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# IDENTIFICATION OF CRITICAL SUCCESS FACTORS FOR LEAN MANUFACTURING USING FUZZY DEMATEL METHOD

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## ABSTRACT

Companies should focus on adopting the most suitable initiatives that support in satisfying their customer needs. Lean is considered as one of the most important initiatives that enhance the internal processes; hence, significant results can be achieved. On the other side, it is crucial to sustain such results over time. In order to achieve such sustainability, companies need to identify and strengthen the lean success factors before establishing a lean program. In this paper, Fuzzy-DEMATEL method is used to identify such factors. The proposed approach is applied in an Egyptian factory. Before the identification of lean critical success factors, the company tried to implement lean applications. Positive results were achieved but on the long run, the system restored its initial performance levels. After applying the proposed approach, it is concluded that "Education and training", "Top management involvement", "Leadership" and "Cultural change" are the critical factors and should be strengthen before lean consultant participation. After working on such factors, continual improvement is achieved and remained since 2015. On average there are 60 improvement actions executed monthly in that firm. Moreover, reducing of work-in-process and improving production rate are continually improved even after closing the lean training program.

KEYWORDS: Lean Manufacturing, Fuzzy DEMATEL, Success Factors, Continual Improvement, Knowledge Management.

## 1. INTRODUCTION

Currently manufacturing companies are facing many market challenges. To gain market competition, organizations should satisfy quickly their customers' needs and reducing their manufacturing costs. Generally, the operational objectives should

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be determined carefully to support achieving organizational targets. There are three strategic concepts: provide better product or at least different; provide cheaper product; and provide product more responsively than competitors [1]. Anyway, the strategic strategies are subjective. Each strategy puts different requirements on operations management i.e. to achieve a specified strategic target; experts should implement convinced operational tactics/initiatives. Tactics are the methods or action plans that can be implemented to change the manufacturing status towards the achievement of the desired target. A range of improvement tactics are available e.g. Lean Manufacturing, Six-Sigma, Total Production Maintenance (TPM), Total Quality Management etc. Organizations that want to implement any improvement initiative still have to know how to be ready before consuming resources. Lean manufacturing approach now is considered as an important improvement tactic that used to improve operational performance. Lean is the way to specify value, lineup value-creating actions in the best sequence, conduct these activities without interruption, and perform them more and more effectively [2]. Principles for practical implementation of the lean manufacturing were described as follows:

- Specify value: It is important for companies to understand what customer particular needs are at a certain time and what they are ready to pay for.
- Identify the value stream: the next lean principle is to identify the actual value stream, i.e. the whole set of activities or services required to produce the specific product.
- Make the value activities flow: This is a very critical step, as it requires a change in thinking: away from the traditional batch production approach thinking in the direction of the continuous flow thinking.
- Apply the pull principle: The pull principle means that you let the customer to pull the product from your company as needed instead of pushing products to the customer and so accumulating huge stocks of products that no one wants.
- Strive for perfection: There is no end in reducing effort, time, space, cost and mistake while simultaneously producing more and more products [3].

Waste elimination is the main purpose of lean applications. While the elimination of waste may seem like a simple and clear subject, it is noticeable that waste is often very conservatively identified; cultural change should occurred to observe different types of waste within production plant. Toyota defined three types of waste: -MURI (or overburden), it focuses on the preparation and planning of the process, or what work can be avoided by design. -MURA (or unevenness), it focuses on implementation and the elimination of fluctuations at the scheduling or operations level, such as quality and volume. Mura is avoided through the Just-in-Time systems. -MUDA (or non-value-added work), it can be discovered after the process is in place and is dealt with reactively [4]. There are seven sources of waste that identify and classify sources that are commonly wasted: 1- Production ahead of demand, 2- Transportation: to move product that is not actually required to perform the processing. 3- Waiting: Waiting for the next production step or for tools. 4- Inventory: All components, work-in-progress and finished product not being processed. 5- Motion: People or equipment moving or walking more than is required to perform the processing. 6- Over-processing: Due to poor tool or product design creating activity. 7- Defects: The effort involved in inspecting for and fixing defects [5]. Once the wastes are identified, the suitable improvement tool that reduces or eliminates this waste should be selected. There are many lean tools that can be used that have been conceived by Toyota production system e.g. Value Stream Map (VSM), production smoothing, continuous improvement, 5S, single-minute die exchange, total quality management, just-in-time, etc., [6]. Actually, the implementation of lean manufacturing involves many changes to the existing manufacturing system. Since every company has different needs, the changes adopted are different to suit the explicit situation. In addition, creativity is a great part of implementing lean manufacturing; experts have to fine tune the ways of lean principle and this is done by trial and error, most of the time [7]. In order to reduce the trial time and sustain the achieved results, firms need to identify the success factors for applying lean tools. In addition, experts' knowledge is used to select the critical success factors based on the understanding and diagnosing of the manufacturing system. A group decision-making tool like Fuzzy-DEMATEL can be used to manage experts' knowledge in order to select/identify the critical success factors for lean manufacturing relying on the interrelationships that can be found among those factors.

Due to this importance, the current paper proposes a sophisticated methodology to identify the critical success factors of lean production relies on experts' knowledge. The proposed methodology uses the Fuzzy-DEMATEL method (Fuzzy-Decision Making Trial and Evaluation Laboratory) to prioritize the selected success factors for lean manufacturing based on their impact and influence. The DEMATEL method has been developed in 1970's at Battelle Memorial Institute at Geneva Research Center by A. Duval, E. Fontela and A. Gabus. It is used to solve multiple problems in science and economy by using expert's decisions [8]. Recently, DEMATEL became a popular method. It is considered as a widespread technique that is able to evaluate all intertwined causes and effect relationships in any structural model. This methodology is able to verify interdependence among the attributes or features and try to reflect the interrelationship between variables [9]. DEMATEL can identify the interdependence among criteria through a causal structure [10]. The literature provides many references that indicate the applicability of such method in analyzing the interrelationships between criteria. It was used in analyzing the interrelation among the core competences of the design service of the integrated circuit [11], and in understanding the relationships between performance metrics of supply chain [12]. Due to this capability of analyzing the relation between system criteria and prioritizing the most important one(s), DEMATEL method is used here for analyzing the relation among the lean success factors and then prioritizing them. Additionally, the fuzzy logic is used to overcome the uncertainty problem associated with experts' evaluations.

## 2. PROBLEM DESCRIPTION

Manufacturing organizations implement various performance initiatives or techniques to improve their internal processes. A range of improvement initiatives are available and can be adopted. One of them is the lean manufacturing. The implementation of lean requires a preparation phase. The different aspects of such phase are considered as the success factors of lean manufacturing. Highlighting these success factors shall enhance applying lean manufacturing. In addition, without the understanding and the employing of these factors most results could not be sustained or maintained. This leads to consume the firm's resources in adopting lean without real significant and sustainable benefits. Moreover, the implementation plan of lean manufacturing relies mainly on the experts' knowledge and their experience during the different phases of the implementation process. The current problem can be summarized by the following questions:

- How can organizations identify and prioritize the success factors of lean manufacturing approach by utilizing experts' knowledge?
- What is the best order of lean critical success factors for the implementation process?
- How can organization enhance the determined critical success factors for sustaining and continually improving lean applications results?

The current research proposes to use Fuzzy-DEMATEL method to answer the first two questions. First, the lean success factors should be identified. The literature provides many attempts to identify these critical success factors. The second step is to use experts' knowledge and skills to evaluate the interrelationships between these factors in a cause and effect relationships. The most critical success factors have a significant effect on others. Fuzzy-DEMATEL method is capable to provide such structured relationships. By interpreting the results of Fuzzy-DEMATEL the most critical success factors can be identified. Moreover, the importance of each factor is ranked that can be used to determine their best order. Regarding the third question, it will be answered by using focused group for brainstorming to introduce the most suitable operational actions that strengthen the lean critical factor.

## 3. PROPSED MEHODOLOGY

### 3.1 Factors Identification

The literature provides many success factors for the implementation of lean manufacturing. The following seven critical success factors for the implementation of lean in IT sectors are concluded as follow: “management leadership”, “management support”, “top management commitment”, “organizational culture”, “communication”, “training and skill building”, “financial capability”, and “measurement framework” [13]. For food industry, It is concluded also that the most important success factor are the “skill of workforce and in-house expertise”, after that respectively come “organizational culture”, “financial capabilities”, and “leadership and management” [14]. It is also considered that the critical success factors of lean manufacturing are: “leadership”, “structured improvement procedures”, “quality information and analysis”, “supplier relationship”, “customer focus”, and “focused metrics” [15]. Moreover, the following factors: “linking to business strategy”, “project management skills and “training” are concluded [16]. In addition, the “Cultural of the organizations" and the “Communication of goals with improvement initiatives” as another success factors in European SMEs are considered [17]. Also “selection of appropriate improvement tools" and "lack of resources" as critical factors needed to prevent failure of lean applications are added [18]. There are 31 research papers that summarized the lean success factors, such as "selection of staff" and "Organization infrastructure" should be considered among success factors [19]. More over there are 19 factors, such as "monitoring and evaluation of performance", "Building of a Kaizen team" and "Consultant participation" should be concluded [20]. Many researchers highlighted and discussed the same previous success factors [21-26]. Table 1 lists the main proposed success factors.

Table 1. Lean manufacturing success factors.

| Lean manufacturing success factors | | Reference | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | [13] | [14] | [15] | [16] | [17] | [18] | [19] | [20] |
| SF1 | Top management involvement and commitment | √ | | | | | | | |
| SF2 | Cultural change | √ | √ | | | √ | | | |
| SF3 | Organizational infrastructure | | | | | | | √ | |
| SF4 | Leadership | √ | √ | √ | | | | | |
| SF5 | Linking method to business | | | | √ | | | | |

| Lean manufacturing success factors | | Reference | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | [13] | [14] | [15] | [16] | [17] | [18] | [19] | [20] |
| | strategy | | | | | | | | |
| SF6 | Linking method to customer | | | √ | | | | | |
| SF7 | Project management skills | | | | √ | | | | |
| SF8 | Education and training | √ | | | √ | | | | |
| SF9 | Reward system | | | | | | | √ | |
| SF10 | Kaizen team | | √ | | | | | √ | √ |
| SF11 | Communication | √ | | | | | | | |
| SF12 | Consultant participation | | √ | | | | | | √ |
| SF13 | Project selection | | | | | | | | √ |
| SF14 | Monitoring and evaluation of performance | | | √ | | | | | |
| SF15 | Data base approach | | | √ | | | | | |
| SF16 | Sufficient and allocated resources | √ | √ | | | | √ | | |
| SF17 | Extending Lean approach to suppliers | | | √ | | | | | |
| SF18 | Understanding tools and techniques | | | | | | √ | | |
| SF19 | Structured improvement procedure | | | √ | | | | | |
| SF20 | Clear operational objectives | | | | | √ | | | |

### 3.2 Identification of Critical Success Factors

Relying on the literatures discussed in the previous section, the topic of the identification of the lean critical success factors attracts the attention of researchers. However, as described in Table 1 there is no agreement between researchers of what are the most critical success factors. Due to this challenge, the current work proposes to use Fuzzy-DEMATEL method to identify the most critical success factors for the implementation of lean manufacturing. The DEMATEL method is adopted in reasons of its capability for solving the problem of interrelationships between factors. In the other side, the fuzzy logic is considered to overcome the problem associated with the uncertainty of experts' decision for evaluating the strength of these relationships. Experts are used to evaluate the relation between factors and their associated importance. In the next section, the Fuzzy-DEMATEL method will be presented in some details. After applying Fuzzy-DEMATEL method, one can have two main attributes of each factor: the “effect given” and the “effect received”. The value by which each factor affects the others factors is called "the effect given ". The effect received means that the current factor is affected by others by this value. Relying on these attributes, the degree of importance and the net effect can be computed for each factor. By the analyses of these values (effect given, effect received, degree of importance, and the net effect), the most critical success factors can be identified.

### 3.3 Fuzzy DEMATEL Method

Fuzzy-DEMATEL is proposed for analyzing the interrelationships among lean success factors considering decision uncertainty. It can be used for gathering experts’ knowledge and forming a structure model that allows the decision-makers to recognize the factors of greater influence. DEMATEL method starts by a preparation step [27]: In which the different lean success factors can be collected as discussed earlier. Organize those factors in an (N×N) matrix, where N is the number of factors. Set the measuring scale that can be used to express the influence of the relationships between factors. A typical form for this scale is zero to four, where (0 = no influence, 1- weak influence, 2- average influence, 3- high influence and 4=very-high influence). Establishment of the Direct Relation Matrix: First, a set of experts are asked to fill-in the prepared matrix by assessing the level which they believe that any of the factors influences each other. A complete matrix is gotten from each expert. The direct relation matrix is obtained by averaging all experts’ evaluations. In this matrix each element ($a_{ij}$) indicates the degree by which factor $i$ influences factor $j$. calculating the normalized direct relation matrix $D$: This is done by dividing each element in the direct relation matrix by the largest row sum of the average matrix. Calculating the Total Relation Matrix ($T$): $T = D \times (I\text{-}D)^{-1}$, where: "$I$" is the identity matrix. Suppose ($R_i$) is the sum of ($i^{th}$) row in $T$ matrix, then ($R_i$) indicates the effects given by factor $i$ to the other factors. Suppose also ($C_j$) denotes the sum of ($j^{th}$) columns in matrix $T$, then ($C_j$) shows the effects received by factor $j$ from other factors. Relying on ($R_i$) and ($C_j$) the degree of importance and the net effect can be computed for each factor. Degree of importance equals ($R_i$ + $C_j$), and net effect equals ($R_i$ - $C_j$) for each $i = j$ and *i = 1, 2… N and j = 1, 2… N*. As mentioned earlier, experts decisions are suffer from uncertainty; to overcome this problem the Fuzzy logic is adopted. The literature provides many membership functions that can be used to represent experts' evaluation of the interrelationships between factors e.g. trapezoidal, triangular, or any other shapes [28-32]. In this paper the triangular fuzzy number is used, to represent the fuzziness of human assessments. Also the Fuzzy-DEMATEL model adopted as follow: the triangular fuzzy number $\tilde{A}$ is characterized as trey (*l*, *m*, *r*) and the membership function $\mu_{\tilde{A}}$ of this number can be represented as:

$$\mu_{\tilde{A}}(x) = \begin{cases} 0 & x < l \\ (x-l)/(m-l) & l \leq x \leq m \\ (r-x)/(r-m) & m \leq x \leq l \\ 0 & x > l \end{cases}$$

The procedures of applying Fuzzy-DEMATEL method can be summarized by the following steps [33]:

Step 1: A set of *n* experts are asked to indicate the level at which they believe that any of the factors influences each other. We get from every expert an (*N*×*N*) answer matrix, where *N* is the number of factors. These crisp evaluations are then fuzzified. The fuzzification can be done according to Table 2. Subsequently, aggregate the *n* Fuzzy decision matrices into an average Fuzzy matrix according to Eqs. (1-4).

Table 2: Fuzzification of crisp evaluation given by experts

| Linguistic terms | Influence crisp score | Triangular Fuzzy numbers |
|---|---|---|
| No influence | 0 | (0, 0, 0.25) |
| Weak influence | 1 | (0, 0.25, 0.5) |
| Average influence | 2 | (0.25, 0.5, 0.75) |
| High influence | 3 | (0.5, 0.75, 1.0) |
| Very high influence | 4 | (0.75, 1.0, 1.0) |

$$\tilde{e}_{ij} = \left(l_{ij}, m_{ij}, r_{ij}\right) \cong Aggregation\ (\tilde{e}_{ij}^{n}, n = 1, \ldots, N) \quad (1)$$

Where:

$$l_{ij} = \min_{n=1,\ldots,N} l_{ij}^{n}, \quad (2)$$

$$m_{ij} = \sum_{n=1}^{N} m_{ij}^{n} / N, \quad (3)$$

$$r_{ij} = \max_{n=1,\ldots,N} r_{ij}^{n}, \quad (4)$$

Step 2: Normalize the obtained matrix, $\tilde{e}_{ij} = (l_{ij}, m_{ij}, r_{ij})$

$$xr_{ij} = (r_{ij} - \min l_{ij})/\Delta_{min}^{max} \tag{5}$$

$$xm_{ij} = (m_{ij} - \min l_{ij})/\Delta_{min}^{max} \tag{6}$$

$$xl_{ij} = (l_{ij} - \min l_{ij})/\Delta_{min}^{max} \tag{7}$$

Where $\Delta_{min}^{max} = \max r_{ij} - \min l_{ij}$

Step 3: Compute right (rs) and left (ls) normalized values:

$$xrs_{ij} = xr_{ij}/(1 + xr_{ij} - xm_{ij}) \tag{8}$$

$$xls_{ij} = xm_{ij}/(1 + xm_{ij} - xl_{ij}) \tag{9}$$

Step 4: Compute total normalized crisp values:

$$x_{ij} = [xls_{ij}(1 - xls_{ij}) + xrs_{ij} \times xrs_{ij}]/(1 - xls_{ij} + xrs_{ij}) \tag{10}$$

Step 5: Compute crisp values

$$Z_{ij} = \min l_{ij} + x_{ij} \times \Delta_{min}^{max} \tag{11}$$

Step 6: Calculate the normalized direct relation matrix D by divide each element by the maximum value of all rows summation.

$$D_{ij} = Z_{ij}/\, max_{1 \le i \le Ta} \sum_{j=1}^{Ta} Z_{ij} \tag{12}$$

Step 7: Calculate the Total Relation Matrix (T):

$$T_{ij} = D_{ij} \times (I - D_{ij})^{-1} \tag{13}$$

Where: (I) is the unity matrix.

Step 8: Calculate summation of each row in the Total Relation Matrix (T):

$$R_i = \sum_{j=1}^{Ta} T_{ij} \quad \forall\, i = 1 \dots ta \tag{14}$$

Step 9: Calculate the summation of each column in the Total Relation Matrix (T):

$$C_j = \sum_{i=1}^{Ta} T_{ij} \quad \forall\, j = 1 \dots ta \tag{15}$$

After applying this process, the effect given ($R_i$), the effect received ($C_i$), the degree of importance ($R_i + C_j$) and net effect ($R_i$ - $C_j$) can be computed. Relying on these attributes, the importance of each success factor can be quantified. In addition, the influence of success factor on each other can be determined. Consequently, the most important or critical success factors for lean implementation can be determined with some analysis. After that, a focus group can be organized to interpret the results and answer the previously highlighted three questions.

## 4. CASE STUDY

The proposed methodology was applied at a home appliance firm located in Egypt to support understanding, identifying, and then strengthen the success factors of lean manufacturing approach. Before adopting the proposed work (before 2015) the firm tries many times to apply lean manufacturing approach. Already good results were achieved, but actually these results were not sustained, and the system restored its initial performance again. The firm decided to start implementing the proposed approach with a manufacturing system that produces a family of refrigerators. The firm aims to find the vital success factors that support applying lean manufacturing. These factors could be considered as a foundation that must be constructed before starting lean manufacturing approach, in order to sustaining the achieved results, and to accelerate its outcomes.

### 4.1 Proposed Lean Success Factors

The top management selects ten experts in Jan. 2015 together with the authors. The manufacturing experts have different experience in all production areas not less than seven years. The success factors of lean manufacturing are selected based on the previous literatures review and as listed in Table 1. The experts need to rank and prioritize these factors based on the degree of their importance, so it is proposed to use Fuzzy-DEMATEL method as a group decision making technique.

### 4.2 Applying Fuzzy- DEMATEL Method

For ranking the success factors based on the associated importance and the influence of each one of them to the others, the previous ten experts have rated each factor impact that it exerts on each other factors using the scale discussed in section 3.3. The experts are given empty matrix templates, and then each one of them fills his template by using the defined scale. After that, the Fuzzy-DEMATEL method is applied as previously presented. The total relation matrix is obtained as listed in Table 3. Based on this matrix, the effects that success factors exert ($R_i$) and receive ($C_j$) are calculated. By combining the impact given and received ($R_i + C_j$), the degree of importance of each factor can be computed, while subtracting them ($R_i - C_j$) gives the net effect. Figure 1 presents the causal diagram of the success factors: it represents ($R_i$-$C_j$) with respect to ($R_i + C_j$).

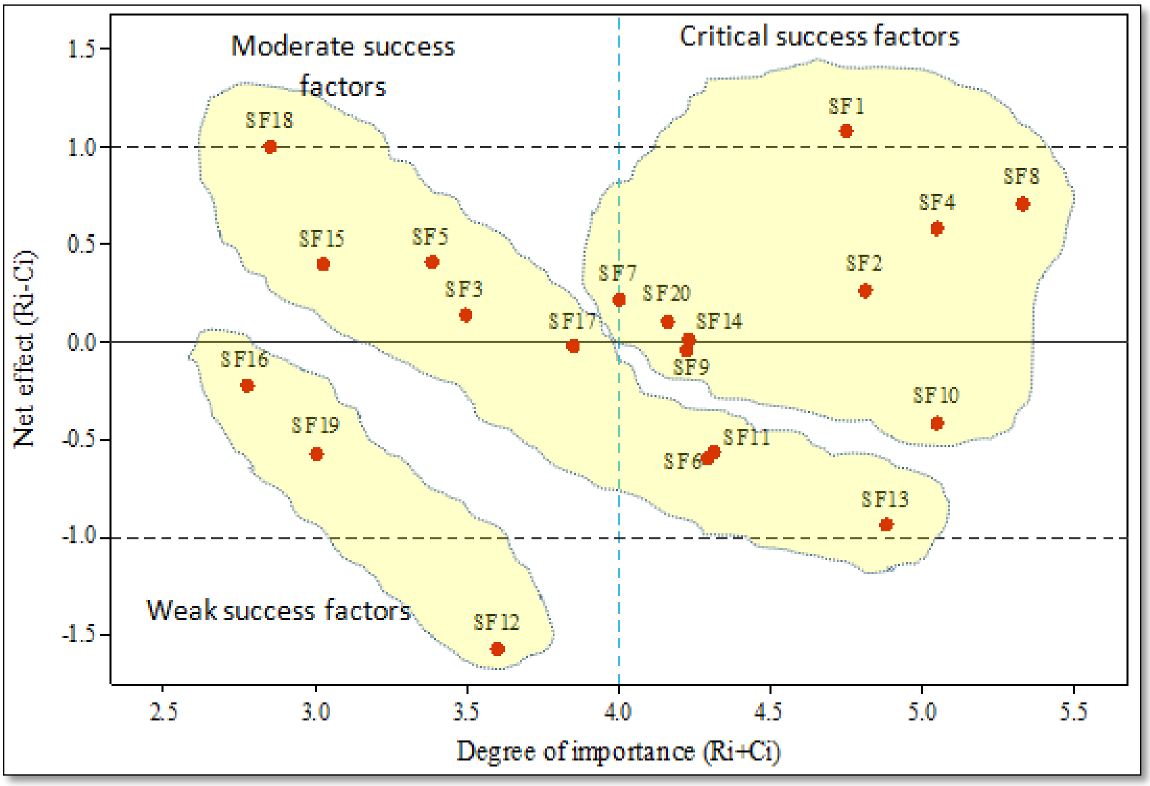


Fig. 1. Causal diagram of the success factors.

Table 3: Total relation matrix by Fuzzy-DEMATEL

| | SF1 | SF2 | SF3 | SF4 | SF5 | SF6 | SF7 | SF8 | SF9 | SF10 | SF11 | SF12 | SF13 | SF14 | SF15 | SF16 | SF17 | SF18 | SF19 | SF20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SF1 | 0.09 | 0.10 | 0.11 | 0.13 | 0.11 | 0.07 | 0.08 | 0.15 | 0.09 | 0.09 | 0.12 | 0.03 | 0.10 | 0.12 | 0.08 | 0.04 | 0.08 | 0.08 | 0.06 | 0.09 |
| SF2 | 0.16 | 0.10 | 0.08 | 0.16 | 0.12 | 0.09 | 0.10 | 0.17 | 0.14 | 0.15 | 0.13 | 0.06 | 0.12 | 0.11 | 0.09 | 0.05 | 0.12 | 0.10 | 0.07 | 0.14 |
| SF3 | 0.14 | 0.12 | 0.05 | 0.10 | 0.09 | 0.06 | 0.12 | 0.11 | 0.09 | 0.09 | 0.08 | 0.04 | 0.10 | 0.09 | 0.05 | 0.08 | 0.08 | 0.06 | 0.04 | 0.08 |
| SF4 | 0.16 | 0.14 | 0.08 | 0.11 | 0.13 | 0.08 | 0.14 | 0.17 | 0.14 | 0.14 | 0.10 | 0.05 | 0.12 | 0.11 | 0.09 | 0.05 | 0.10 | 0.12 | 0.07 | 0.14 |
| SF5 | 0.10 | 0.08 | 0.06 | 0.09 | 0.05 | 0.06 | 0.07 | 0.10 | 0.08 | 0.08 | 0.07 | 0.05 | 0.07 | 0.08 | 0.09 | 0.04 | 0.08 | 0.10 | 0.06 | 0.09 |
| SF6 | 0.17 | 0.15 | 0.12 | 0.17 | 0.11 | 0.08 | 0.11 | 0.18 | 0.13 | 0.16 | 0.10 | 0.09 | 0.13 | 0.12 | 0.12 | 0.06 | 0.13 | 0.13 | 0.08 | 0.13 |
| SF7 | 0.14 | 0.10 | 0.07 | 0.14 | 0.09 | 0.12 | 0.07 | 0.16 | 0.10 | 0.10 | 0.09 | 0.04 | 0.11 | 0.13 | 0.06 | 0.04 | 0.09 | 0.11 | 0.04 | 0.09 |
| SF8 | 0.17 | 0.15 | 0.12 | 0.16 | 0.10 | 0.13 | 0.14 | 0.12 | 0.14 | 0.12 | 0.10 | 0.06 | 0.12 | 0.11 | 0.09 | 0.10 | 0.12 | 0.08 | 0.05 | 0.12 |
| SF9 | 0.16 | 0.15 | 0.08 | 0.16 | 0.10 | 0.08 | 0.13 | 0.13 | 0.08 | 0.14 | 0.10 | 0.05 | 0.11 | 0.11 | 0.09 | 0.09 | 0.10 | 0.10 | 0.07 | 0.13 |
| SF10 | 0.19 | 0.17 | 0.14 | 0.19 | 0.12 | 0.14 | 0.15 | 0.20 | 0.16 | 0.11 | 0.14 | 0.07 | 0.13 | 0.13 | 0.08 | 0.10 | 0.12 | 0.16 | 0.08 | 0.15 |
| SF11 | 0.17 | 0.16 | 0.13 | 0.17 | 0.11 | 0.13 | 0.10 | 0.18 | 0.12 | 0.15 | 0.08 | 0.07 | 0.12 | 0.14 | 0.10 | 0.08 | 0.11 | 0.10 | 0.07 | 0.13 |
| SF12 | 0.18 | 0.15 | 0.12 | 0.18 | 0.13 | 0.12 | 0.13 | 0.17 | 0.14 | 0.14 | 0.13 | 0.05 | 0.14 | 0.14 | 0.10 | 0.12 | 0.09 | 0.11 | 0.10 | 0.13 |
| SF13 | 0.21 | 0.19 | 0.16 | 0.21 | 0.11 | 0.16 | 0.17 | 0.22 | 0.13 | 0.18 | 0.11 | 0.07 | 0.10 | 0.17 | 0.13 | 0.11 | 0.12 | 0.12 | 0.06 | 0.16 |
| SF14 | 0.16 | 0.14 | 0.12 | 0.15 | 0.09 | 0.12 | 0.13 | 0.16 | 0.11 | 0.14 | 0.09 | 0.04 | 0.10 | 0.08 | 0.11 | 0.05 | 0.09 | 0.09 | 0.04 | 0.10 |
| SF15 | 0.09 | 0.08 | 0.07 | 0.09 | 0.05 | 0.05 | 0.07 | 0.11 | 0.05 | 0.07 | 0.07 | 0.05 | 0.05 | 0.07 | 0.04 | 0.05 | 0.05 | 0.07 | 0.05 | 0.09 |
| SF16 | 0.14 | 0.09 | 0.07 | 0.12 | 0.07 | 0.07 | 0.08 | 0.10 | 0.06 | 0.06 | 0.05 | 0.03 | 0.10 | 0.10 | 0.09 | 0.03 | 0.05 | 0.07 | 0.05 | 0.06 |
| SF17 | 0.16 | 0.13 | 0.06 | 0.14 | 0.09 | 0.09 | 0.07 | 0.15 | 0.07 | 0.14 | 0.11 | 0.04 | 0.09 | 0.09 | 0.08 | 0.06 | 0.07 | 0.09 | 0.09 | 0.11 |
| SF18 | 0.05 | 0.07 | 0.03 | 0.05 | 0.03 | 0.03 | 0.04 | 0.11 | 0.06 | 0.04 | 0.03 | 0.04 | 0.03 | 0.06 | 0.05 | 0.03 | 0.09 | 0.03 | 0.02 | 0.04 |
| SF19 | 0.13 | 0.12 | 0.08 | 0.13 | 0.06 | 0.06 | 0.11 | 0.16 | 0.09 | 0.12 | 0.08 | 0.05 | 0.06 | 0.07 | 0.07 | 0.04 | 0.11 | 0.10 | 0.04 | 0.10 |
| SF20 | 0.14 | 0.13 | 0.06 | 0.16 | 0.13 | 0.11 | 0.09 | 0.15 | 0.10 | 0.10 | 0.09 | 0.06 | 0.07 | 0.10 | 0.11 | 0.04 | 0.11 | 0.11 | 0.07 | 0.08 |

Table 4 represents the values of ($R_i$), ($C_j$), ($R_i$-$C_j$), and ($R_i$+$C_j$) for all success factors. Then the authors together with the experts classify these factors into two main groups:

- Group 1): factors have positive net effect {*SF1, SF2, SF3, SF4, SF5, SF7, SF8, SF14, SF15, SF18, SF20*}
- Group 2): factors have negative net effect {*SF6, SF9, SF10, SF11, SF12, SF13, SF16, SF19*}.

Based on this classification, factors in group one can be considered as the cause factors (higher net effect), while factors in group two can be considered as the effect factors (lower net effect). Regarding to the given impact ($R_i$), Fig. 2 illustrates the success factors in descending order, it is observed that *SF8*: “education and training” has the highest given value, while *SF12*: “consultant participation” has the lowest.

Table 4: Results of Fuzzy-DEMATEL

| *Factor* | *Ri* | *Ci* | *Ri+Ci* | *Ri-Ci* |
|---|---|---|---|---|
| SF1 | 2.92 | 1.84 | 4.75 | 1.08 |
| SF2 | 2.54 | 2.27 | 4.81 | 0.27 |
| SF3 | 1.82 | 1.67 | 3.49 | 0.14 |
| SF4 | 2.82 | 2.23 | 5.05 | 0.58 |
| SF5 | 1.89 | 1.49 | 3.38 | 0.41 |
| SF6 | 1.85 | 2.45 | 4.29 | -0.6 |
| SF7 | 2.11 | 1.89 | 4 | 0.22 |
| SF8 | 3.02 | 2.31 | 5.33 | 0.71 |
| SF9 | 2.09 | 2.13 | 4.22 | -0.04 |
| SF10 | 2.32 | 2.73 | 5.05 | -0.41 |
| SF11 | 1.87 | 2.43 | 4.31 | -0.56 |
| SF12 | 1.01 | 2.58 | 3.6 | -1.57 |
| SF13 | 1.97 | 2.91 | 4.88 | -0.94 |
| SF14 | 2.13 | 2.11 | 4.23 | 0.02 |
| SF15 | 1.71 | 1.31 | 3.02 | 0.4 |
| SF16 | 1.28 | 1.49 | 2.77 | -0.22 |
| SF17 | 1.91 | 1.93 | 3.85 | -0.02 |
| SF18 | 1.93 | 0.93 | 2.85 | 1 |
| SF19 | 1.21 | 1.79 | 3 | -0.57 |
| SF20 | 2.13 | 2.03 | 4.16 | 0.11 |

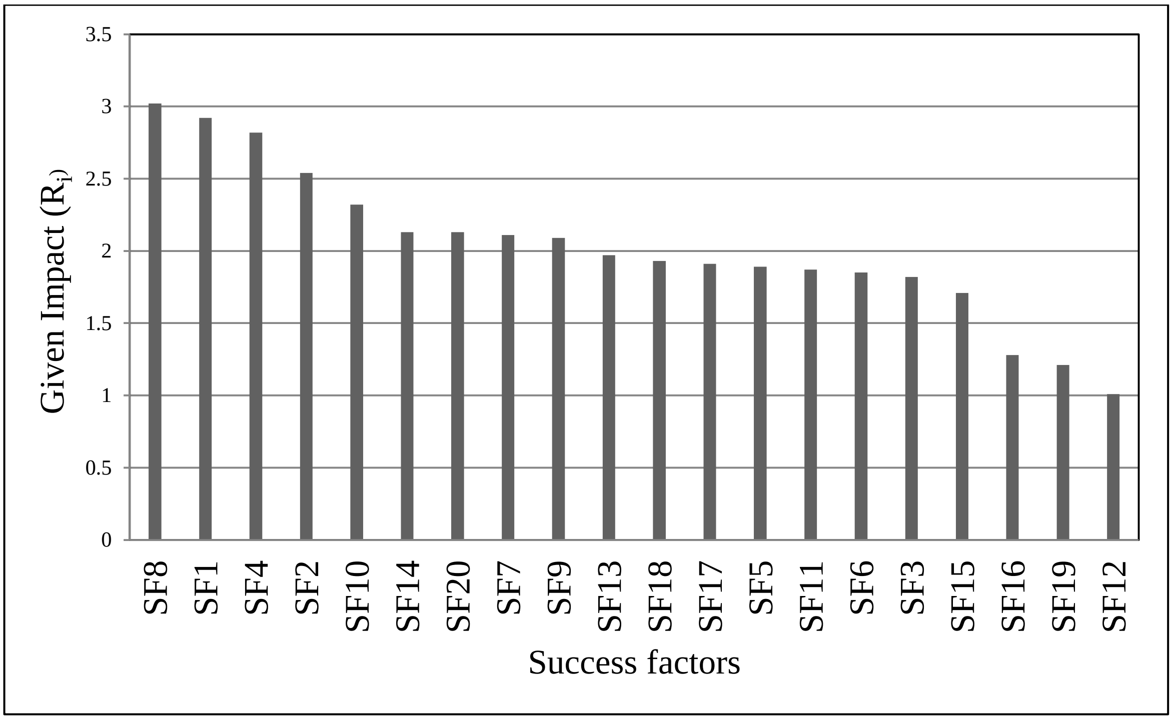


Fig. 2. Ranking of lean success factors based on given impact ($R_i$).

### 4.3 Analysis for Critical Success Factors

The critical success factors of lean manufacturing could be identified and prioritized by observing both Figs. 1, 2. Among all factors in the cause group, the following have the highest given impact ($R_i$): *SF8* (Education and training), -*SF1* (Top management involvement and commitment), -*SF4* (Leadership), -*SF2* (Cultural change). So, these four factors can be considered as the most critical success factors of lean approach. As shown by Fig. 1 these factors form a cluster of great net-effect and degree of importance. These cause factors have higher given impact, so more attention should be exerted to strengthen them in order to enhance the effect factors as a result i.e. improving these four factors can easily enhance others. The subsequent important factors are {*SF20, SF14, and SF7*}; these cause factors are respectively ranked relying on ($R_i$) values. Relying on the highest given impact ($R_i$+$C_i$), one can consider another significant group of factors that have the highest ($R_i$+$C_i$), even they have negative net effect, they can be ranked according to ($R_i$) as: {*SF10 and SF9*}. For easily converting the current production system into more lean production one, organization should start suitable education and training program for all levels to be aware about lean philosophy and culture (*SF8*), focuses on top management commitment and involvement (*SF1*), empowers leadership skills and attitude among the supervisors (SF4), and supports cultural change process (*SF2*). Besides and as previously described, the clear operational objectives (*SF20*), monitoring and evaluation of performance (*SF14*), and enhancing the project management skills (*SF7*) can be considered as critical success factors as they have positive net effect values and higher given factors than others. Moreover, forming of kaizen teams (*SF10*), and establishing of rewarding system (*SF9*) can be added to the lean critical success factors list. It is concluded that {*SF8, SF1, SF4, SF2, SF20, SF14, SF7, SF10,* and *SF9*} are the critical success factors of lean manufacturing, thus the organization need to enhance and strengthen these factors for easily adopting lean principles, and for sustaining and continually improving results. Besides, {*SF13, SF18, SF17, SF5, SF11, SF6, SF3*, and, *SF15*} respectively ranked based on ($R_i$) could be considered as success factors of lean manufacturing but not significant as the critical group.

The factors that have lowest degree of importance and negative net effect such as *SK16* (Allocated resources) could not be recognized as critical success factors, wherever Lean philosophy depends on small and continual improvement actions, hence no need for huge financial resources during starting lean approach. Similarly, *SK19* (Improvement procedures) this factor is a result factor, before applying improvement procedures all other factors like training, leadership, communications should be established. *SF12* (Consultant participation) has the lowest net effect, this means that before asking lean consultant to participate and before starting lean journey all previous success factors should be considered. In most cases, firms start lean applications by asking consultant to participate and not considering what they have to do first. To illustrate the effect of all success factors on *SF12*, Fig. 3 is introduced based on the effect given to *SF12* from all other factors. Many factors have significant impact on *SF12*. Consequently, organization should consider a set of actions before asking Lean consultant to participate.


Fig. 3. The influence of all factors on the participation factor.

### 4.4 Putting Success Factors in Actions

It is reported by the organization's experts that before 2015 the organization at hand started lean journey directly by asking consultant to participate, but the obtained results were not sustained. After providing this work, the organization makes an action plan to strengthen the identified success factors. There are two perspectives in this plan:

- Training Perspective: in which the company provided the following training program: -Team building, -Leadership, -Problem solving methods, - Management of innovations, -Project management tools, Kaizen philosophy, and -How to see the seven types of wastes.
- Managing Perspective: in which the company established new rules such as: -Forming cross functional Kaizen team, -Setting relevant operational objectives and indicators in all working areas using dashboards, -Establishing monthly rewarding system, -Performing monthly periodic meeting between top management and supervisors.

As described, the organization applied series of training programs at the first half of 2015 and before consultant participation to enhance the leadership skills and attitude focusing on supervisors and head of departments. In addition, training programs related to culture change (focusing on the difference between lean and mass production systems, how to see different types of waste, and Kaizen culture), and project management tools were provided. Moreover top management are holding two meeting monthly with supervisors and head of departments to follow up improvement actions and progress and follow up the relevant operational indicators, and to provide the needed support as a type of commitment. Another type of the top management commitment is the establishment of a reward system. The best three kaizen sheets are selected monthly based on clear criteria to motivate labors and to improve the predefined indicators continually. These indicators also are illustrated in each workstation/department using dashboards. All labors together with supervisors make daily stand up meeting to be involved with the current work challenges. Table 5 summarizes the actions taken based on experts' discussions to put the success factors in action before asking consultant to participate. The order of the success factors shown in Table 5 is the same as the order discussed previously.

These different considerations enhance lean applications when consultant of lean starting work in the middle of 2015, and keep improved results sustainable. Kaizen teams still work smoothly and gradually with performance improvement. On average there are 60 Kaizens introduced monthly from all the factory labors. These Kaizen actions lead to many progress such as reducing work in process (WIP), increasing production rate, improving quality rate (first pass yield), reducing assembly lead time, reducing the different types of waste, and improving the work environmental conditions even without participation of consultant; this means that the fifth lean principle "Strive for perfection" is achieved. It was reported that the total production rate improved by about %14.5 in 2016 as a result of continuous improvement actions. These significant results indicate the criticality of identifying the critical success factors of any performance improvement tactic before starting its application.

Table 5. Roadmap of Success Factors Enhancements.

| Factors | Methods of enhancement | Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|---|---|
| SF8 | Understanding Lean principles, and the types of wastes | √ √ | √ √ | | | | |
| SF1 | 1. Identify strategic objectives and targets<br>2. Establish monthly reward system<br>3. Set a regular follow up meetings | √ √ | | | | | |
| SF4 | Apply relevant tainting programs | √ √ | √ | | | | |
| SF2 | Provide training programs in - the difference between mass and lean systems, and - Kaizen culture | | √ √ | √ | | | |
| SF20 | Cascading of the operational objectives based on understanding of the strategic objectives | | √ √ | | | | |
| SF14 | Define the evaluation criteria | | | √ | | | |
| SF7 | Apply relevant tainting programs | | | √ √ | √ √ | | |
| SF10 | Build cross functional improvement team | | | | √ | | |
| SF9 | Define the criteria of best Kaizen selection | | | | √ | | |
| SF13 | Define the criteria of project selection | | | | √ | | |
| SF18 | Apply relevant tainting programs | | | | √ | √ √ | √ √ |
| SF17 | Review and modify delivery and packing conditions with the key suppliers | | | | √ | √ √ | |
| SF5 | Clarify the organization objectives | | | | √ | | |
| SF11 | Establish new reporting system between all levels | | | | √ | √ | |
| SF6 | Understand the product values from the point of view of customers | | | | | √ √ | |

| Factors | Methods of enhancement | Jan | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|---|---|
| SF3 | Modify the ERP system to follow up inventory level, and production plans, from point of view of sales plan. | | | | | √ √ | √ √ |
| SF15 | Provide training on problem solving methods, and -Data analysis | | | | | √ | √ √ |

## 5. CONCLUSIONS

The paper proposed a research methodology with a case study to select and understand the critical success factors for lean manufacturing to support in achieving organization’s operational goals. The proposed work is developed based on managing experts' knowledge by utilizing fuzzy-DEMATEL method. The proposed work was adopted in an Egyptian manufacturing firm from 2015, in one of its factories that is dedicated to produce home refrigerators. The results indicate that “Education and training”, “Top management involvement and commitment”, “Leadership”, and “Cultural change” respectively are the most critical success factors for lean manufacturing implementation. Strengthen these factors before consultant participation leads to sustainable achievements. For the case study, lean applications were started in 2015 and results indicate that continual improvements still occurred gradually and smoothly also achieved results are sustained. On average there are 60 Kaizen sheet were introduced monthly by kaizen teams, focusing on work in process reduction, increasing quality (first pass yield), reducing assembly lead-time, and eliminating different types of waste. It was reported that the total production rate improved by about %14.5 in 2016.

## REFERENCE


1. Heizer, J., and Render, B. "Principles of Operations Management” 4th Edition". Pearson College Div. 2000.
2. Womack, J. P., and Jones, D. T., “Lean Thinking: Banish Waste and Create Wealth in Your Corporation”. Simon and Schuster, 2010.
3. Womack, J. P., and Jones, D. T., "Lean Consumption". Harvard Business Review, Vol. 83, No. .3, pp. 58-68, 2005.

4. Moleiro Naval, Pablo “Process Improvements in a Material Handling Activity by Applying Lean Production Techniques”. Master's Thesis. Universitat Politècnica de Catalunya. 2008.
5. Hirano, H., “JIT Implementation Manual-The Complete Guide to Just-In-Time Manufacturing: Vol. 2-Waste and the 5S's”. CRC Press, 2016.
6. Liker, J., and Gary, L. C., “The Toyota Way to Lean Leadership: Achieving and Sustaining Excellence Through Leadership Development”. McGraw-Hill Education, 2011.
7. McClellan, J.J., “The Benefit of Using Simulation to Improve the Implementation of Lean Manufacturing Case Study: Quick Changeovers to Allow Level Loading of the Assembly Line”. Master's thesis, Brigham Young University – Provo, 2004.
8. Falatoonitoosi, E., Leman, Z., and Sorooshian, S.,. “Decision-Making Trial and Evaluation Laboratory”. Research Journal of Applied Sciences, Engineering and Technology, Vol. 5, No. 13, pp. 3476-3480, 2013.
9. Tamura, H., and Katsuhiro, A., "Stochastic DEMATEL for Structural Modeling of a Complex Problematique for Realizing Safe, Secure and Reliable Society”. Journal of Telecommunications And Information Technology, pp. 139-146, 2005.
10. Yang, Y. O., Shieh, H., and Leu, J.,. “A Novel Hybrid MCDM Model Combined with DEMATEL and ANP with Applications”. International Journal of Operations Research, Vol. 5, No. 3, pp. 160-168, 2008.
11. Tseng, M., Lin, Y., “Application of Fuzzy DEMATEL to Develop A Cause and Effect Model of Municipal Solid Waste Management in Metro Manila”. Environmental Monitoring and Assessment, Vol. 158, No. 1, pp. 519-533, 2009.
12. Najmi, A., and Makui, A.,. “A Conceptual Model For Measuring Supply Chain's Performance”. Production Planning & Control, Vol. 23, No. 9, pp. 694-706, 2012.
13. Kundu, G., and Murali, B. M., "Critical Success Factors For Implementing Lean Practices in IT Support Services". International Journal for Quality Research, Vol. 6, No. 4, pp. 301-312, 2012.
14. Dora, M., Kumar, M., Goubergen, D. V., Molnar, A., and Gellynck, X., “Operational Performance and Critical Success Factors of Lean Manufacturing in European Food Processing SMEs,” Trends Food Science and Technology., Vol, 31, No. 2, pp. 156-164, 2013.
15. Fadly, H. N., and Sha'ri, M. Y., "Critical Success Factors of Lean Six Sigma for the Malaysian Automotive Industry". International Journal. of Lean Six Sigma, Vol. 4, No.1, pp. 60-82, 2013.
16. Manville, G., Krishnasamy, R., and Parker, D.. “Critical Success Factors for Lean Six Sigma Programmes: a View from Middle Management”. International. Journal. of Quality & Reliability Management, Vol. 29, No. 1, pp. 7-20, 2012.
17. Bakås, O., Tim, G., and Hendrik, V. L., “Challenges and Success Factors for Implementation of Lean Manufacturing in European SMES”. In: 13th International conference on the Modern Information Technology in the

Innovation Processes of the Industrial Enterprise (MITIP 2011). Tapir Academic Press, 2011.

18. Albliwi, S., Antony, J., Abdulhalim, S., and Wiele, T., "Critical Failure Factors of Lean Six Sigma: a Systematic Literature Review". International Journal of Quality & Reliability Management, Vol. 31, No. 9, pp. 1012-1030, 2014.
19. Laureani, A., and Jiju, A., "Critical Success Factors for the Effective Implementation of Lean Sigma: Results from an Empirical Study and Agenda for Future Research". International Journal of Lean Six Sigma, Vol. 3, No. 4, pp. 274-283, 2012.
20. Alhuraish, I., Christian, R., and Abdessamad, K., "Key Success Factors of Implementing Lean Manufacturing and Six Sigma". In: Liverpool (2014): 17th Toulon-Verona Conference" Excellence in Services". 2014.
21. Henderson, K. M., and James, R. E., "Successful Implementation of Six Sigma: Benchmarking General Electric Company". Benchmarking: An International Journal, Vol. 7, No. 4, pp. 260-282, 2000.
22. Brun, A., "Critical Success Factors of Six Sigma Implementations in Italian Companies". International Journal of Production Economics, Vol. 131, No. 1, pp. 158-164, 2011.
23. Jeyaraman, K., and Leam, K. T., "A Conceptual Framework for Critical Success Factors of Lean Six Sigma: Implementation on the Performance of Electronic Manufacturing Service Industry". International Journal of Lean Six Sigma, Vol. 1, No. 3, pp. 191-215, 2010.
24. Näslund, D., "Lean and Six Sigma–Critical Success Factors Revisited". International Journal of Quality and Service Sciences, Vol. 5, No.1, pp. 86-100, 2013.
25. Achanga, P., Shehab, E., Roy, R., and Nelder, G.,. "Critical Success Factors for Lean Implementation within SMEs". Journal of Manufacturing Technology Management, Vol. 17, No. 4, pp. 460-471, 2006.
26. Coronado, R. B., and Antony, J., "Critical Success Factors for the Successful Implementation of Six Sigma Projects in Organisations". The TQM Magazine, Vol. 14, No. 2, pp. 92-99, 2020.
27. Lin, Y., "Using DEMATEL Method to Explore the Core Competences and Causal Effect of the IC Design Service Company: an Empirical Case Study. Expert Systems with Applications, Vol. 38, No. 5, pp. 6262-6268, 2011.
28. Chang, B., Chih-Wei, C., and Chih-Hung, W., "Fuzzy DEMATEL Method for Developing Supplier Selection Criteria". Expert Systems with Applications, Vol. 38, No. 3, pp. 1850-1858, 2011.
29. Jassbi, J., Farshid, M., and Hossein, N., "A Fuzzy DEMATEL Framework for Modeling Cause and Effect Relationships of Strategy Map". Expert Systems with Applications, Vol. 38, No. 5, pp. 5967-5973, 2011.
30. Malviya, R. K., and Ravi, K., "Green Supply Chain Management (GSCM): a Structured Literature Review and Research Implications". Benchmarking: An International Journal, Vol. 22, No. 7, pp. 1360-1394, 2015.

31. Patil, S. K., and Ravi, K., "A Hybrid Approach Based on Fuzzy DEMATEL and FMCDM to Predict Success of Knowledge Management Adoption in Supply Chain". Applied Soft Computing, Vol. 18, pp. 126-135, 2014.
32. Kabak, M., "A Fuzzy DEMATEL-ANP Based Multi Criteria Decision Making Approach For Personnel Selection". Journal of Multiple-Valued Logic & Soft Computing, Vol. 20, 2013.
33. Wu, W., Lee, Y., "Developing Global Managers' Competencies using the Fuzzy DEMATEL Method". Expert Systems with Applications, Vol. 32, No. 2, pp. 499-507, 2007.

## تحديد العوامل الحرجة لنجاح التصنيع الرشيق باستخدام طريقة الـ Fuzzy DEMATEL

فى ظل التحديات التي تواجه المؤسسات الصناعية، أصبح من الضروري استخدام منهجيات التحسين بطريقة تلائم ظروف كل مؤسسة. التصنيع الرشيق واحد من أهم المنهجيات التى تساعد فى تحسين مؤشرات الاداء. ولكن تبقى المشكلة فى استمرارية التحسينات. هنا كان من الضروري التعرف على عوامل نجاح هذه المبادرات، تم فى البحث مراجعة الأدبيات السابقة للتعرف على عوامل نجاح التصنيع الرشيق وتم ملاحظة انها لم تتطرق الى ترتيب هذه العوامل بطريقة تتناسب مع كل شركة، لذلك تم اقتراح طريقة الـ Fuzzy–DEMATEL لدراسة التأثير المتبادل بين عوامل النجاح، ومن ثم التعرف على العوامل الاكثر تأثيراً والتى يراعى تدعيمها لضمان نجاح واستمرارية النتائج الخاصة بتطبيقات التصنيع الرشيق كما تم تنفيذ الدراسة فى أحد المصانع، وأثبتت النتائج تحسن مؤشرات الاداء مثل زيادة عدد الافعال التحسينية "KAIZEN" الى ٦٠ فعل تحسينى شهرياً، وتقليل حجم المخزون البينى و زيادة معدل الانتاج، حتى بعد الانتهاء من برامج التدريب الخاصة بالتصنيع الرشيق.