Development of Lean Assessment Model
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Abstract— To be successful, lean implementation for the adoption of lean principles leads to a positive outcome with stable and/or increasing profitability. The paper reports a detailed study for development of leanness assessment model. The research involved the identification of suitable manufacturing organizations for the conduct of case study and a questionnaire was developed according to their operations. The data gathered from the experts of the organizations in response to the questionnaire was used for further analysis. Then a multi-grade fuzzy approach for leanness measurement was applied, the leanness index was computed and the areas for leanness optimization have been identified.

Key words: Lean Manufacturing; Leanness Assessment; Fuzzy Methods; Leanness Index

I. INTRODUCTION
Lean production is “lean” because it uses less of everything compared with mass production—half the human effort in factory, half the manufacturing space, half the investment tools, half the engineering hours to develop a new product in half time. Also, it requires keeping far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever growing variety of products. Lean Production’s origins in Japan are very important to understand; understanding the concept behind a—method allows greater proficiency when implementing it. Going through the step by step process of integrating the system into a company or business, showing why it will work for any company that wants to reduce waste, and raise the overall quality of their product is why many companies adopt Lean Production. Companies that correctly implement Lean into their production systems find that Lean results in a more positive bottom line for the company or business, stemming from improved cost saving or efficiencies and better customer satisfaction from the increase in overall product quality. Ultimately, the purpose of Lean, and of business, is to improve the bottom line profit.

The philosophy of Fuzzy Logic (FL) may be traced back to the diagram of Taiji created by Chinese people before 4600 B.C. But the study of Fuzzy Logic Systems (FLS) began as early as the 1960s. In the 1970s, FL was combined with expert systems to become a FLS, which imprecise information mimics a human-like reasoning process. FLS make it possible to cope with uncertain and complex agile manufacturing systems that are difficult to model mathematically [12]. By opinion of [13], in managerial practice, there are often situations when it is not enough for managers to rely on their own instincts. With specific fuzzy programs it is even possible to choose suppliers, service providers or to buy necessary goods. Using the classical logic or set theory, the products or elements are expressed through membership or non-membership (an element either belongs to the set or not, the statement is regular or irregular). But it is not everyday practice. It is preferable to use FL that determines the extent to which the element belongs to the set or not. FL allows paradoxes; instead of black and white 0/1 it brings the vision range of options - from irregular over almost entirely false, paradoxical, almost true to completely true. The researched model is based on fuzzy numbers. Fuzzy numbers are special fuzzy sets in the set of real numbers R = (- ∞, + ∞). Fuzzy number intuitively represents the value that is imprecise; it is a value that can be verbally described as "about" or "approximately" [14].

A. Fuzzy logic
Fuzzy logic is a type of numerous esteemed logic that arrangements with estimated, as opposed to altered and definite thinking. Compared to traditional binary logic (where variables may tackle genuine or false values), fuzzy logic variables may have a truth esteem that ranges in degree somewhere around 0 and 1. Fuzzy logic has been reached out to handle the idea of fractional truth, where reality worth may range between totally genuine and totally false.

B. Applications:
- In philosophical logic, fuzzy ideas are regularly viewed as ideas which in their application, or formally talking, are neither totally genuine nor totally false, or which are mostly genuine and incompletely false; they are thoughts which require further elaboration, particular or capability to comprehend their pertinence (the conditions under which they truly make sense).
- In math and measurements, a fuzzy variable, (for example, "the temperature", "hot" or "chilly") is a worth which could lie in a plausible extent characterized by quantitative breaking points or parameters, and which can be helpfully depicted with loose classes, (for example, "high", "medium" or "low") utilizing a subjective scale.
- In math and software engineering, the degrees of appropriate importance of a fuzzy idea are depicted regarding quantitative connections characterized by coherent administrators. Such a methodology is at times called "degree-theoretic semantics” by scholars and philosophers; however the more regular term is fuzzy logic or numerous esteemed logic. The oddity of fuzzy logic is, that it "breaks with the customary rule that formalization ought to right and maintain a strategic distance from, yet not bargain with, vagueness”.
- The essential thought of fuzzy logic is, that a genuine number is relegated to every announcement written in a dialect, inside of a reach from 0 to 1, where 1 implies that the announcement is totally genuine, and 0 implies that the announcement is totally false, while values under 1 however more noteworthy than 0 speak to that
the announcements are "part of the way valid", to a given, quantifiable degree.

II. LITERATURE REVIEW

In 1988, "lean" was firstly utilized by Krafčík to portray Toyota production system (Krafčík, 1988) et al.[7]. Notwithstanding, the across the board utilization of this word delayed until 1990 when a book entitled as "The machine that changed the world" was distributed (Womack et al., 1990)[3]. The book was gathered by Womack, Jones and Roos from MIT University through exploration. They presented lean production as a blend of Ford conventional generation model and social control model at Japanese creation environment.

Through an exhaustive investigation of introduced inquires about and by blending the said components in these definitions, Shah and Ward (2007), et al.[1] give the accompanying complete definition for leanness: "lean production is an incorporated socio-specialized framework whose primary target is to dispense with waste by simultaneously lessening or minimizing supplier, client, and inner variability". Wacker (2004) proposes that a reasonable definition ought to show confirmation of clarity, transferability, consistency, niggardliness, differentiability, inclusivity, and restrictiveness. This definition meets these criteria and can be utilized as an lean definition as a part of the present examination. Distinctive specialists, consider different measurements and parts for displayed ideas in lean production's definition. Simons and Zokaie (2005) consider lean production theory taking into account waste disposal and scanning for flawlessness and Kaizen; in addition they characterize incline generation method as lean stock, smooth generation stream, laborers preparing, urge specialists to partake and giving recommendation, quality circles, long range relations with suppliers, preventive support arrangement, and duty to constant change. Kojima and Kaplinsky (2004) accept that lean production is quantifiable in three sections: adaptability, consistent change, and quality.

In their late research, Shah and Ward (2007), et al.[1] with a far reaching look and within regards to all inward and outside measurements of lean production attempted to characterize and test proper scales for organizational leanness measuring. The criteria for measuring subjects and phenomena are diverse base on organizational conduct and research necessities. In any case, what that would be alter everlastingly, is the procedure and technique for measuring. In this procedure, individual or persons who appreciate enough ability on the exploration question space would change subjective information to differentiable qualities. Be that as it may, mind must be connected that such a strategies, disregard uncertainty identified with people judgment and their worth changes amid change to numbers (Chakraborty, 1975). Fuzzy logic was first presented by Professor Zadeh (1965) et al.;[10], to answer such a test. He accepts that human's logic can take favorable position of ideas and learning that don't have very much characterized outskirts (Yen and Langari, 1999) et al.;[5]. Fuzzy logic include a wide range of hypotheses and systems primarily built upon four ideas: fuzzy sets, phonetic variables, likelihood dispersion (participation capacity), and fuzzy if-then guidelines (Yen and Langari, 1999) et al;[5],Bayou and De-korvin (2008)et al;[2]have demonstrated that assembling leanness has seven qualities, for example, relative, dynamic, long haul, fuzzy intelligent, objective, coordinating and far reaching. They have utilized fuzzy logic approach for measuring leanness. Bhasin (2008, 674) et al.;[6]states that 'organizations need to see how key execution measures can direct furthermore, center an association towards prevalent results in their picked zone'. Correspondingly, Saurin, Marodin, and Ribeiro (2011) et al.[11]recognized the significance of actualizing lean evaluation amid the early phases of lean practices.

The literature was dissected in subtle element, yet there were constrained studies on lean assessment: 30 articles, 2 graduate proposals and 9 books. Only Mann’s (2005) book, titled Creating a Lean Culture, had an appendix on qualitative lean assessment. In research for this paper, each relevant study was analyzed in terms of lean assessment approaches. Based on the literature review, it has been found that couple of researchers has contributed certain methodologies for leanness evaluation. A large number of the methodologies have not been approved in the modern situation. The models utilized as a part of those tasks have not been completely supported with literature. In this context, the target of this paper is to report a venture in which the applied model has been taken from literature and the model has to be practically validated in the industry scenario.

III. METHODOLOGY

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

The framework comprises of three levels. The principal level comprises of five leanness empowering enablers; the second level comprises of 20 lean criteria; and the third level comprises of a few lean attributes. The leanness estimation framework is complete as it reviews leanness from different points of view. As a sample, the management responsibility enabler has been explained. The two noteworthy points of view of management obligation are organizational structure and nature of administration which frames the criteria. The organization structure criteria comprise of characteristics, for example, smooth data stream, group administration for choice making and between alterability of staff. The way of administration criteria comprises of plainly known administration destinations, administration association, and straightforward data sharing.
A. Case Study 1

About case company 1 is one of the growing organizations established in the year 1999 with a view to design and manufacture specialized engine, vehicle & drive line test equipment’s & setup by a group of well qualified engineers each one of them having more than twenty years of experience in the field.

1) Assessment of leanness using fuzzy logic:
The equation for leanness index is given by, \( I = W \times R \)
The assessment has been divided into five grades since every leanness factor involves fuzzy determination. (8–10 represents ‘extremely lean’, 6–8 represents ‘lean’, 4–6 represents ‘generally lean’, 2–4 represents ‘not lean’ and less than 2 represents ‘extremely not lean’).

2) First assessment calculation:
Weights pertaining to organizational structure criterion, \( W_{11} = (0.2, 0.6, 0.2) \)
Assessment vector pertaining to organizational structure criterion, \( R_{11} = [5, 3, 64, 9, 8, 78, 7, 8, 76] \)
Index pertaining to organizational structure criterion, \( I_{11} = (7.6, 7.6, 6.6, 7.6) \)

3) Second assessment calculation:
The calculation pertaining to ‘management responsibility leanness’ enabler is given by,
\( I_1 = W_1 \times R_1 \)
Index pertaining to ‘management responsibility leanness’ enabler is given by,
\( I_1 = (8.01, 7.49, 7.01, 6.94) \)
\( I_2 = (6.385, 6.015, 5.625, 5.955) \)
\( I_3 = (6.76, 6.68, 6.28, 7.12) \)
\( I_4 = (4.12, 4.24, 4.46) \)
\( I_5 = (6.96, 6.94, 6.66, 7.6) \)

4) Third assessment calculation:
The value of leanness index of case company has been computed as follows,
Leanness index, \( I = W \times R \)
\( W = \) overall weight
\( R = \) overall assessment vector
\( I = (5.83) \sim (6) \)
Hence the assessment has been divided into five grades, it comes under 4–6 represents ‘generally lean’.

5) Some of the areas identified for leanness improvement:
- Transforming starting with one shift then onto the next was making long stretches of low or no production.
- Since this was a three shift operation with movement changes averaging 30 minutes three times each day, this turned into an expensive and destructive routine.
- Their lead times were too long, costs were too high, and delivery performance was not so good.
- They needed to reduce setup times and WIP (work in process) inventory.
- They likewise battled with quality consistency issues that justified prompt consideration.
- Quality defects and raw material waste issues.

B. Case Study 2

About case company 2 manufactures Hydraulic gear pumps, pump flanges, spool valves, hydraulic valve body & spools, hydraulic piston pumps and priority valve. The products accommodate the needs of various industries like automobiles and others. The products have received immense acclaims from national as well as international clients for their features such as wear & tear resistance, durability, compact designs and longer life.

1) Assessment of leanness using fuzzy logic:
The equation for leanness index is given by, \( I = W \times R \)
The assessment has been divided into five grades since every leanness factor involves fuzzy determination. (8–10 represents ‘extremely lean’, 6–8 represents ‘lean’, 4–6 represents ‘generally lean’, 2–4 represents ‘not lean’ and less than 2 represents ‘extremely not lean’).

2) First assessment calculation:
Weights pertaining to organizational structure criterion, \( W_{11} = (0.2, 0.6, 0.2) \)
Assessment vector pertaining to organizational structure criterion, \( R_{11} = [8, 8, 88, 8, 6, 66, 6, 8, 76] \)
Index pertaining to organizational structure criterion:
\[ I_{11} = (7.4, 7.4, 7.1, 6.8) \]
\[ I_{12} = (7.9, 8.0, 7.7) \]
\[ I_{13} = (7.5, 5.0, 6.5, 7.5) \]
\[ I_{14} = (6.5, 6.0, 5.6, 6.5) \]
\[ I_{15} = (7.2, 6.4, 7.2, 7.2) \]
\[ I_{16} = (7.7, 7.2, 6.8, 7.4) \]
\[ I_{17} = (8.6, 7.2, 7.2, 7.2) \]

\[ W_1 = (6.3, 7.1, 7.0, 7.4) \]
\[ I_{21} = (6.9, 6.5, 7.0, 7.7) \]
\[ I_{22} = (6.0, 7.0, 6.0, 7.0) \]
\[ I_{23} = (5.3, 7.6, 6.7, 1.17) \]
\[ I_{24} = (6.6, 6.2, 4.8, 7.6) \]
\[ I_{25} = (6.8, 7.2, 7.0, 7.5) \]
\[ I_{26} = (6.4, 6.5, 5.0, 4.4) \]
\[ I_{31} = (6.9, 6.8, 6.4, 5.9) \]
\[ I_{32} = (6.3, 7.5, 6.8, 7.4) \]
\[ I_{33} = (5.7, 6.4, 6.5, 5.7) \]
\[ I_{34} = (8.2, 6.8, 8.7, 6.7) \]
\[ I_{35} = (6.4, 6.8, 8.4, 8.4) \]
\[ I_{36} = (6.4, 6.0, 8.0, 8.4) \]

3) Second assessment calculation:

The calculation pertaining to ‘management responsibility leanness’ enabler is given by:
\[ I_1 = W_1 \times R_1 \]

Index pertaining to ‘management responsibility leanness’ enabler is given by:
\[ I_1 = (7.6, 7.6, 7.7, 7.16) \]
\[ I_2 = (7.24, 6.185, 6.855, 7.235) \]
\[ I_3 = (6.48, 6.76, 7.42) \]
\[ I_4 = (6.4, 7.156, 4.56, 6.95) \]
\[ I_5 = (6.68, 6.48, 7.74, 7.58) \]

4) Third assessment calculation:

The value of leanness index of case company has been computed as follows,
Leanness index,
\[ I = W \times R \]
\[ W = \text{overall weight} \]
\[ R = \text{overall assessment vector} \]
\[ I = (6.935) \sim (7) \]

Hence the assessment has been divided into five grades, it comes under 6-8 range, which represents “lean”.

5) Some of the areas identified for leanness improvement

- Workforce has not been trained to become flexible and multi-skilled.
- Non value adding activities have not been identified.
- Efforts have not been taken to quantify seven deadly wastes.
- 5S method has not been used.
- Concern about proper care and maintenance of equipment warranted a proactive effort.
- Increasing teamwork and cooperation between shifts was also at issue.

C. Case Study 3

About case company—Case company 3 has been commenced its commercial production at Nashik, Maharashtra, India in the year 1984 as Sheet Metal Automotive Component manufacturing unit. Over the years the Group has broadened its product range to sheet metal stampings and its assemblies like Load Body (Cargo), Door Assemblies, Floor Assemblies, Machined Components like Salisbury Tube Assemblies, Banjo Beam Assembly and also Bus Body Building, Tipper manufacturing and Roll forming. plants are ISO 9001 / TS 16949 certified.

1) Assessment of leanness using fuzzy logic:
The equation for leanness index is given by, \[ I = W \times R \]
The assessment has been divided into five grades since every leanness factor involves fuzzy determination. (8-10 represents ‘extremely lean’, 6-8 ‘represent ‘lean’, 4-6 represents ‘generally lean’, 2-4 represents ‘not lean’ and less than 2 represents ‘extremely not lean’).

2) First assessment calculation:

Weights pertaining to organizational structure criterion, \[ W_{11} = (0.3, 0.3, 0.4) \]
\[ R_{11} = \begin{bmatrix} 9 & 8 & 98 \\ 9 & 9 & 88 \\ 9 & 8 & 89 \end{bmatrix} \]

Index pertaining to organizational structure criterion,
\[ I_{11} = (9.0, 8.3, 8.3, 8.4) \]
\[ I_{12} = (7.6, 8.2, 8.4, 7.4) \]
\[ I_{13} = (8.8, 8.4, 7.8, 7.4) \]
\[ I_{14} = (7.0, 6.0, 7.0, 7.0) \]
\[ I_{15} = (8.5, 8.1, 7.3, 7.7) \]
\[ I_{16} = (6.6, 7.0, 6.8, 6.3) \]
\[ I_{17} = (7.7, 8.0, 7.7, 7.3) \]
\[ I_{18} = (7.0, 7.6, 7.7, 6.0) \]
\[ I_{19} = (7.2, 6.0, 6.8, 7.2) \]
\[ I_{20} = (7.6, 6.6, 7.6) \]
\[ I_{21} = (6.6, 6.9, 6.8, 5.6) \]
\[ I_{22} = (6.0, 7.4, 5.4, 6.2) \]
\[ I_{23} = (6.7, 6.5, 6.2, 6.4) \]
\[ I_{24} = (6.8, 6.9, 7.6, 6.8) \]
\[ I_{25} = (7.1, 6.4, 6.3) \]
\[ I_{26} = (8.1, 7.8, 7.5, 7.9) \]
\[ I_{27} = (6.7, 6.9, 5.6, 6.3) \]
\[ I_{28} = (8.2, 8.2, 7.2, 7.2) \]
\[ I_{29} = (7.5, 7.0, 8.0, 6.5) \]
\[ I_{30} = (6.6, 6.7, 8.8, 8.0) \]

3) Second assessment calculation:

The calculation pertaining to ‘management responsibility leanness’ enabler is given by,
\[ I_1 = W_1 \times R_1 \]

Index pertaining to ‘management responsibility leanness’ enabler is given by,
\[ I_1 = (7.88, 8.22, 8.38, 7.60) \]
\[ I_2 = (7.75, 7.1619, 7.4, 7.03) \]
\[ I_3 = (7.32, 6.18, 6.74, 7.32) \]
\[ I_4 = (7.235, 7.18, 9.76, 7.65) \]
\[ I_5 = (7.67, 7.76, 7.06, 7.03) \]

4) Third assessment calculation:

The value of leanness index of case company has been computed as follows,
Leanness index,
\[ I = W \times R \]
\[ W = \text{overall weight} \]
\[ R = \text{overall assessment vector} \]
\[ I = (7.89) \sim (8) \]

Hence the assessment has been divided into five grades, it comes under (8-10) “extremely lean”.

5) Some of the areas identified for leanness improvement

- Pressure from their customers for shorter lead times and enhanced time conveyance execution was...
bringing about this privately held organization severe difficulty.

- They expected to be able to place an order today and pick up or have their order shipped first thing the next day.
- The company had spent many months attempted to make the transition to lean on their own, with minimal success.
- Lead times were still too long, and delivery performance was unacceptable.

IV. CONCLUSION

Product complexity and business sector dynamism are the two choice variables dependable for the change of manufacturing standard. The manufacturing standard has been seen a movement from craft manufacturing to lean manufacturing. Lean manufacturing is described by low buffering expense, least handling time and high conveyance speed. The assessment of assembling leanness increases essential significance.

Based on the assessment of leanness, leanness index computed using multi-grade fuzzy approach for case company 1, case company 2, case company 3 are found to be 5.83, 6.935, 7.89 respectively and below graph shows case company 1, case company 2, case company 3 are lean, leaner, leanest respectively. To make case companies a world class organization, scope still exists for improving the leanness of the organization. Many areas of leanness improvement has been identified. The assessment of manufacturing leanness increases key significance. In this connection, this paper reports a contextual investigation in which the leanness of a manufacturing organization has been surveyed utilizing the created reasonable model. The assessment result shows that the organization is lean.

![Graph showing grades of case companies](image)

REFERENCE


V. APPENDIX

A. Company Details:
1) Name of the company
2) Year of establishment
3) Address
4) Average number of employees working in the company
5) Type of the quality certification if any
6) Type of the company:
   - Expert oriented unit
   - Ancillary unit
   - General unit
   - Others
7) Name of the person interviewed
8) Contact details of person interviewed
   - Mobile:
   - Email:
9) Training received (please mention specifically any training received in Lean Manufacturing)
   10) Lean Manufacturing Tools/Techniques used:
       - SS System
       - Visual Control
       - Standard operation procedures (SOPs)
       - Just in Time (JIT)
       - KANBAN System
       - Cellular Layout
       - Value Stream Mapping
       - POKA YOKE or Mistake Proofing
- SMED (Single Minutes Exchange of Dies or Quick Changeover)
- TPM (Total Productive Maintenance)
- KAIZEN BLITZ-Rapid Improvement Process

11) Are you involved in providing Training employees about Lean Manufacturing for Micro, Small Medium Enterprises (MSME)

12) Please provide details of Benefits/Results after Implementation of Lean Manufacturing if you have implemented before.

B. Questionnaire format:

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<th>Criteria</th>
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<td>Manufacturing management</td>
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<td>Frequent follow-up with customer for quality feedback</td>
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<td>Change in business and technical processes</td>
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<td>Conduct product capability studies before the product has been launched</td>
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<td>Employees identify defective parts and they stop the line</td>
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<td>Equipment maintenance records has been kept for active sharing with employees</td>
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<td>SPC techniques are used to reduce process variance</td>
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<td>Single minute exchange of die techniques are used</td>
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<td>We give the feedback to our suppliers on quality and delivery performance</td>
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<td>We solve the problems jointly with our suppliers</td>
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<td>Streamlining of processes</td>
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<td>Value stream mapping is employed in the firm</td>
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<td>Quantifying seven deadly wastes</td>
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<td>Cellular manufacturing</td>
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<td>Production system works on cellular manufacturing system</td>
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<td>Focus on whole firm production system</td>
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<td>Implementation of experimental design for continuous improvement</td>
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<td>3</td>
<td>Technology leanness</td>
<td>Manufacturing set-ups</td>
<td>Flexibility in machines setups</td>
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<td>Usage of automated tools/AGV’S</td>
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<td>Less time is required for changing the machine setups</td>
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<td>Product service</td>
<td>Active policy to keep work areas clean</td>
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<td>Product design</td>
<td>Products are designed in such a way to get easy service</td>
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<td>Service centers are well equipped with spares</td>
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<td>Employees are practice job rotation between design manufacturing engineering</td>
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<td>Creating new ways for coordination for design and manufacturing issues</td>
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<td>Usage of value stream mapping</td>
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<td>Non-manufacturing operations are standardized</td>
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<td>In-house technology</td>
<td>Improvement of present equipment before considering new equipment</td>
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<td>Development of specific technologies for specific product use</td>
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<td>Design and development of proprietary items for own use</td>
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<td>Production methodology</td>
<td>Lean manufacturing principles are used for the elimination of wastes</td>
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<td>Interest of the management towards the investment on FMS concepts</td>
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<td>IT application is used for better vendor and supplier management</td>
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<td>Manufacturing technology</td>
<td>Appropriate measuring devices are readily available and use to achieve the quality required</td>
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<td>Average age or time in years since overhaul of equipment on your production floor</td>
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<td>Company is currently using the technologies like automated inspection/cnc m/c tools/programmable robots</td>
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<td>Where a controlled environment(such as temp or humidity) is important to product quality, appropriate limits are specified, controlled and verified</td>
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<td>Manufacturing strategy leanness</td>
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<td>Status of quality</td>
<td>The quality manual is kept up to date</td>
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<td>What percentage of components purchased from suppliers is defective</td>
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<td>What percentage of finished products returned as defective by the customer</td>
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<td>Status of productivity</td>
<td>Productivity which has been pulled by the shipment of finished goods</td>
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<td>Production at the stations is pulled by the current demand of the next station</td>
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<td>During the past seven days, how much did your problem affect your productivity while you were working</td>
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<td>Overall productivity in getting the job done</td>
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<td>Cost management</td>
<td>Whether the company takes initiative’s to minimize the non-value added activities</td>
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<td>The areas of cost reduction and cost control normally identified</td>
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<td>Time management</td>
<td>Accomplish what needs to be done</td>
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<td>Workforce leanness</td>
<td>Employee status</td>
<td>Employees undergo cross functional training</td>
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<td>Employees give the suggestions while manufacturing process is going on</td>
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<td></td>
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<td>Percentage of multiskilled employees</td>
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<td></td>
<td>Employee involvement</td>
<td>Employee involvement and cooperation</td>
<td>Employees are cross functionally trained and flexible to rotate into different jobs</td>
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