Measuring leanness index using fuzzy logic approach

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Abstract. Continuing competitive advantage will be a goal that will be increased by all types of industry to win the competition. The application of Lean production is a necessity for the industry to be able to increase the competitive advantage. This competitive advantage is achieved by waste elimination and cost reduction programs through the implementation of lean practice. In its implementation, there are many obstacles that occur, including lack of understanding and implementation of lean production that should be carried out. Leanness is a measure of the level of implementation of lean practices. In this paper, the dimensions that are the main areas of concern in lean production implementation are quality, customer, process, human resource and delivery-supplier. By using the advantages of fuzzy logic in performance appraisal and giving qualitative importance to avoid data imprecision and vagueness. The built-in fuzzy linguistic level is used to identify the position of the industry at the level of application of lean production expressed by Fuzzy Leanness Index. The built model can be used for assessment and identify areas in the industry that have and have not contributed to the implementation of lean production.

1. Introduction
The increasing global competition in the industry today and the growing variety of consumer demand, requires the industry to abandon the traditional production system model. Modern industrial models rely on practices that attend for increasing competitive advantage of the industry continuously. Competitive advantage can only be achieved if the Industry is able to produce high-quality products at lower costs with more variety of products produced and the shortest time to market [1]. Lean production can maintain the level of industry satisfaction through manufacturing operations and customer satisfaction [2]. For this purpose, many companies adopt a lean production approach [3–5]. Lean Production arises by taking advantage of mass production and craft production by using fewer resources [3].

Lean Production, first appeared in a United States automotive industry development business that wanted to match what had been done in the automotive industry in Japan, especially Toyota. Toyota developed the Toyota Production System to contribute to the sustainability of the industry in difficult times. The main purpose of the Toyota Production System is to reduce costs and increase productivity through reducing various types of waste [6].

Based on the success of the Toyota Production System, the presence of Lean production is a concern for the industrial world. The application of lean production begins with the automotive industry, followed by various industries, many of which use this approach and get significant results in improving
company performance [7]. The implementation and effects of Lean production cannot be felt in a short time, so the program needs sustainability in the long term and continue to be able to see the results of its application [8,9]. According to Bhasin the application of lean production requires a deep understanding and great commitment from internal resources and external parties in its application [10]. He also stated that an "audit" was needed to see how much the implementation of Lean Production was. The sustainability of this lean program is determined by how much understanding and application of lean practices in an industry. The need for an assessment process is about the level of understanding and implementation of Lean production to be able to determine the accuracy of the implementation direction. This is in line with what is shown by Behrouzi and Wong [11], which states that one of the causes that influence the failure of implementing lean programs is the failure of understanding and measuring lean performance. Determination of lean status or level leanness is the final result that you want to know from this process. The goal of leanness level measurement as part of the benchmarking and visualization process of the lean level [12].

2. Literature review

2.1. Lean production

The definition of lean production is widely discussed in several publications since it was first popularized in a book of The Machine That Can Changed the World [3]. One of the most frequently cited definitions of some publications is what is stated by Shah and Ward [13]. They define lean production based on the development of lean production from the future to the main components of lean production. That definition is, Lean production is an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability.

Gupta and Jain define lean production as principles and main concepts based on lean philosophy [14]. Bhasin and Burcher tend to argue that lean is a philosophy in eliminating waste [15]. The main concern in lean production is cost reduction, through elimination of waste [3,7]. According to Bragilia, Carmignani, and Zammori create values for the end customer is the main concept in implementing lean production [16]. This can be achieved if the production system always pays attention to perfection with smoothing material flow and is determined by consumer demand. Jasti and Kodali revealed the goal of lean production is waste reduction [17]. Many studies reveal the benefits of implementing lean production. Among them are improving quality, safety, flexibility, market share and increasing work culture in eliminating waste [14]. They also revealed a decrease in equipment search time, pressure and fatigue at work.

2.2. Lean assessment

Research on lean assessment continues to grow, along with the development of lean production applications. This level of importance in lean assessment is needed an evaluation of the level of forward lean production. The level of adoption and realization of lean philosophy is defined as leanness [18]. They also define Lean assessment or Lean Quantification related to the process or procedure to determine the level of application of lean production. Taj uses a lean assessment tool (LAT) by distributing 40 questions to 65 companies in China with 9 dimensions developed by Strategos Inc. to find out the level of implementation of lean production [2]. Pakdil and Leonard measured leanness levels by combining 2 measurements, quantitative and qualitative models using fuzzy logic and radar charts [4]. Seyedhosseini, Taleghani, Bakhsha, and Partovi build lean assessment criteria based on balanced scorecard [19]. Susilawati, Tan, and Sarwa measuring lean application levels in large, medium and small industries in Indonesia through surveys [20].

Leanness assessment framework by using DMAIC as its conceptual form supported by quantitative and qualitative data [12]. Developed a lean production performance measure using 10 dimensions which are divided into 3 main groups, namely suppliers, customers and internal processes [13]. The end result of the lean assessment process is expected to find the Lean Index which can be used as a reference for
the improvement process. The Lean Index is the sum of the weighted values of the performance variables [12]. From the lean definition the index can draw conclusions about the need for lean index determination is the existence of performance variables or dimensions to be measured, the value of these dimensions and the weight of each dimension. Lean index measurements are qualitatively used more than quantitative in measurements. Qualitative assessment is more suitable for use in calculating lean index, this is based on the basic concept of lean production is a philosophy [12].

3. Research methodology
- Defining lean attributes, this definition is based on the main areas in the application of lean production and has been used in previous studies. The main area is divided into two groups of areas namely internal namely quality, process, human resources. And external, namely customer and delivery-supplier. Each area will be explained in the attributes used to determine the capability / performance value. Lean details of attributes that are built in each area as in table 1.
- Determining the formation of lean expert for assessment.
- Choosing the right linguistic scale that can represent the expert's assessment related to the determination of the importance of each attribute and the main dimension and the assessment of each attribute. Determination of linguistic scale terms and adjustments to fuzzy membership functions which are based on previous research [21]. With adjustments to adjusted linguistic terms in terms of Lean production. (Table 2)
- Assess the importance of weight and assess the performance of each attribute.
- Estimation of subjective expert judgment (in linguistic form) with fuzzy numbers
- The integration of performance ($P_{ij}$) and importance ($W_{ij}$) values of each attribute ($i$) is in the form of a fuzzy number from each expert ($j$) using an average.
- Estimating the value of fuzzy Lean Index. In this process, two stages are calculated. The first calculation is done to get the lean performance of each dimension ($i$). The second calculation is to assess fuzzy lean index by using the weight of each dimension (table 4) with the lean performance of each dimension.
- Match the fuzzy level membership function with the leanness level linguistic membership function which is a set of natural language expressions. Difference in value of fuzzy lean index membership function with leanness level linguistic membership function is perceived using the Euclidean distance method. Vinodh and Vimal uses the term Leanness level linguistics which is divided into five levels which are expressed in natural language namely extremely lean (EL), Very Lean (VL), Lean (L), Fairly Lean (FL), Slowly Lean (SL) [22]. Leanness matching linguistic levels related to membership functions can be seen in Figure 2.

4. Results and discussion
Case studies have been held at steel processing companies in the area of Gresik, Indonesia. The company produces flat bars and round bars. The company has also implemented lean production through lean practice applications including 5S, SMED, TPM, Kaizen, waste elimination and pull systems. Based on the results of discussions with several parties in the company has been determined 5 people lean experts from several parts of the company namely the production, maintenance, customer service, quality control and production planning and control. Performance appraisal data and importance weight of each attribute and importance weight for each dimension / area as in table 3.
### Table 1. Lean assessment criteria.

| Dimensions          | Attribute                                                                 |
|---------------------|---------------------------------------------------------------------------|
| **Lean Index**      | **Quality (Q)**                                                          |
|                     | Defect reduction mechanism (Q1)                                           |
|                     | Culture defect reduction / Adoption TQM (Q2)                              |
|                     | Product Quality information system (Q3)                                   |
| **Customer (C)**    | Incorporation of customer feedback mechanism (C1)                        |
|                     | Proper capture of customer requirement (C2)                              |
|                     | translation customer need into operational level (C3)                    |
|                     | Share information about current and future demand (C4)                   |
| **Process (P)**     | Effective usage of quality tools/techniques (P1)                         |
|                     | Proper storage of tools (P2)                                              |
|                     | Minimum idle time of machines (P3)                                       |
|                     | Planning of work cells (P4)                                               |
|                     | Adoption of TPM (P5)                                                     |
|                     | Value stream mapping / Value identification (P6)                          |
|                     | Effective product family formation (P7)                                   |
|                     | Utilization of work cells (P8)                                            |
|                     | Visual information systems (P9)                                           |
| **Human Resources (H)** | Employee involvement (H1)                                     |
|                     | Employee empowerment (H2)                                                 |
|                     | Implementation of job rotation system (H3)                               |
|                     | Multi-skilled personnel (H4)                                              |
| **Delivery & Supplier (D)** | Involvement of suppliers (D1)                        |
|                     | Training to supplier (D2)                                                 |
|                     | Supplier collaboration (D3)                                               |
|                     | Demand-driven production (D4)                                             |
|                     | JIT Purchase & Delivery (D5)                                              |
|                     | Selection Supplier (D6)                                                  |

### Table 2. Linguistic variables and fuzzy numbers.

| Performance Rating | Importance Weighting |
|--------------------|----------------------|
| **Linguistic Variable** | **Fuzzy Number** | **Linguistic Variable** | **Fuzzy Number** |
| Worst (W)          | (0, 0.5, 1.5)       | Very Low (VL)           | (0.0, 0.05, 0.15) |
| Very Poor (VP)     | (1, 2, 3)           | Low (L)                 | (0.1, 0.2, 0.3)   |
| Poor (P)           | (2, 3.5, 5)         | Fairly Low (FL)         | (0.2, 0.35, 0.5)  |
| Fair (F)           | (3, 5, 7)           | Medium (M)              | (0.3, 0.5, 0.7)   |
| Good (G)           | (5, 6.5, 8)         | Fairly High (FH)        | (0.5, 0.65, 0.8)  |
| Very Good (VG)     | (7, 8, 9)           | High (H)                | (0.7, 0.8, 0.9)   |
| Excellent (E)      | (8.5, 9.5, 10)      | Very High (VH)          | (0.85, 0.95, 1.0) |
Table 3. Importance weighting \((W_{ijk})\) data for quality and customer dimensions.

|     | Expert 1 | Expert 2 | Expert 3 | Expert 4 | Expert 5 |
|-----|----------|----------|----------|----------|----------|
| Q1  | VH       | H        | VH       | H        | H        |
| Q2  | VH       | H        | VH       | H        | H        |
| Q3  | VH       | VH       | VH       | H        | H        |
| C1  | H        | H        | FH       | VH       | FH       |
| C2  | VH       | H        | FH       | VH       | H        |
| C3  | VH       | VH       | H        | H        | VH       |
| C4  | VH       | VH       | VH       | H        | VH       |

Table 4. Performance rating \((P_{ijk})\) data for quality and customer dimensions.

|     | Expert 1 | Expert 2 | Expert 3 | Expert 4 | Expert 5 |
|-----|----------|----------|----------|----------|----------|
| Q1  | G        | G        | G        | G        | F        |
| Q2  | G        | G        | G        | G        | F        |
| Q3  | VG       | G        | G        | G        | F        |
| C1  | G        | G        | F        | G        | 0        |
| C2  | G        | F        | G        | G        | 0        |
| C3  | F        | G        | G        | F        | F        |
| C4  | G        | VG       | VG       | VG       | G        |

Table 5. Dimensions of Importance Weighting \((W_{ij})\).

| Code | Importance Weighting \((W_{ij})\) |
|------|----------------------------------|
|      | Exp 1 | Exp 2 | Exp 3 | Exp 4 | Exp 5 |
| Q    | VH    | VH    | VH    | H     | H     |
| C    | VH    | H     | FH    | VH    | FH    |
| P    | H     | H     | H     | H     | H     |
| H    | H     | H     | H     | H     | FH    |
| D    | H     | H     | FH    | H     | FH    |

To unify the assessment of each model the average value of importance weighting and rating performance on the lean attribute Q1.

\[
P_{ij} = \left( a_{ij}, b_{ij}, c_{ij} \right) = \frac{\sum_{t=1}^{m} p_{ijt}}{m} \quad (1)
\]

\[
W_{ij} = \left( x_{ij}, y_{ij}, z_{ij} \right) = \frac{\sum_{t=1}^{m} w_{ijt}}{m} \quad (2)
\]
Information:

\[ P_{ij} \]: The number of fuzzy performance levels is close to the linguistic level in the dimension of \( i \)th (\( i = Q, C, P, H, D \)) attribute to \( j \) and expert to \( t \)

\[ W_{ij} \]: Fuzzy numbers the importance weights that approach the linguistic level in the dimensions of \( i \)th (\( i = Q, C, P, H, D \)) attribute to \( j \) and expert to \( t \)

\[ P_{ij} \]: Performance level in the \( j \)th dimension of the \( i \)th attribute

\[ W_{ij} \]: The importance of interest in the \( j \)th dimension of the \( i \)th attribute

Examples of calculating the average value of the performance level and the weighting criteria of each attribute in each dimension with five expert experts.

\[ P_{Q1} = [(5.6,5.8) + (5.6,5.8) + (5.6,5.8) + (5.6,5.8) + (3.5,7)]/5 \]

\[ P_{Q1} = [4.6,6.2,7.8] \]

\[ W_{Q1} = \left[ (0.8,0.95,1) + (0.7,0.8,0.9) + (0.8,0.95,1) + (0.7,0.8,0.9) + (0.7,0.8,0.9) \right]/5 \]

\[ W_{Q1} = [0.76,0.86,0.94] \]

4.1. The first stage

The first stage of the calculation process is the determination of the lean performance of each dimension which is carried out by formula 3:

\[ LP_i = \frac{\sum_{j=1}^{n} w_{ij} \times p_{ij}}{\sum_{j=1}^{n} w_{ij}} \quad (3) \]

Information:

\[ LC_i \]: Lean ability in \( i \)th dimensions (\( i = Q, C, P, H, D \))

\[ n \]: The number of attributes in a lean dimension

Example of lean index calculation for LC quality dimensions using formula 3:

\[ LP_Q = \left[ (4.6,6.2,7.8) \times (0.76,0.86,0.94) + (4.6,6.2,7.8) \times (0.76,0.86,0.94) + (5.6,8.8) \times (0.79,0.89,0.96) \right]/5 \]

\[ LP_Q = [4.7368, 6.4046, 7.8676] \]

4.2. The second stage

Using formula 4, fuzzy lean index is calculated:

\[ (\text{Fuzzy Lean Index}) \text{ FLI} = \frac{\sum_{i=1}^{n} LP_i \times w_i}{\sum_{i=1}^{n} w_i} \quad (4) \]

The following are the fuzzy lean index calculation models:

\[ \text{FLI} = \left[ \begin{array}{c}
(4.736,6.404,7.867) \times (0.79,0.89,0.96) + (4.980,6.502,8.01) \times (0.68,0.8,0.9) + (4.620,6.143,7.669) \times (0.7,0.8,0.9) + (4.892,6.5,7.948) \times (0.66,0.77,0.88) + (1.471,2.345,3.22) \times (0.62,0.74,0.86)
\end{array} \right]/\left[ (0.79,0.89,0.96) + (0.68,0.8,0.9) + (0.7,0.8,0.9) + (0.66,0.77,0.88) + (0.62,0.74,0.86) \right] \]
FLI = [4.204, 5.639, 6.983]

After obtaining the FLI results, the distance between FLI and leanness level (LL). The following are examples of calculations and the results of calculating the distance between FLI and LL.

\[ D(FLI, LL_i) = \left\{\sum (f_{FLI}(X) - f_{LL_i}(X))^2\right\}^{1/2} \]

\[ (FLI, EL) = \{(4.42 - 7)^2 + (5.81 - 8.5)^2 + (7.86 - 10)^2\}^{1/2} = 4.30 \]

\[ D(FLI, EL) = 4.30; \quad D(FLI, VL) = 1.73; \quad D(FLI, L) = 1.83; \]

\[ D(FLI, FL) = 5.26; \quad D(FLI, SL) = 7.85 \]

\[ SL (0,1.5,3) FL (1.5,3,4.5) L (3.5,5,6.5) VL (5.5,7,8.5) EL (7,8.5,10) \]

These results show the distance between FLI to leanness level extremely lean as far as 4.30. The distance between FLI to leanness level very lean as far as 1.73. The distance between FLI to leanness level lean as far as 1.83. The distance between the FLI to the leanness level fairly lean as far as 5.26, the distance between the FLI to the leanness level slowly lean as far as 7.85.

5. Conclusion

The results of the research conducted show the importance of assessing the level of understanding and application of lean production. Each organization that adopts lean has a different understanding and level of implementation so an assessment is needed that can accommodate the level of implementation and compliance. Through a weighted performance appraisal, it is an assessment process that is very appropriate to see how much the importance of these attributes to the application of lean production through the performance evaluation of each attribute. Attributes are grouped into five dimensions which are the main areas in implementing lean production. By using fuzzy logic, to avoid imprecise, vagueness and ambiguity, we get importance and performance levels for each attribute and importance weight values for each dimension. For the development of research, a dimension that develops dimensions is needed, such as the dimensions of leadership, culture and environment. As well as being able to develop measurement models that can combine assessment with qualitative and quantitative data.

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