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A toolset for complex decision making in analyze phase of Lean Six Sigma Project: A case validation

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Abstract

Purpose: The analyze phase of Lean Six Sigma (LSS) project is an important phase where the project heads and organizational directors need to select the critical issues for further improvements. The present work is primarily focused on analyze phase of LSS project to prioritized the Critical to Quality (CTQs) in a particular case industry.

Design/methodology/approach: The CTQs prioritization is being done based on the five evaluation criteria found from the literature. The weights of the criteria are determined through the Modified Digital Logic (MDL) method. The identified CTQs in assembly section of case industry have been ranked through the Grey Relation Analysis (GRA) under fuzzy environment. The results of the study have been validated using fuzzy VIKOR.

Findings: It is found that the 'cost' criterion is the most significant among other criteria with MDL weight of 0.3. Through fuzzy-GRA, out of ten identified CTQs, non-availability of rack system is found to be the most critical issue in assembly section of case industry. The perceptions of industrial manager and production head of case industry are strongly in favor of the obtained results and has implemented the suggested solutions.

Originality/value: To sustain in the competitive environment and produce quality product at right time, organizations need to control their CTQs as per their criticality. For this, the decision making becomes quite complex to select the most critical factors due to the fascinating nature of various criteria and sub-criteria. The present study is the first attempt that has implemented the multi-criteria decision-making approach in analyze phase of LSS project.

Keywords: Lean Six Sigma; Analyze phase; Grey relational analysis; VIKOR; Fuzzy Logic; Case study.

1. Introduction

The manufacturing organizations are struggling to settle into the current volatile economy and fluctuating technological environment (Singh, Rathi and Garza-Reyes, 2021). Such circumstances enforced to the manufacturing organizations for adopting continuous improvement approach to produce quality product within a specific time period to fulfill the customer demands. Lean Six Sigma (LSS) is one of the emerging and efficient continuous improvement strategy adopted by various corporations to achieve business excellence (Singh and Rathi, 2019). LSS approach leads to reduced wastes, process variability, and defects that subsequently results in increased organizational capability (Sony *et al.*, 2020). The Literature reveals that LSS as a breakthrough strategy tried to adopted in numerous environments like manufacturing, service, software, process industry irrespective of the size of business (Antony *et al.*, 2017); (Raja Sreedharan *et al.*, 2018). The successful implementation of LSS approach is based upon not only on technical considerate, but also on behavioral consciousness (Rathi *et al.*, 2016a). This approach is based upon the DMAIC (Define, Measure, Analyze, Improve, and Control) methodology which comprises the five phase logically related with each other (Swarnakar *et al.*, 2020). The DMAIC methodology provides the main improvements in the process through elimination of excessive wastes and causes (Singh *et al.*, 2019). Manufacturing organizations can put into act such methodology to improve the productivity of their manufacturing processes (Garza-Reyes *et al.*, 2016).

In the present case study, we are concentrating on the analysis phase of DMAIC methodology through which complete LSS project are accomplished. In the analysis phase, the collected data is to be examined through understanding and statistical tools to make the problem easier. The objective is to look for the aspects that have the greatest impact on process performance and figure out the root causes. In this case, we have identified critical factors of Poor Material Handling (PMH) in assembly section of medical equipment manufacturing company. The prime motive of study is to rank the most responsible factors for PMH in assembly section for further improvement. In this context, the main factors were listed with the help of perceptions of case industry's personals, but the clarity among the views of industry's persons are missing. So, it become essential to predict the smart solution in terms of picking the most critical factors for such problems through Multi Criteria Decision Making (MCDM) approaches.

The MCDM approaches are utilized to nominate the best possible factors from the large number of options for a set of selection criteria (Singh and Rathi, 2021a). These approaches have been successfully adopted to a wide range of technical and scientific decision-making situations. In literature, various methods are noted under MCDM category like Analytic Hierarchy Process (AHP) (Rathi *et al.*, 2015a), VlseKriterijumska Optimisacija I Kompromisno Resenje (VIKOR)

(Tabatabaei *et al.*, 2020); (Singh, Rathi, Antony, *et al.*, 2021), technique or order preference by similarity to ideal solution (TOPSIS) (Vinodh and Swarnakar, 2015); (Gupta *et al.*, 2019), simple additive weighting (SAW) (Farsijani *et al.*, 2015), Grey Relation Analysis (GRA) (Venkatachalam *et al.*, 2021), Best-worst method (Singh and Rathi, 2020a), and many more. Among these, GRA is outstanding MCDM approach adopted in numerous advance manufacturing, production planning, supplier selection (Banaeian *et al.*, 2018). Because, GRA offers distinct advantages over other methods like dynamic nature that gives opportunities for the change in the number of parameters and transformation in computer algorithm for the quick solution (Li *et al.*, 2019). Therefore, In the present study, Grey Relation Analysis (GRA) is adopted as MCDM approach for ranking the identified critical factors in LSS project. This approach executed under fuzzy environment because of human invention in decision matrix formation in qualitative nature (Farsijani *et al.*, 2015). At the end, the obtained results are compared and validated through VlseKriterijumska Optimisacija I Kompromisno Resenje (VIKOR) approach.

This manuscript contains five distinct sections, including the introduction. The 2nd section of the article depicts the literature review of the related work. The research methodology is presented in the 3rd section of the manuscript. The case study with detailed discussion is shown in the 4th section of the paper. The 5th section exhibits the managerial implications of the outcomes of this research work. The conclusion and future research direction is exhibited in the 6th section of the manuscript.

1.1 Research objectives

The following research objectives have been set for this research by the authors:

- *To develop a methodology of complex MCDM approach under the fuzzy environment for evaluating the critical factors in analyze phase of DMAIC methodology.*
- *To check the efficacy of developed methodology through a case study conducted in an Indian medical equipment manufacturing industry.*
- *To prioritize and identify the critical factor for PMH in assembly section of selected site.*

2. Literature Review

2.1 Review of poor material handling evaluation criteria

LSS is an breakthrough method that can overcome the ongoing economic vagueness and motivating market settings (van de Kaa *et al.*, 2017) (Singh and Rathi, 2020b). It requires competence to meet business's opportunities and subtle consumer necessities through successful execution of DMAIC methodology (Sreedharan V and Sunder M, 2018). In DMAIC, even though all phases are inter-linked, but it is very tedious to analyze the subjective data in analysis phase (Kumar *et al.*, 2019). In the current case study, we have mainly directed towards the analyze phase of DMAIC methodology of LSS strategy. In analyze phase, the selection of critical factors is a very key aspect for the effective implementation of LSS because the wrong selected factors can degrade the whole performance of a manufacturing firm (Singh and Rathi, 2020a). The selection of critical factors is always based upon some pertinent evaluation criteria (Wang *et al.*, 2014). A number of published articles have been reviewed on the selection criteria adopted for root causes identification in analysis phase (Govindan *et al.*, 2015); (Seth *et al.*, 2018). The various criteria have been found from the literature review pertaining to Lean Production, Six Sigma. Lean Six Sigma, and sustainability. With the help of expert's input, five main criteria are selected for assessment of the critical factors to PMH in assembly section in case industry. Table 1 summaries these criteria and the related references to each category.

Table 1: Summary of evaluation criteria for selection of critical to PMH

2.2 Review of multi criteria decision making method

There have been several complex decision-making methods existing in literature, ranging from simple single-objective methods to complex multi-objective systems. The hybrid methods that combine more than two methodologies have gotten a lot of attention recently because of their flexibility (Nguyen *et al.*, 2014). Despite this, due to the complexity associated with modelling integrated techniques and the relatively recent emergence of integrated methods, over 80% of published models are based on single methods. In the literature, various MCDM approaches reported like Analytical Hierarchy Process (AHP) (Lee, 2009); (Yadav *et al.*, 2018), Graph Theory and Matrix Approach (GTMA) (Jain and Raj, 2016); (Virmani *et al.*, 2021), VIKOR (Rathi *et al.*, 2016b); (Venkatachalam *et al.*, 2021), technique for order preference by similarity to ideal solution (TOPSIS) (Gandhi *et al.*, 2018); (Ma *et al.*, 2020), GRA (Haeri and Rezaei, 2019); (Ullah *et al.*, 2021) and many more. These approaches have been significantly adopted in numerous domains of engineering and among these; GRA and VIKOR are noticed the ultimate

MCDM approaches. Literature reveals that GRA approaches have been implemented to solve real-time problems relevant to manufacturing (Chakraborty *et al.*, 2019), supplier selection (Çalı and Balaman, 2019), machine tool selection (Ayag and Gürcan Özdemir, 2012), production planning (Kim and Ahn, 2019), and supply chain management (Sanayei *et al.*, 2010) and many more. These approaches provide prominent results because of their features to work on crisp value of attributes (Hashemi *et al.*, 2015). Therefore, the present study is used GRA approach the under fuzzy environment to evaluate the critical factors to PMH in assembly section of case industry.

2.3 Research Gaps

LSS is one of the continuous improvement strategies that are based on DMAIC methodology. The all phases of DMAIC methodology are equally important for getting the desired results. But the literature presents limited studies on the analyze phase to explore and highlights the root cause of problems. Also, the limited studies are focusing on evaluation of critical parameters in manufacturing setting using MCDM approach (Rathi *et al.*, 2016a). On the other hand, GRA approach provided the excellent results in various field of engineering for evaluating critical factors (Li and Zhao, 2016) (Kuo and Liang, 2011). As per author's best of knowledge, no article found which explore the adoption of GRA approach under fuzzy environment in analyze phase of LSS project. This research gap provides the motivation to the authors for conducting the present research work.

3. Research Methodology

In this paper, a research project study is shown that is conducted from 10 October, 2018 to 31 March, 2020 by the LSS project team and experts from industry and academia. This project work is carried in a medical equipment manufacturing industry located in North India. This industry is registered as a micro small and medium scale industry of the manufacturing sector. In present study, the research methodology is developed for prioritization of the critical factors responsible for PMH in assembly section at selected site. Figure 1 exhibit the proposed research methodology to conduct the present study and quantify the opinions of the decision makers. The proposed methodology exploits MDL weight for inter-comparison among selected criteria followed by the ranking of critical to PMH through fuzzy GRA and validating the obtained results by VIKOR approach under fuzzy environment.

Figure 1: Adopted research methodology

3.1 Methods

Modified Digital Logic: The evaluation parameters are not equally effect on the selection of critical factors, so cannot be assigned same weightage. In this situation, it is important to evaluate the rank of each parameter on the basis of organization's resources. Modified Digital Logic (MDL) is an admirable technique to estimate the parameter's weights in complex situations. This method is advanced version of Digital logic and having implausible features over digital logic (Rathi *et al.*, 2016b). It comprises the expert opinions in term of numeric value like 1, 2, and 3 for less, equal and higher substantial, correspondingly. Thereafter, MDL decision matrix is framed with mutual assessment on the basis of expert opinions. In MDL decision matrix, the positive decisions can be calculated by using Equation 1, where n is the number of parameters. Moreover, the final weight (W_j) of parameters is computed through Equation 2, where (*X*) is the positive decisions for the parameter.

$$N = \frac{n\,(n-1)}{2} \qquad (1)$$

$$W_j = \frac{X_j}{\sum_{j=1}^{n} X_j} \qquad (2)$$

Fuzzy Logic: It is a multivariate logic that provides consent to intermediate values to be represented in between conventional assessments like good/bad, right/wrong, agree/disagree etc. These types of values can be formulated mathematically that is managed by computers. Fuzzy approach is utilized for making decision among multi criteria where the emphasis is on opportunity rather than probability (Rathi *et al.*, 2015b). The fuzzy logic is significant where uman judgement involved in the interpretations. This approach was utilized to tackle the problem where strong edges not exist between two parameters and difficult to differentiate between participators and non- participators of a set (Al-Najjar and Alsyouf, 2003). This approach depends on set theory having a membership function lies in the range of 0 to 1. This approach provides a systematic solution to the fuzzy values, e.g. most, many, few, not many, etc. and widely applicable with various features. There are different fuzzy numbers like triangular, trapezoidal, intersection of two triangular fuzzy numbers etc. reported in the literature (Rathi *et al.*, 2016a). Trapezoidal fuzzy numbers are mostly used due to its simplicity and data processing (Rathi *et al.*, 2017). In present research work, the authors used trapezoidal fuzzy numbers (a, b, c, d) for {a, b, c, d ∊ R; a ≤ b ≤ c ≤ d} as shown in Figure 2. In trapezoidal fuzzy number, membership function $\mu_w(x)$ is represented in Equation 3.

Figure 2: Trapezoidal fuzzy number

$$\mu_w(x) = \begin{cases} \frac{x-a}{b-a}, & x \in [a,b] \\ 1, & x \in [b,c] \\ \frac{d-x}{d-c}, & x \in [c,d] \\ 0, & otherwise \end{cases} \tag{3}$$

GRA: The grey theory proposed by Deng (1982) has widely used by the decision-makers in real-life applications. It has proved to be quite efficient in situations where the information is incorrect and uncertain. It has applicable in various real-life situations like exploring the sustainable supply chain barriers (Sridharan et al., 2019); green supplier selection (Hashemi et al., 2015); cotton fabric selection (Chakraborty et al., 2019), etc. GRA has a distinct advantage over other decision-making approaches (analytical hierarchy process) like dynamic nature that gives opportunities for the change in the number of parameters; transformation in computer algorithm for the quick solution and its emphasis on objective factors rather than dependency or trust.

VIKOR: In 1998, Opricovic was developed VIKOR method for multi-criteria optimization of intricate structures (Opricovic, 1998). VIKOR prioritizes alternatives and examine the reasonable solution of problem near to the ideal solution. Its main effort is to provide ranking of alternatives and determines feasible solutions for a problem with conflicting criteria, which can assist decision makers to achieve final decision. This method utilizes linear normalization to diminish the units of criterion function and offers robust ranking of alternatives.

The steps of adopted decision-making approach are mentioned as follows:

Step 1: MDL weights (W_i) are estimated for all evaluation parameters. This step offers the weights of different parameters.

Step 2: Linguistic variables and corresponding fuzzy numbers are defined. A set of fuzzy rates is essential for comparing all critical to PMH with respect to evaluation parameters. These fuzzy numbers are allocated by the decision makers and accountable for intra parameters comparisons of the critical factors.

Step 3: Construction of Decision Matrix

Let assume $\mathcal{M}$ is the evaluation parameters and $\aleph$ is the critical factors during formation of decision matrix $\mathcal{L}$. The aggregating fuzzy rating for *n* parameters using *k* number of decision makers is represented as $\text{ҳ}_{ijk} = \{\text{ҳ}_{ij1}, \text{ҳ}_{ij2}, \text{ҳ}_{ij3}, \text{ҳ}_{ij4}\}$. For $i = 1,2,\ldots.\ \mathcal{M}$; $j = 1,2,\ldots.\ \aleph$; $k = 1,2,\ldots.\ k$. ҳ_{ijk} is estimated using Equation 4, considered from (Rathi *et al.*, 2016a).

$$\begin{cases} \text{ҳ}_{ij1} = minimum(k)\ \{\mathscr{g}_{ijk1}\} \\ \qquad \text{ҳ}_{ij2} = \frac{1}{k}\sum\{\mathscr{g}_{ijk2}\} \\ \qquad \text{ҳ}_{ij3} = \frac{1}{k}\sum\{\mathscr{g}_{ijk3}\} \\ \text{ҳ}_{ij4} = maximum(k)\ \{\mathscr{g}_{ijk4}\} \end{cases} \tag{4}$$

Hence the obtained decision matrix ($\mathcal{L}$) is shown in Equation 5 as (Kahraman *et al.*, 2003).

$$\mathcal{L} = \begin{bmatrix} \text{ҳ}_{11} & \cdots & \text{ҳ}_{1\mathcal{M}} \\ \vdots & \ddots & \vdots \\ \text{ҳ}_{\aleph 1} & \cdots & \text{ҳ}_{\aleph\mathcal{M}} \end{bmatrix} \tag{5}$$

Step 4: Normalization of aggregating fuzzy rating

In this step, the aggregating fuzzy rating is normalized for making uniformity among all contrasting comparison quantities. Mathematically, the normalization is carried out using the Equation 6 and 7, respectively (Banaeian *et al.*, 2018).

$$\lambda_{ij} = \left(\frac{\text{ҳ}_{ij1}}{\text{ҳ}_{ij1}^{+}}, \frac{\text{ҳ}_{ij2}}{\text{ҳ}_{ij2}^{+}}, \frac{\text{ҳ}_{ij3}}{\text{ҳ}_{ij3}^{+}}, \frac{\text{ҳ}_{ij4}}{\text{ҳ}_{ij4}^{+}}\right),\ j \in £ \tag{6}$$

$$\lambda_{ij} = \left(\frac{\text{ҳ}_{ij1}^{-}}{\text{ҳ}_{ij1}}, \frac{\text{ҳ}_{ij2}^{-}}{\text{ҳ}_{ij2}}, \frac{\text{ҳ}_{ij3}^{-}}{\text{ҳ}_{ij3}}, \frac{\text{ҳ}_{ij4}^{-}}{\text{ҳ}_{ij4}}\right),\ j \in £' \tag{7}$$

Where ҳ_{ij4}^{+} = maximum (ҳ_{ij4}), $j \in £$; $\text{ҳ}_{ij1}^{-} =$ minimum (ҳ_{ij1}), $j \in £'$; *j* represents higher desired value and £' represents lower desired value.

Step 5: Defuzzification

Defuzzification is a process of getting crisp values for parameters with respect to corresponding factors. A quantitative value is obtained for linguistic variables and corresponding values are assigned on the basis of verbal reasoning. The Equation 8 is used for estimation of crisp values (Rathi *et al.*, 2016b).

$$\aleph_{ij} = Defuzz\left(\text{ꭓ}_{ij}\right) = \frac{\int \lambda(\text{ꭓ}).\text{ꭓ}d\text{ꭓ}}{\int \lambda(\text{ꭓ}).d\text{ꭓ}}$$

$$\aleph_{ij}= \frac{\int_{\text{ꭓ}_{ij1}}^{\text{ꭓ}_{ij2}}\left\{\frac{(\text{ꭓ}-\text{ꭓ}_{ij1})}{(\text{ꭓ}_{ij2}-\text{ꭓ}_{ij1})}\right\}.\text{ꭓ}d\text{ꭓ} + \int_{\text{ꭓ}_{ij2}}^{\text{ꭓ}_{ij3}}\text{ꭓ}d\text{ꭓ} + \int_{\text{ꭓ}_{ij3}}^{\text{ꭓ}_{ij4}}\left\{\frac{(\text{ꭓ}_{ij4}-\text{ꭓ})}{(\text{ꭓ}_{ij4}-\text{ꭓ}_{ij3})}\right\}.\text{ꭓ}d\text{ꭓ}}{\int_{\text{ꭓ}_{ij1}}^{\text{ꭓ}_{ij2}}\left\{\frac{(\text{ꭓ}-\text{ꭓ}_{ij1})}{(\text{ꭓ}_{ij2}-\text{ꭓ}_{ij1})}\right\}.d\text{ꭓ} + \int_{\text{ꭓ}_{ij2}}^{\text{ꭓ}_{ij3}}d\text{ꭓ} + \int_{\text{ꭓ}_{ij3}}^{\text{ꭓ}_{ij4}}\left\{\frac{(\text{ꭓ}_{ij4}-\text{ꭓ})}{(\text{ꭓ}_{ij4}-\text{ꭓ}_{ij3})}\right\}.d\text{ꭓ}}$$

$$\aleph_{ij}= \frac{-\text{ꭓ}_{ij1}\text{ꭓ}_{ij2} + \text{ꭓ}_{ij3}\text{ꭓ}_{ij4} + \left(\frac{1}{3}\right)(\text{ꭓ}_{ij4}-\text{ꭓ}_{ij3})^2 + \left(\frac{1}{3}\right)(\text{ꭓ}_{ij2}-\text{ꭓ}_{ij1})^2}{-\text{ꭓ}_{ij1}-\text{ꭓ}_{ij3}-\text{ꭓ}_{ij3}+\text{ꭓ}_{ij4}} \qquad (8)$$

Steps of Fuzzy GRA:

Step 6: Normalization of crisp matrix

In this step, the obtained crisp matrix is converted into normalized matrix using Equation 9 (Mouad and Cherkaoui, 2017). Here, ӿ_i^* represents the normalized value of critical to PMH of “i” with respect to evaluation parameter“*”.

$$\text{ӿ}_i^* = \frac{\text{ӿ}_i - min\,(\text{ӿ}_i)}{max\,(\text{ӿ}_i) - min\,(\text{ӿ}_i)} \qquad (9)$$

Step 7: Formation of Deviation Sequence Matrix

In the second step of the grey relational analysis, the deviation sequence (Ɵ_i) is calculated using Equation 10 (Gumus *et al.*, 2013).

$$\text{Ɵ}_i = \left\| max\left(\text{ӿ}_i^*\right) - \text{ӿ}_i^* \right\| \qquad (10)$$

Step 8: Estimation of grey relational coefficients

In this step, the grey relational coefficient (ʒ_i) is calculated using Equation 11(Kaswan *et al.*, 2021). Here, Ɵ_{min} represents the minimum value of the deviation sequence and Ɵ_{max} designates the maximum value of the deviation sequence. The value of ʒ is considered as 0.5.

$$\xi i = \frac{\theta_{min} + \xi.\theta_{max}}{\theta_i + \xi.\theta_{max}} \tag{11}$$

Step 9: Ranking as per grey relational grade

In this step, the grey relational grade ($\bar{\Upsilon}_i$) is estimated using Equation 12 (Singh, Rathi, Antony, *et al.*, 2021). Here "n" is the number of evaluation parameters for selection of critical to PMH at selected case industry.

$$\bar{\Upsilon}_i = \frac{1}{n}\sum_{i=1}^{n} \xi i \tag{12}$$

Steps of Fuzzy VIKOR:

Step 6: Identify beneficial and non-beneficial parameters

Beneficial parameter- Whose larger value is desired

Non-beneficial parameter - Whose smaller value is desired,

Step 7: Find best and worst value of each parameter

To find the best and worst value of screened parameters, Equation 13 and Equation 14 is being used respectively (Opricovic, 2011).

$$Best\left(X_i^+\right) = \begin{cases} max\left(X_{ij}\right) for\ beneficial \\ \min\left(X_{ij}\right) for\ non - beneficial \end{cases} \tag{13}$$

$$Worst\left(X_i^-\right) = \begin{cases} min\left(X_{ij}\right) for\ beneficial \\ \max\left(X_{ij}\right) for\ non - beneficial \end{cases} \tag{14}$$

Step 8: Compute utility measure (S_i) and regret measure (R_i)

The utility measure and regret measure are computed by using Equation 15 and Equation 16 (Liu *et al.*, 2012).

$$S_i = \sum_{j=1}^{m}\left(W_j * \frac{X_i^+ - X_{ij}}{X_i^+ - X_i^-}\right) \tag{15}$$

$$R_i = max_j\left(W_j * \frac{X_i^+ - X_{ij}}{X_i^+ - X_i^-}\right) \tag{16}$$

Step 9: Calculate VIKOR index (Q_i)

Finally, VIKOR ranking is estimated based on the index value *(Q_i)*, which was computed using Equation 17-21 (Sanayei *et al.*, 2010); (Singh and Rathi, 2021a).

$$Q_i = v * \frac{S_i - S^*}{S^- - S^*} + (1 - v) * \frac{R_i - R^*}{R^- - R^*} \quad (17)$$

$$S^- = max_i\, S_i \quad (18)$$

$$S^* = min_i\, S_i \quad (19)$$

$$R^- = max_i\, R_i \quad (20)$$

$$R^* = min_i\, R_i \quad (21)$$

The critical factor with the least value of VIKOR index is chosen for further improve phase.

4. Case Study

The present case study was conducted in an Indian organization engaged in the manufacturing of medical equipments. The main focus of the case industry is to fulfill customer's requirements related to product quality and environmental sustainability. The management of case company is much concerned about the lower production rate, high wastage in product OT table. To resolve these issues, the product Operation Theatre (OT) table as a case product is selected and DMAIC based approach has been adopted to execute the case. This study is mainly focused on the detailed analysis of analyze phase of DMAIC approach. Moreover, a brief discussion of Define-Measure-Improve-Control phases have also been presented to understand the nature of the present case clearly.

4.1 D-Define Phase

Define phase aims to identify the problem and explore the scope of the project. In this phase, the requirement of customers has been collected through the Voice of Customer (VOC) and associated with Voice of Business (VOB). A project team of senior manager, LSS experts, academician, section head, and coordinators have been formed. The selected team members are having rich knowledge of LSS and its implementation. The coordinators are representatives of top management and having a reasonable knowledge of LSS. In this phase, the manufacturing process flow chart, project charter, pie chart and high-level SIPOC chart are constructed to have a clear understanding of the project scope and associated goals. The result of this phase exhibits that prime issues are poor material handling (40%), unnecessary movement of men and material both (28%), environmental issues (18%), and reworks (7%). The section-wise data related to the most critical i.e. poor material handling is collected and further analyzed it.

4.2 M-Measure Phase

In this study, the main aim of the M-Measure phase is to explore the current status of the system and to find out root causes of inefficiencies. After extracting the possible causes of deviation from a set of targets, a Pareto chart is being used to highlight the most significant cause among the listed one. For the project team, the data collection is a critical task because the whole project improvement and success are based on the collected baseline data. Therefore, critical to quality measures have been determined from a customer viewpoint and environmental perspective. The current production data of OT table is collected and analyzed statistically. Statistical results exhibit that mean of current production data is 160 products with a standard deviation of 9.7503. The comparison is made by forming the ratio of the spread between the process specifications to the spread of the process standards. Parts Per Million (PPM) below the lower specification limit are 944015.9 based on potential performance, this reveals a large number of non-conforming parts of the process lie outside the specification limits. Such non-confirming parts are further required rework during drilling operations. The Defects Per Million Opportunities (DPMO) at current production level of OT table is computed as 309523 PPM. During this phase, we have identified the possible reasons which are responsible for PMH in assembly section as shown in Table 2.

Table 2: Critical to PMH in assembly section

The hierarchical structure for the selection of critical to PMH is shown in Figure 3. In this structure, level 1 represents the goal of study to selection of critical factors that to be designated from the identified ten significant factors to PMH as indicated in level 2. The selections of critical factors are based on evaluation parameters as illustrated in level 3.

Figure 3: Hierarchical structure for the selection critical to PMH in assembly section

4.3 A-Analyze Phase

Analyze phase elaborates the analysis of collected facts and data of the existing system and outlines the critical to PMH in assembly section at the plant. The collected data in Table 2 is further need to ranked as per their criticality and therefore, adopted MCDM approach to tackle this complexity. To identifying the impact of selection criteria on critical factors, significant knowledge of both technological and economic aspects is required. This is time consuming process and therefore, MDL method is used to compute the criteria weight. As per this method, numeric values on the scale of 1-3 are assigned to the parameters and pair-wise comparison matrix is formed. Table 3 represents the relative decision matrix and MDL weights computed with the help of Equation 2. Cost (C3) found as the most dominant parameter for the selection of critical factors to PMH, while measurement system (C5) appears as the least dominant parameter. The contribution of parameters towards selection of critical factors is shown in Figure 3. It observed that the contributions of parameters would be varying from shop floor of industry to industry.

Table 3: Evaluation criteria weight by MDL

Further, the decision maker's opinion is collected through fuzzy logic approach for comparison of all critical factors for each parameter. In fuzzy hypothesis, linguistic variables are used for constructing the decision matrix among parameters and critical factors. With the help of Table 4, these linguistic variables are further transformed into fuzzy numbers for the present case study. The most significant relation among parameter and critical factor is represented by Extremely High (EH) and the least is termed by Extremely Low (EL).

Table 4: Linguistic variable and corresponding fuzzy numbers

Through brainstorming session with decision makers, a single linguistic decision matrix is formed for GRA approach as demonstrated in Table 5. But it is evidently recognized that final decision matrix can be alter as per the existing condition and requirement of the plant.

Table 5: GRA linguistic decision matrix for critical to PMH

In next step, fuzzy values are altered into crisp values with the help of Equation 8. Table 6 demonstrates the estimated crisp values of critical to PMH for GRA approach.

Table 6: Estimated GRA crisp values

The estimated crisp values (from Table 6) are further used for solving the steps of GRA approach by using Equations 9-12. The final ranking to critical factors as per Grey Relational Grade (GRG) is exhibited in Table 7.

Table 7: GRA rank of critical to PMH

Furthermore, the obtained ranking of critical factors through GRA are compared with the VIKOR approach as shown in Table 8 and observed that ranking is almost same, which exhibits the robustness of adopted methodology.

Table 8: Comparison of GRA results with VIKOR approach

The obtained result shows that non-availability of the rack system is the main factor responsible for PMH in assembly section. Other prime responsible factors to PMH are poor indoor air quality, no bin system used, not used the bin card facility, and poor space utilization, respectively (refer Table 8). It is also observed that improper specification of material and violation of rules are rarely responsible for PMH in this section. Overall, it founds that the industrial managers and section head are also agreed with the obtained results. The top management and official of case industry are ready to adopt the corrective action plan immediately, so that productivity level of the plant could be increased through proper material handling in the assembly section.

4.4 I-Improve Phase

In this phase, the possible solutions are identified, implemented, and tested in the plant. Each proposed solution is implemented in such a way that a proper recording is performed to compare current outcomes with the previous one. The required training to employees and managers is provided from time to time for the successful implementation of LSS. Besides, lean tool i.e. 6S is adopted for building appropriate solutions of identified critical factors to PMH is assembly section. Here 6S stands for Seri, Seiton, Seso, Seiketsu, Shitsuke, and SeJizoku kanosei which means sort, streamline, shine, standardizes, sustain, and sustainability, respectively. During Seri step, the parts and equipment were sorted out as per their used frequency. After sorting, the resetting of all parts and equipment is done to streamline the flow of material.

4.5 C-Control Phase

To support improvement activities, the changes incorporated in business must be reported. The control process ensures that the gains acquired after the adopting improvement steps are maintained correctly after the completion of the project. After successful implementation of suggested solutions, ten months of production data of case industry are collected to authenticate the alterations made for attaining the required specifications. The mean of production data is improved to 201 products with a standard deviation of 3.5401. The DPMO at improved production level of OT table is computed as 48951.44 PPM. The analysis shows that variation is declined reliably and the selected process metrices improved significantly. The process metrices evaluation after the analysis is shown in Table 9. From the analysis, it is observed that the production per month of OT table is increased by 15.18% because of reduction in unnecessary movement of both, men and material by 63.08%.

Table 9: Process metrices evaluation before and after LSS project execution

5. Managerial, Research and Societal Implication

The present research work prompts the managers and practitioners to implement MCDM approach to solve complex decision-making problems particularly in analyze phase of LSS project. The unique application of fuzzy-GRA method was used to prioritize the critical to PMH in assembly section of case industry. If available data is insufficient, subjective in nature, and large number of variables/parameters exists, than in such situation, GRA method provides highly reliable results instead of conventional tools (Kuo and Liang, 2011). The benefits of the adopted method provide a motivation to the industrial managers to implement LSS in the current process or system to turn it into eco-friendly ones. The current study offers a motivational sight for the application of the integrated fuzzy-GRA method in other sectors like hospitality, healthcare, heavy industries, etc.

In the current scenario, manufacturing industries in developing nations are facing tremendous pressure of competition to produce quality product on time to meet market demand. The proper analysis of critical to quality (CTQs) in LSS project selection will reduce the capacity waste, unnecessary movement of man and material, rework etc. The prioritization of CTQs enables the organizational managers to tackle in the most influential CTQ that has the maximum impact on organizational productivity, profitability, and environmental sustainability. The researchers will be facilitated from this research in terms of developing and understanding the criteria selection, weights determination, and more importantly the selection of appropriate CTQ. The comprehensive learning on CTQs selection will develop the decision-making capability to select appropriate factors in other areas of the LSS project. Moreover, society will be promoted present work as smart selection of CTQs in LSS project leads to lesser rework, waste, and reduction in the current level of emission of the organization. So, successful LSS implementation not only leads to better health of the case industry personnel but also the society.

6. Conclusion and future research direction

The present research work deals with the selection of the CTQ in analysis phase of LSS project executed in a manufacturing organization based on five criteria those extracted from literature. As each criterion plays a different to other, so the weightage of the criteria was found through the MDL method based on the responses of twenty experts from different manufacturing industries. A case study was executed in a medical equipment manufacturing industry in India to to improve operational and environmental performance. But the present study primarily focused on analysis phase of LSS project to find the prominent CTQ that has the maximum potential for sustainability improvement. To prioritize the CTQ in analysis phase, Fuzzy GRA is used in the present research work, so that CTQ as per their ranking can be considered for further improvement. The obtained GRA ranking was validated through VIKOR approach and found almost same results. It was found that non-availability of rack system, poor indoor air quality, no bin system used, not used the bin card facility, and poor space utilization are found the most critical to PMH in assembly section. To tackle these most prominent critical factors, we have suggested solutions to case industry and general manager and section head of case industry were also in the favor of suggestions and implemented them with immediate effect in company. Finally, the case study result reveals that cycle time decreases by 30.08%, lead time decreases by 37%, 63.08% reduction in unnecessary movement of men and material, 27.45% reduction in change over time, and production level per annum increases by 15.18%.

Although the study depicts the prioritization of CTQ in analyze phase through Fuzzy GRA, there still exist some areas of improvement. Firstly, the present study considers five major criteria like environmental, cost, safety, awareness, and measurement aspects that are significant in attribute decision making. However, other criteria like cultural aspects and customer consensus related are also prominent factors for CTQ selection. Secondly, the CTQ prioritization considered in context only PMH in assembly section of the medical equipment manufacturing industry. Therefore, this approach can also be implemented to improve other section of same organization. Besides, to make the adopted approach more generalized the case studies from the different manufacturing sectors with varied nature (chemical, semi-conductors, construction, food and drinks, aerospace) and size (large, medium, and small enterprises) is required. Also, this methodology can be implemented in industries in context of developing and developed nation. The present research work can be extended in the future by organized investigation of the CTQ selection criteria using an advanced decision-making approach, DEMATEL, Best-Worst Method (BWM) that will provide a better estimate of the intriguing nature of the criteria.

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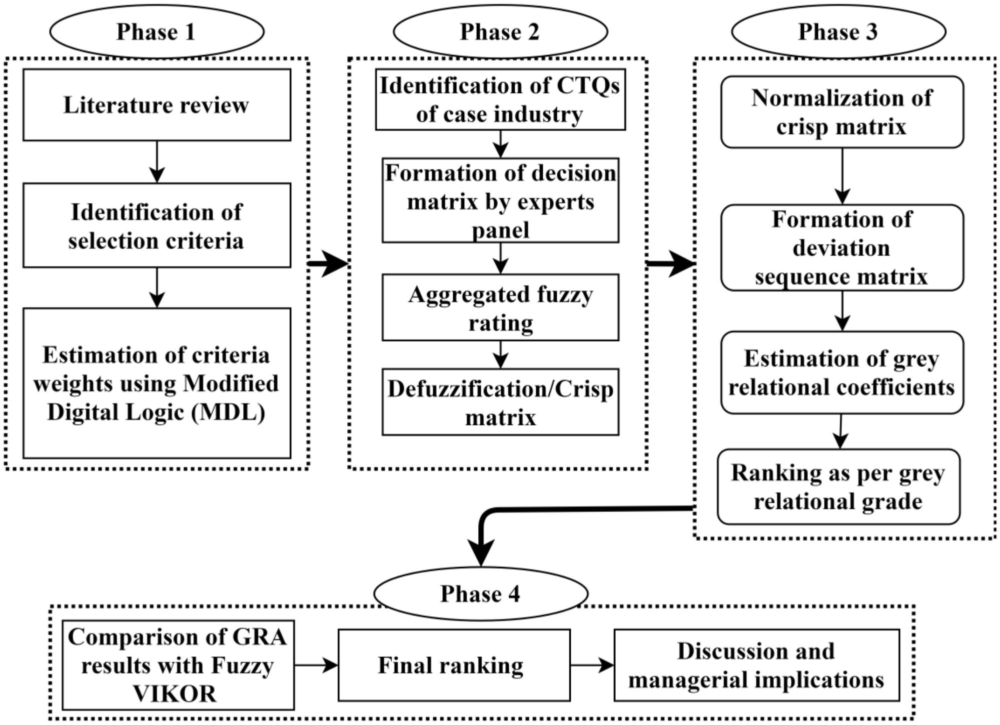

Figure 1

1385x999mm (72 x 72 DPI)

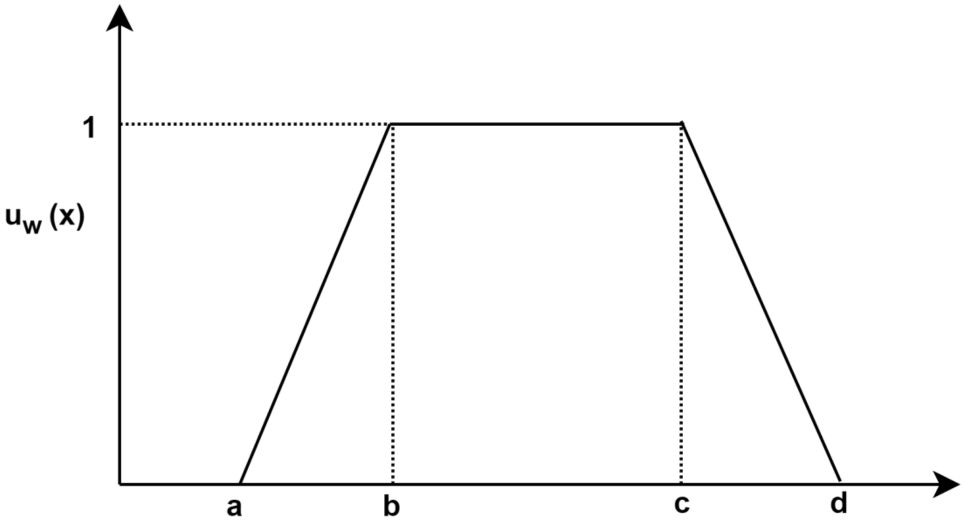

Figure 2

587x335mm (72 x 72 DPI)

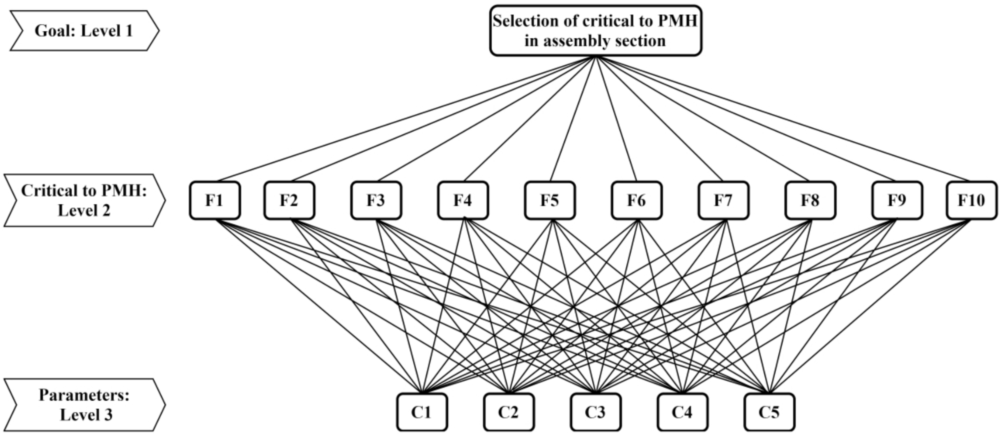

Figure 3

1421x615mm (72 x 72 DPI)

Table 1: Evaluation Criteria for selection of critical to PMH

References	**Criteria**	**Notation**	**Description**
(Gupta *et al.*, 2019); (Huijbregts *et al.*, 2017)	Environmental effect	C1	Environmental effect attempts to rate the work done for green concept adoption, energy used, and wastage at an assembly section. The environmental possessions are knowingly more incorporating than impartial energy. High energy shop floors can not a green workshop, but an environmental friendly shop floor will be energy efficient.
(Singh *et al.*, 2021)	Safety	C2	Safe work station is the prime aspect due to the principle of safe way is the right way. The expenses of injuries and ill health can be unreasonably high for engineers in assembly section and machine section. Many workers are "important," who are seriously disrupted in production and efficiency and profitability by losses from injury or ill health.
(Onut *et al.*, 2009)	Cost	C3	This includes all expenses for breakdown, repairing, preservation and other required activities, in order to fulfill other operating criteria over the entire service life. It is a prime factor for examining the critical to PMH.
(Govindan *et al.*, 2015)	Awareness	C4	Awareness provides the way to solve the critical issues on time and in accurate manner. This factor is highly responsible for selection of critical to PMH in assembly section.
(Ghobakhloo and Fathi, 2020); (Singh and Rathi, 2019)	Measurement system	C5	In machine section and assembly section, the accurate measurement system helps in quality production and reduces the cost used for rework the components.

Table 2: Critical to PMH in assembly section

S.N.	Critical to PMH	Abbreviation
1	Improper flow of material	F1
2	Lack of maintenance	F2
3	Poor material testing	F3
4	Non-availability of the rack system	F4
5	Poor indoor air quality	F5
6	Unavailability of bin system	F6
7	Bin card is not used	F7
8	Improper specification of material	F8
9	Poor space utilization	F9
10	Violation of rules	F10

Table 3: Selection criteria weight by MDL

Evaluation criteria	C1	C2	C3	C4	C5	Positive Decision	MDL weight	Rank
C1	2	3	1	1	3	8	0.2	3
C2	1	2	1	1	3	6	0.15	4
C3	3	3	2	3	3	12	0.3	1
C4	3	3	1	2	3	10	0.25	2
C5	1	1	1	1	2	4	0.1	5

Table 4: Linguistic variable and corresponding fuzzy numbers

Linguistic variable	**Fuzzy number**
Extremely High (EH)	0.8,0.8,1.0,1.0
Very High (VH)	0.7,0.8,0.8,0.9
High (H)	0.5,0.6,0.7,0.8
Above Average (AA)	0.4,0.5,0.5,0.6
Average (A)	0.2,0.3,0.4,0.5
Very Low (VL)	0.1,0.2,0.2,0.3
Extremely Low (EL)	0.0,0.0,0.1,0.2

Table 5: GRA linguistic decision matrix for critical to PMH

Evaluation criteria	**Critical to PMH**									
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**
C1	A	AA	VH	EL	A	VL	A	VH	A	EH
C2	AA	A	A	EH	H	VH	VH	VL	H	EL
C3	H	VH	VH	EL	A	VL	A	EH	AA	EH
C4	AA	AA	A	EH	VH	VH	VH	VL	H	EL
C5	AA	AA	A	EH	H	VH	VH	VL	H	VL

Table 6: Estimated GRA crisp values

Critical to PMH	**Evaluation Criteria**				
	C1	**C2**	**C3**	**C4**	**C5**
F1	0.441667	0.683333	0.741667	0.683333	0.683333
F2	0.683333	0.441667	0.983333	0.683333	0.683333
F3	0.983333	0.441667	0.983333	0.441667	0.441667
F4	0.177778	0.944444	0.177778	0.944444	0.944444
F5	0.441667	0.741667	0.441667	0.983333	0.741667
F6	0.383333	0.983333	0.383333	0.983333	0.983333
F7	0.441667	0.983333	0.441667	0.983333	0.983333
F8	0.983333	0.383333	0.944444	0.383333	0.383333
F9	0.441667	0.741667	0.683333	0.741667	0.741667
F10	0.944444	0.177778	0.944444	0.177778	0.383333

Table 7: GRA rank of critical to PMH

Critical to PMH	**Evaluation Criteria**					**GRG**	**GRA Rank**
	C1	**C2**	**C3**	**C4**	**C5**		
F1	0.604167	0.573123	0.416667	0.573123	0.5	0.533416	6
F2	0.443425	0.426471	0.333333	0.573123	0.5	0.45527	7
F3	0.333333	0.426471	0.333333	0.426471	0.356436	0.375209	8
F4	1	0.91195	1	0.91195	0.885246	0.941829	1
F5	0.604167	0.625	0.604167	1	0.553846	0.677436	4
F6	0.6621	1	0.6621	1	1	0.86484	2
F7	0.604167	1	0.604167	1	1	0.841667	3
F8	0.333333	0.401662	0.344418	0.401662	0.333333	0.362882	9
F9	0.604167	0.625	0.443425	0.625	0.553846	0.570288	5
F10	0.344418	0.333333	0.344418	0.333333	0.333333	0.337767	10

Table 8: Comparison of GRA results with VIKOR approach

Critical to PMH	**S**	**R**	**Q**	**GRA Rank**	**VIKOR Rank**
F1	0.575517	0.201724	0.618227	6	6
F2	0.622586	0.223448	0.680628	7	7
F3	0.722414	0.223448	0.732287	8	8
F4	0.014483	0.014483	0	1	1
F5	0.29569	0.09	0.277767	4	4
F6	0.127586	0.063793	0.144882	2	2
F7	0.277586	0.09	0.268399	3	3
F8	0.948966	0.3	0.983583	9	9
F9	0.335517	0.111724	0.336421	5	5
F10	0.98069	0.3	1	10	10

Table 9: Process metrices evaluation before and after LSS project execution

Process metrices	**Total Count units (Before implementation)**	**Total Count units (After implementation)**	**Performance improvement (%)**
DPMO	309523	48951.44	84.18%
Production per month	160 units	201 units	15.18%
Unnecessary movement	325 feet	120 feet	63.08%