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EVALUATION OF CRITICAL SUCCESS FACTORS FOR GREEN MANUFACTURING USING FUZZY TOPSIS

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ABSTRACT:

The challenges of mitigating the adverse effects manufacturing on environment, coupled with a need for optimum utilization of resources and increasing complexities in waste management are important factors which are motivating businesses to espouse green manufacturing. Alignment of the environmental considerations with the manufacturing activities in an organization is at the essence of Green Manufacturing. The performance of green manufacturing is evaluated using operational, environmental, financial and social criteria. There are various factors which act as pivots for promoting a transition towards green manufacturing are identified as 'critical'. This study uses Fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method to filter the uncertainties and ambiguity in linguistic terms and prioritizes the critical success factors for adoption of green manufacturing. This study offers managerial insights to effectively evaluate the interdependencies between these critical success factors. The results obtained indicate that factors viz., 'adoption of eco-innovations' and 'reverse logistics' are placed at priority Level of I and II. This study will help businesses concentrate on those factors that have maximum influence on implementing green manufacturing.

KEYWORDS: *Green manufacturing, Critical success factors, Fuzzy TOPSIS*

1. INTRODUCTION

Population explosion and the rapid industrialization are resulting in the depletion of non-renewable resources like fossil fuels, metals and minerals. This has aggravated the problems like climate change and global warming. Consequentially, serious environmental disasters, natural calamities etc are causing huge damages to life and property. The international community has become increasingly aware of these environmental concerns. The businesses' today are using green manufacturing techniques to prevent further damage to the ecosystem. They are espousing eco-efficient practices such as reduced hazardous gases emissions, optimal use of resources, proper waste management system etc**. Melnyk S A and Smith R T.[1996]**.

A quantitative analysis of factors which are critical for green manufacturing needs to be carried out. The green manufacturing initiatives are based on over-all assessments on the environmental impacts of manufactured products, energy consumption and waste generation using the Life Cycle Assessment (LCA) **Dechant, K. and Altman, B., [1994].** The performance of green manufacturing can be evaluated based on operational, environmental, financial and social criteria.

Table 1: Criteria's for evaluating effectiveness of green manufacturing initiatives

Operational	Environmental	Financial	Social
· Optimum use of natural resources · Recycling of end - of-life products · Replacement of hazards products · Adoption of energy-saving processes and equipment	· Pre-use risk assessments for residual substances · Reducing the total waste generated · Proper waste segregation of substances produced · Using reverse logistics · Reducing greenhouse gases produced	· Revenue Growth · Reduced operating cost · Tax benefits and cheaper financing · Increased brand reputation	· Community well being · Safer working environment · Greater regulatory compliance

The main objectives of this study are:

i. to determine the critical success factors for implementation green manufacturing
ii. To filter the uncertainties and ambiguity in linguistic terms using fuzzy techniques.
iii. Analyze interdependencies among critical success factors and rank the same by employing TOPSIS method

2. LITERATURE REVIEW

Many researchers have conducted studies on various elements of green manufacturing. Literature on issues such as green manufacturing, green design, sustainability, eco-innovation and lean manufacturing was studies. Based on this literature review, various critical success factors for green manufacturing were identified and the same are listed below:

2.1 Adopting Eco-innovations

These innovations are divide into, add-on innovations, integrated innovations and macro-organizational innovations .**Liu, A. Z., and Seddon, P. B. [2009].** Successful commercial implementation of newer methods requires a setting of cross functional team and financial resources **George, J. M., and Jones, G. R. [2008].** The critical factors considered for implementing new systems are integration and maintainability of newer technological processes and products with the existing system.

2.2 Setting up of Green supply chain

Establishing a comprehensive green supply chain system encompassing the various purchase activities, and suppliers, reduce the ecological impact of industrial activity**. Routroy S. (2009), Raut R. D. et al. [2017**]. Conceptualization of environmentally benign procurement schemes with emphasis on communication, empowerment, vendor development, training and education of suppliers, financial support etc are key to adopting green manufacturing. **Handfield et al. (1997), Lee et al. [2001]** Unambiguous directions and frequent communications reduce the risk of conflicts among various stakeholders **ElTayeb, T. K [2010].**

2.3 Integration with other waste reduction techniques (WRT)

Manufacturers need to conserve and reduce resources by assimilating the various waste reduction techniques like lean methodologies, with the green manufacturing implementation process **Halme, M. et al [2007]**. **Liu, F. et al [2005]** highlighted the direct correlation relationship between lean methodologies and green manufacturing. Manufactures need to focus on reducing, recycling, remanufacturing, reuse, returnable packaging and waste segregation.

2.4 Use of green products and process

Environmental regulatory compliances are driving organizations to adopt green processes and products. Substitution of hazardous substances by green products is critical for green manufacturing. **Azzone, G., and Noci, G. [1988],** Manufactures are reorienting their operations by use of green products and processes. To survive the competitive pressures, manufactures need to incorporate green practices to project a green brand image. **Digalwar, A. K., and Sangwan, K. S. [2007].**

2.5 Support of management

For successful implementation of green manufacturing, sincere and sustained support of top management is imperative. **Huang, Y.et al. [2009]**. A progressive management provides entrepreneurship skills, leadership, commitment, clear vision, and sufficient resources for investment in green manufacturing. Implementation of green manufacturing requires full-time competent, cross-functional, and process-centric teams possessing a comprehensive business and technical acumen **Kassinis and Vafeas [2002]**.

2.6 Using alternative energy sources

Manufactures are adopting alternative energy sources due to reduction in their cost and increased reliability. **Bonilla, S. H.et al. [2010],** Alternative energy sources are those that can generate electricity with negligible harmful emissions. These inexhaustible sources offer environmental and economic benefits compared to fossil fuel energy sources **Barbara, linke. Et al. [2012]**. Use of alternative energy source is paramount for establishing green manufacturing system.

2.7 Adopting Green disposal

Establishing an effective waste management system is critical for espousing green manufacturing. The regulatory and legal frameworks are being enacted based on the "polluter pay principal" **Lisney, R. et al [2003}** Manufactures are implementing waste prevention strategies to reduce the cost of waste disposal. Adopting effective green manufacturing systems also involves less or no use of hazardous substances resulting in reduction of waste disposal cost. **Polcari, M. R. [2007].**

2.8 Government and regulatory support

Setting up of enabling infrastructure, financial incentives and regulatory norms are critical factors for transitioning to greener manufacturing. **Huang, Y.et al. [2009].** Effective financial incentives such as subsidies, tax exemptions and green permits are incentivize green manufacturing. Government and regulatory support stimulate confidence in manufactures to invest in technologies for green manufacturing. **Dobers, P., and Wolff, R. [2000].**

2.9 Use of reverse logistics

Businesses are espousing processes which adopt reverse logistics techniques **Zhao, L. J. [2008].** This reduces the use of resources for making new products. Manufacturers utilize previously shipped products for consumption through recycling and re-manufacturing. Reverse logistics uses products obtained from 'returns' due to defective production ; commercial returns because of low sales ; product recalls, warranty returns, service returns, end-of-use returns etc. **Shan, H., and Yao, F. Y. [2009], Wang, S., and Gong, D.N. [2007].**

2.10 Enhancing consumer base

Increased consumer acceptance of environmentally benign products is critical for green manufacturing. A green brand image helps in attracting a newer client base. This encourages manufactures to invest in green technologies. Flexibility in business model and effective financial management are critical elements for maintaining a strict environmental marketing budget. **Chien, M. K., and Shih, L. H. [2007].**

2.11 Environmental Benchmarking

Using an effective benchmarking system for Environmental Management that sets challenging goals and empowers employees to achieve them act as powerful tool in augmenting green manufacturing. **Presley, A. and Meade, L. [2010],** Manufacturers are utilizing environmental benchmarking to improve their market competitiveness **Ginsberg, J. M., and Bloom, P. N. (2004).** The critical success factors along with references are shown in table 2.

Table 2: Critical success factors in green manufacturing

Sl. No.	Critical success factor	Source
1	Adopting Eco innovations	Liu, A. Z., and Seddon, P. B. (2009), Geroge, J. M., and Jones, G. R. (2008)
2	Setting up of Green supply chain	Routroy S. (2009), Raut R. D. et al. (2017), Handfield et al. (1997), Lee et al. (2001), ElTayeb, T. K (2010),industry expert
3	Integration with other WRT	Halme, M. et al. (2007), Liu, F. et al. (2005)
4	Use of green products and process	Azzone, G., and Noci, G. (1988), Digalwar, A. K., and Sangwan, K. S. (2007)
5	Support of management	Huang, Y et al. (2009), Kassinis and Vafeas (2002), industry expert
6	Using alternative energy sources	Bonilla, S. H.et al. (2010), Barbara, linke. et al. (2012)
7	Adopting Green disposal	Lisney, R. et al. (2003), Polcari, M. R. (2007)
8	Government and regulatory support	Dobers, P., and Wolff, R. (2000)
9	Use of reverse logistics	Zhao, L. J. (2008), Shan, H., and Yao, F. Y. (2009), Wang, S., and Gong, N. (2007)
10	Enhancing consumer base	Chien, M. K., and Shih, L. H. (2007), industry expert
11	Environmental Benchmarking	Presley, A. and Meade, L. (2010), Ginsberg, J. M., and Bloom, P. N.(2004)

3. METHODOLOGY

In this study, factors responsible for successful transitioning to green manufacturing were identified based on literature reviews and opinion of professionals from industry and academia. Multi-criteria decision-making techniques (MCDM), is one of the effective methodologies in decision making for complicated problems that exhibit uncertainty, conflicts, alternatives, variable interests and multiple criteria. MCDM methodologies are used for prioritizing, weighting and selecting the most appropriate factors. MCDM techniques commonly used for such type of research are: AHP, ANP, TOPSIS, and VIKOR etc.

In the present research, TOPSIS has been preferred over other MCDM techniques. This is due to the fact that TOPSIS does not have any explicit limit over the number of alternatives/criteria that can be considered. Moreover, TOPSIS technique does not require pair-wise comparison or a consistency check. This makes TOPSIS a better and simpler method for decision making. Researchers have successfully used TOPSIS in different business areas like manufacturing systems, supplier selection and logistics, engineering design and marketing strategies.

TOPSIS method was introduced for the first time by **Yoon and**

Hwang, [1981] and later modified by Hwang, Lai, and Liu, [1993].The fuzzy version of the TOPSIS was suggested by **Triantaphyllou and Lin, [1996].** TOPSIS is a goal based approach for finding the factors that is closest to the ideal solution. Various factors are ranked based on their similarity with ideal solution. An option is ranked higher if it is more similar to an ideal solution. Fuzzy TOPSIS is a useful method dealing with multi-attribute or MCDM problems. Fuzzy TOPSIS enables the measurement of the inherent ambiguity associated with decision maker's subjective judgment in an uncertain and complex environment.

Fuzzy TOPSIS methodology is explained below:

Step 1: Determine the Linguistic variables and fuzzy scale for criteria and factors

Step 2: Construct the matrix for assessment of criteria. Replace the linguistic ratings by their fuzzy membership functions and calculate their Aggregate Fuzzy Weight.

Step 3: Construct the decision matrix. Replace the linguistic ratings by their fuzzy membership functions

Step 4: Normalize the decision matrix

Step 5: Calculate the weighted normalized matrix by using matrix obtained in step 2 and step 4.

Step 6: Determine the positive ideal solution and negative ideal solution by vertex method.

Step 7: Calculate the separation measure & calculate the relative closeness to the ideal solution

Step 8: Rank the preference order.

The fuzzy mathematical programming was developed for treating uncertainties *i.e.* ambiguity and vagueness in real life. In fuzzy set theory, a triangular fuzzy number can be defined by a triplet and the conversion scales are applied to transform the linguistic terms into fuzzy numbers. Table 3 shows the Linguistic variables and fuzzy scale for criteria and critical success factors for implementing green manufacturing

Table 3: Linguistic variables and fuzzy scale for criteria and critical success factors

Linguistic terms for Criteria	Linguistic terms for factors	Membership Function on Fuzzy Scale
Poor	Not Important	(1,1,3)
Fair	Less Important	(1,3,5)
Good	Fairly Important	(3,5,7)
Very good	Important	(5,7,9)
Excellent	Very Important	(7,9,9)

For this study Operational, Environmental, Financial and Social factors are identified as criteria for evaluating successful transition from traditional to green manufacturing. A panel of three different decision maker groups was formed. These comprised of experts from government, industry and academies working in the field of green manufacturing. Their assessment ratings so obtained are shown in table 4.

Table 4: Assessment of criteria

Criteria	Group I	Group II	Group III
Operational	Very Good	Very Good	Good
Environmental	Good	Very Good	Very Good
Financial	Good	Very Good	Excellent
Social	Good	Excellent	Very good

The linguistic ratings are replaced by their fuzzy membership functions using table 3 and their Aggregate Fuzzy Weight calculated using the relationship below.

$$X = \min_u (x_u), \qquad Y = \frac{1}{U}\sum_{U=1}^{U} y_u, \qquad Z = \max_u (z_u)$$

Aggregate Fuzzy weights of the criteria are shown Table 5.

Table 5: Aggregate fuzzy weights of the criteria

Criteria	Group I	Group II	Group III	FUZZY WEIGHTS	
Operational	(5,7,9)	(5,7,9)	(3,5,7)	W1	(3,6.33,9)
Environmental	(3,5,7)	(5,7.,9)	(5,7,9)	W2	(3,6.33,9)
Financial	(3,5,7)	(5,7,9)	(7,9,9)	W3	(3,7,9)
Social	(3,5,7)	(7,9,9)	(5,7,9)	W4	(3,7,9)

The decision matrix for the various critical success factors obtained in linguistics terms from experts is shown below in table 6.

Table 6: Assessment of critical success factors

Criteria → / CSF ↓	Operational	Environmental	Financial	Social
C1	Fairly Important	Important	Very Important	Important
C2	Important	Very Important	Important	Important
C3	Important	Less Important	Important	Fairly Important
C4	Fairly Important	Important	Very Important	Very Important
C5	Important	Important	Very Important	Important
C6	Fairly Important	Important	Important	Fairly Important
C7	Important	Important	Important	Important
C8	Important	Fairly Important	Important	Very Important
C9	Important	Important	Very Important	Important
C10	Less Important	Important	Very Important	Fairly Important
C11	Important	Important	Important	Very Important

The linguistic ratings are replaced by their fuzzy membership functions of different alternatives using table 3 is indicated below in Table 7.

Table 7: Assessment of critical success factor in fuzzy terms

Criteria → / CSF ↓	**Operational**	**Environmental**	**Financial**	**Social**
C1	(3,5,7)	(5,7,9)	(7,9,9)	(5,7,9)
C2	(5,7,9)	(7,7,9)	(5,7,9)	(5,7,9)
C3	(5,7,9)	(1,3,5)	(5,7,9)	(3,5,7)

C4	(3,5,7)	(5,7,9)	(7,9,9)	(7,9,9)
C5	(5,7,9)	(5,7,9)	(7,9,9)	(5,7,9)
C6	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)
C7	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)
C8	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)
C9	(5,7,9)	(5,7,9)	(7,9,9)	(5,7,9)
C10	(1,3,5)	(5,7,9)	(7,9,9)	(3,5,7)
C11	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,9)

The various alternatives are then normalized using a linear scale transformation as given below.

$$\tilde{r} = \left(\frac{a}{c_{ij}^*}, \frac{b}{c_{ij}^*}, \frac{c}{cij^*}\right)$$

c^* $=max\{c\}$ (Benefit or Importance Criteria) c_{ij}^*

This is to align the various alternative scales on a comparable scale as shown in Table 8.

Table 8: Normalized valve of critical success factors

Criteria → / CSF ↓	Operational	Environmental	Financial	Social
C1	(0.33,0.56,0.78)	(0.56,0.78,1)	(0.78,1,1)	(0.56,0.78,1)
C2	(0.56,0.78,1)	(0.78,0.78,1)	(0.56,0.78,1)	(0.56,0.78,1)
C3	(0.56,0.78,1)	(0.11 ,0.33,0.56)	(0.56,0.78,1)	(0.33,0.56,0.78)
C4	(0.33,0.56,0.78)	(0.56,0.78,1)	(0.78,1,1)	(0.78,1,1)
C5	(0.56,0.78,1)	(0.56,0.78,1)	(0.78,1,1)	(0.56,0.78,1)
C6	(0.33,0.56,0.78)	(0.56,0.78,1)	(0.56,0.78,1)	(0.33,0.56,0.78)
C7	(0.56,0.78,1)	(0.56,0.78,1)	(0.56,0.78,1)	(0.56,0.78,1)
C8	(0.56,0.78,1)	(0.33,0.56,0.78)	(0.56,0.78,1)	(0.78,1,1)
C9	(0.56,0.78,1)	(0.56,0.78,1)	(0.78,1,1)	(0.56,0.78,1)
C10	(0.11 ,0.33,0.56)	(0.56,0.78,1)	(0.78,1,1)	(0.33,0.56,0.78)
C11	(0.56,0.78,1)	(0.56,0.78,1)	(0.56,0.78,1)	(0.78,1,1)

The weighted normalized matrix is calculated using the weights of criteria (P_{ij}) in table 5 and normalize alternatives value x (α_{ij}) in table 8.

$V_{ij} = (P_{ij})$ x (α_{ij})

The weighted normalized matrix is given below in table 9

Table 9: Weighted normalized value of critical success factors

Criteria → / CSF ↓	Operational	Environmental	Financial	Social
C1	(0.99,3.54,7.02)	(1.68,4.94,9)	(2.34,7,9)	(1.68,5.46,9)
C2	(1.68,,4.94,9)	(2.34,4.94,9)	(1.68,5.46,9)	(1.68,5.46,9)
C3	(1.68,,4.94,9)	(0.33,2.08,5)	(1.68,5.46,9)	(0.99,3.92,7.02)
C4	(0.99,3.54,7.02)	(1.68,4.94,9)	(2.34,7,9)	(2.34,7,9)
C5	(1.68,,4.94,9)	(1.68,4.94,9)	(2.34,7,9)	(1.68,5.46,9)
C6	(0.99,,3.54,7.02)	(1.68,4.94,9)	(1.68,5.46,9)	(0.99,3.92,7.02)
C7	(1.68,,4.94,9)	(1.68,4.94,9)	(1.68,5.46,9)	(1.68,5.46,9)
C8	(1.68,,4.94,9)	(0.99,3.54,7.02)	(1.68,5.46,9)	(2.34,7,9)
C9	(1.68,,4.94,9)	(1.68,4.94,9)	(2.34,7,9)	(1.68,5.46,9)
C10	(0.33 ,2.08,5)	(1.68,4.94,9)	(2.34,7,9)	(.99,3.92,7.02)
C11	(1.68,,4.94,9)	(1.68,4.94,9)	(1.68,5.46,9)	(2.34,7,9)
V_j+	(9,9,9)	(9,9,9)	(9,9,9)	(9,9,9)
Vj^-	(0.33, 0.33, 0.33)	(0.33, 0.33, 0.33)	(0.33, 0.33, 0.33)	(0.33, 0.33, 0.33)

TOPSIS involves calculating the Fuzzy positive ideal solution and Fuzzy negative ideal solution. Table 10 indicates that Fuzzy Positive ideal solution maximizes the benefit criteria, and minimizes the cost criteria. This situation is depicted by: $V_j+ = \{v_i+\ldots v_n+\} = [(\max v_{ij} \mid i \in I), (\min v_{ij} \mid i \in I)]$

Table 10: Fuzzy Positive ideal solution

Criteria → / CSF ↓	Operational	Environmental	Financial	Social
C1	5.679	4.809	3.995	4.671
C2	4.809	4.481	4.671	4.671
C3	4.809	6.774	4.671	5.561
C4	5.679	4.809	3.995	3.995
C5	4.809	4.809	3.995	4.671
C6	5.679	4.809	4.671	5.561
C7	4.809	4.809	4.671	4.671
C8	4.809	5.684	4.671	3.995
C9	4.809	4.809	3.995	4.671
C10	6.372	4.809	3.995	5.561
C11	5.319	4.809	4.671	3.995

Table 11 indicates Fuzzy Negative ideal solution showing the maximum cost criteria and minimizes the benefit criteria. This is given by

$V_j^- = \{v_i^- \ldots v_n^-\} = [(\min v_{ij} \mid i \in I), (\max vij \mid i \in I)$.

Table 11: Fuzzy Negative ideal solution

Criteria → / CSF ↓	Operational	Environmental	Financial	Social
C1	4.280	5.694	6.389	5.839
C2	5.694	5.758	5.839	5.839
C3	5.694	2.865	5.839	4.378
C4	4.280	5.694	6.389	6.389
C5	5.694	5.694	6.389	5.839
C6	4.280	5.694	5.839	4.378
C7	5.694	5.694	5.839	5.839
C8	5.694	4.279	5.839	6.389
C9	5.694	5.694	6.389	5.839
C10	5.081	5.694	6.389	4.378
C11	3.865	5.694	5.839	6.389

Calculate the separation measure & calculate the relative closeness to the ideal solution using vertex method. It is expressed as aggregated closeness coefficient. The mathematical relationship is as below

$$S_1^+ = \{\frac{1}{3} x \sum_{j=1}^{n} (\mathbf{vij} - \mathbf{vj}^+)^2\}^{0.5}$$

$$S_2^- = \{\frac{1}{3} x \sum_{j=1}^{n} (\mathbf{vij} - \mathbf{vj}^-)^2\}^{0.5}$$

The Aggregated closeness coefficient for critical success factors calculated as:

$$S_= \frac{S_2^-}{S_1^+ + S_2^-}$$

The aggregated closeness coefficient for the critical success factors are as shown in Table 12.

Table 12: Closeness coefficient for critical success factors

Critical success factor	S_1+	S_2^-	S= $\frac{-}{^{+}+^{-}}$
C1	19.153	22.202	0.53686
C2	18.631	23.129	0.56364
C3	21.815	18.776	0.55386
C4	18.477	22.752	0.55185
C5	18.283	23.616	0.54886

C6	20.720	20.191	0.5484
C7	18.959	23.065	0.53688
C8	19.158	22.201	0.53679
C9	18.283	22.202	0.50952
C10	20.737	21.542	0.49354
C11	18.794	21.786	0.46257

Rank the critical success factors according to the closeness coefficient in decreasing order. The best alternative is closest to the FPIS and farthest from the FNIS. Table 13 depicts the ranking of critical success factors based on their aggregated closeness coefficient.

Table 13: Ranking of critical success factors

Priority Rank	Critical Success Factor	Aggregated closeness coefficient
1	Adopting Eco innovations	0.563643
2	Use of reverse logistics	0.553857
3	Government and regulatory support	0.551846
4	Adopting Green disposal	0.548859
5	Using alternative energy sources	0.548403
6	Support of management	0.536876
7	Use of green products and process	0.536859
8	Integration with other WRT	0.536793
9	Setting up of Green supply chain	0.509523
10	Environmental Benchmarking	0.493536
11	Enhancing consumer base	0.462566

The closeness coefficient for individual criteria is evaluated to determine the effect of individual factor with respect to different criteria's. Table 14 shows closeness coefficient for individual criteria.

Table 14: Closeness coefficient for critical success factors

Factor → / Criteria ↓	Adopting Eco innovations	Setting up of Green supply chain	Integration with other WRT	Use of green products and process	Support of management	Using alternative energy sources	Adopting Green disposal	Govt and regulatory support	Use of reverse logistics	Enhancing consumer base	Environmental Benchmarking
Operational	0.430	0.542	0.542	0.430	0.542	0.430	0.542	0.542	0.471	0.444	0.421
Environmental	0.542	0.562	0.297	0.542	0.542	0.542	0.542	0.430	0.542	0.542	0.542
Financial	0.615	0.556	0.556	0.615	0.615	0.556	0.556	0.556	0.615	0.615	0.556
Social	0.556	0.556	0.440	0.615	0.556	0.440	0.556	0.615	0.556	0.440	0.615

4. RESULT AND DISCUSSION

As compared to traditional manufacturing, green manufacturing has the distinguishing features such as reduction in hazardous emissions, optimal use of resources and efficient waste management. This study ranks the various factors, which act as pivots for promoting a transition towards green manufacturing. These factors are ranked using Fuzzy Logic for Order Preference by mapping these to an Ideal Solution. The analysis highlights that the factor *"adoption of eco-innovations"* has an aggregated closeness coefficient of 0.563643 which is ranked I and is therefore of paramount importance. Use of eco-innovations provides enhanced flexibility and automation through use of newer technologies like AI, IoT, smart sensors etc. Use of eco-innovations is followed by *"Use of reverse logistics"* having an aggregated closeness coefficient of 0.553857 and is ranked II. This factor emphasizes on re-manufacture and reuse of materials for resource conservation. *"Government and regulatory support"* have an aggregated closeness coefficient of 0.551846 and is ranked III. This factor highlights the fact that government should extend tax incentives and subsidies for transitioning towards Green manufacturing. A business-friendly regulatory structure is critical for stimulating green manufacturing. *"Adopting Green disposal*" has an aggregated closeness coefficient of 0.548859 and is ranked IV. This factor highlights that *"Green products"* need to be designed based on LCA (Life Cycle Assessment) and End of life disposal policy. On a similar note, other factors have been ranked as given in table 13. *"Support of management"* has an important role towards environment protection thus paving the way for greener manufacturing. There is an urgent need for switching to *"Alternate energy sources"* so as to minimize hazardous gas emission. *"Setting up of Green supply chain"* with green credentials can enable organizations to substitute hazardous products with environment friendly products. "*Enhancing consumer base*" highlights the need to leverage green brand image to attract a new and broader client base resulting in increased revenues.

For *operations criteria,* setting up of green supply chain, integration with other waste reduction techniques, and support of management, green disposal, and government and regulatory support with 0.542 closeness coefficient are paramount. For *environmental criteria,* adopting eco innovations, green supply chain, use of green products and adopting green disposal with 0.562 closeness coefficient are critical. For *financial criteria,* adopting eco innovations, use of green products and processes, management support, use of reverse logistics with coefficient of 0.615 are important. For *social criteria*, government and regulatory support, use of green products and processes with closeness coefficient of 0.615 are important.

5. CONCLUSION

Manufactures today are using green techniques to make their operations environmentally benign and prevent damage to the ecosystem. They are implementing systems to make manufacturing eco-efficient by reducing hazardous gases emissions, optimal utilization of resources , proper waste disposal system etc. This study identifies the critical success factors for transitioning from traditional to green manufacturing. The study uses Fuzzy TOPSIS to filter the uncertainties and ambiguity in linguistic terms to evaluates and rank critical success factors for implementing green manufacturing. The effects of these factors on green manufacturing are evaluated using operational, environmental, financial and social criteria. This study provides managerial insights to the decision makers in prioritizing factors which affect the green manufacturing paradigm. Specifically for the current study, factors of adoption of eco-innovations and reverse logistics are placed at priority Level I & II. Each critical factor is designated by a particular value of closeness coefficient which reveals the 'nearness' to FPIS and distance from the FNIS. Extending this approach coupled with other MCDM techniques help us arrive at more accurate results.

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