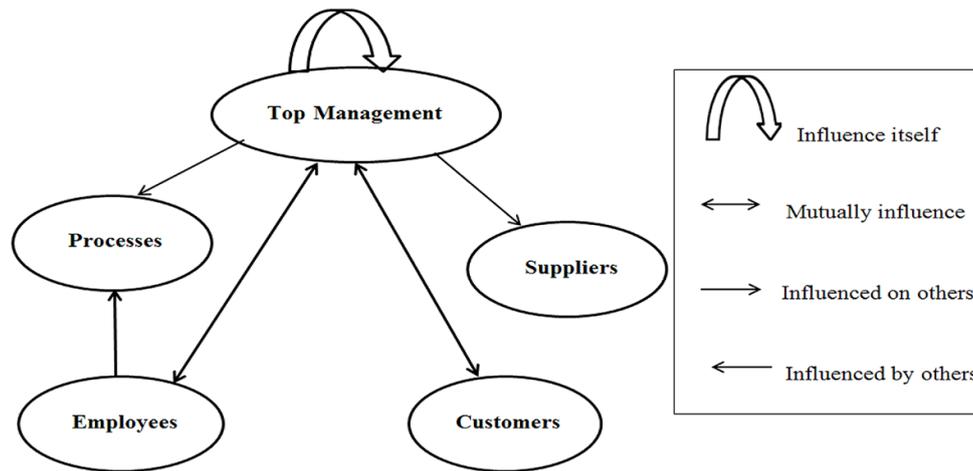


Fig. 10. Interrelationship diagram of lean dimensions

$t_{TP} = 0.58 > 0.28(\alpha)$ so this relation can be represented and influence direction can be visualized by an arrow that out from top management toward processes and indicate that processes is affected by top management and the whole relationship among lean dimensions can be identified by the same process.

Interrelationship diagram, Figure 10 illustrates the interrelationship of the influence among all lean dimensions where the top management has the highest effect on all the lean dimensions compare with other at the same time employees has an influence on both processes and top management while processes and suppliers dimensions have not have any effect on top management and employees. Improvement the lean dimensions can be conducted using lean philosophy practices and policies that association with each dimension of these five lean dimensions.

CONCLUSIONS

Lean manufacturing is considered an efficient manufacturing philosophy for improving organization performance through eliminating all type of waste throughout it where involving participate of all level of organization such top management, employees in addition to the important role of suppliers

and customers in the improvement process. Five essential lean dimensions has been selected based on survey namely; top management, processes, suppliers, customers and employees. This research has investigated the degree and type of relation among the five lean dimensions and assessed importance of each one. Cause-effect-importance diagram has developed to categorize lean dimensions into four groups according to degree of relation influence and importance. Top management is the most important and influence dimension than other lean dimensions that has the highest importance and highest degree of relation influence thus, it is considered the driving lean dimension to improving lean performance where any improvement in management performance will directly influence on the other lean dimensions. The interrelationship among the five dimensions has established using interrelationship diagram where top management has highest effect on all dimensions whereas employees has influence only on both top management and processes. Many other lean dimensions with sub lean criteria can be included in future work for more insight study to investigate influence not only the lean dimensions on each other but also influence of sub criteria on each other and identify level of importance of them in addition get opinion of more than 5 companies and experts.

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