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MODELING TOWARDS THE AUGMENTATION OF MANUFACTURING EFFICIENCY – AN ISM APPROACH

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Abstract

Increasing business competition is bound to compelthe manufacturers in improving their operational efficiency for the sake of their own survival. Promoting manufacturing efficiency calls for restructuring of business process, saving of resources including energy resources, cultivating skill of employees, waste reduction, periodic maintenance of machines, focus on standardization, automation and several such other steps. In order to improve manufacturing efficiency different issues that affect manufacturing process need to be analyzed and efforts to be put to optimize them. Review of literatures and expert's opinion helped inrecognizing important metrics considered as vital issues towards enhancing manufacturing efficiency. These relates to quality, efficiency, product, process, environment, market, economy and related issues. These are also criticalfrom sustainable manufacturing viewpoint. The identifiedmetrics has been used to formulate an ISM modelfor the enhancementof manufacturing efficiency. The analysisreveals that employee training & participatory teamwork and Innovations & use of advanced Manufacturing technologies are two significant drivers for the enhancement of manufacturing efficiency.

Keywords: *manufacturing; efficiency; interpretive structural modeling (ISM); micmac; transitivity; metrics*

1 Introduction

Any Manufacturing system consists of man, machine, material within a suitable environment to create varieties of goods and products. As per Patra,S.K. et al. (2015)manufacturing involves human activities to transform raw materials into finished goods and is commonly associated with industrial production. Manufacturing has gone through various stages of evolution like Craft Production, Mass Production, Lean Production, Mass Customization, Sustainable manufacturing etc. To cope-up with the rising demand for a variety of goods and products for human use, the role of manufacturing can never be undermined. The growth of a country largely depends on its manufacturing capability and especially on their manufacturing efficiency. Manufacturers are under constant stress to operate their business in such a way that they can deliver high quality products with the minimum use of resources. (Colledani, M. et al., 2014).

1.1 Manufacturing and efficiency of manufacturing

Whereas some manufacturing units are engaged withdiscreet type of production, others are involved with Continuous production process. Manufacturing efficiency is the indication of the **level of performance in an organization. Manufacturers need to continually upgrade their product quality by improving their manufacturing efficiency. This is vital for their survival.** Manufacturing efficiency is essential for increasing productivity, perfection of quality, reduction of waste or losses and a lot more reasons. **There exist several metrics that are key to the success of business. Among them the importance of human knowledge and skill are of paramount importance.** Figure 1 gives a step- by- step generalized approach that may give encouraging result in improving manufacturing efficiency of an organization.

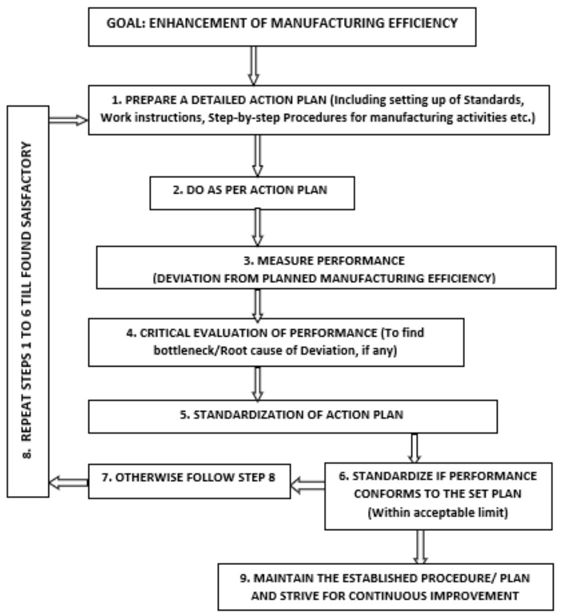

Fig.1: Ways to enhance manufacturing efficiency

1.2 Objectives of study

The main objectives of the current study are listed below:

- Review of literatures to identify various metrics that affect manufacturing efficiency in an Industrial setup
- Preparation of contextual relationships among these metrics through Experts' opinion
- Development of ISM model for the enhancment of manufacturing efficiency

1.3 Identified Metrics for manufacturing efficiency

Literature review reveal a large number of metrics that affect manufacturing systems. A panel of experts helped to identify following 10 metrics considered as vital towards enhancing manufacturing efficiency. This is represented below in Table1.

Table 1: Identified Metrics towards Manufacturing efficiency

Metrics No.	Description of Metrics	References
1	Inspection and Quality control	Chua, Z. Y. et al. (2017), Colledani, M. et al. (2014)
2	Waste Reduction and Recycling practices	Latif, H. H. et al. (2017), Warnecke, H.J. (2012), Masui,T. et al. (2000)
3	Goal setting and compliance to Standardized practices	Berger, A. (1997), experts' opinion
4	Preventive Maintenance of machines and equipment	Das, K. et al. (2007), Alsyouf, I. (2007)
5	Innovations and use of advanced Manufacturing technologies	Udo, G. J., & Ehie, I. C. (2002), Boyer, K. K.et al. (1997), Cagliano, R. & Spina, G. (2000)
6	Focus on Cost reduction & increasing Profitability	Agrell, P. J., & Martin West, B. (2001)
7	Employee training and Participatory teamwork	Hanaysha, J.(2016), experts' opinion
8	Control of Emission and Pollution	Michael Bowenchael, D. H. (1969), experts' opinion
9	Energy optimization	Hirst, N. A. C.(2018),Bunse, K. et al. (2011), Salonitis, K. & Ball, P. (2013)
10	Process control	Process dynamics and control. (2013), Tapia, G. & Elwany, A. (2014), experts' opinion

2 Interpretive Structural Modeling

Interpretive Structural Modeling (ISM) which is a well-known multicriteria decision making (MCDM) technique has been used in the present analysis to find the inter-relationships among the identified metrics. The various steps followed in ISM are:

- Development of SSIM (Structural Self-Interaction Matrix) for the identified metrics
- Construction of Reachability matrix
- Level partitioning
- Development of Conical matrix
- MICMAC analysis

2.1 Development of Structural Self-Interaction Matrix (SSIM)

A panel consisting of Academicians and Industry Experts' were involved to develop the contextual relationship among the identified metrics. Four symbols V, A, X and O have been used to denote the mutual relationship among a pair of metrics (m, n) as given below:

'V' - If m helps to achieve n; **'A'** - If n helps to achieve m; **'X'** - If both m and n help to achieve each other; **'O'** - If m and n has no relationship

Table 2 depicts the contextual relationship among the metrics in the SSIM.

Table 2: SSIM for selected metrics in manufacturing

Metrics No.	→	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**
↓	Identified Metrics towards manufacturing efficiency	Process control	Energy optimization	Control of Emission and Pollution	Employee training and Participatory	Focus on Cost reduction &	Innovations and use of advanced Manufacturing	Preventive Maintenance of machines and	Goal setting and compliance to Standardized	Waste Reduction and Recycling practices
1	Inspection and Quality	**V**	**V**	**V**	**A**	**V**	**O**	**X**	**X**	**V**
2	Waste Reduction and Recycling practices	**A**	**V**	**V**	**A**	**V**	**A**	**A**	**A**	
3	Goal setting and compliance to Standardized practices	**X**	**V**	**V**	**A**	**O**	**O**	**V**		
4	Preventive Maintenance of machines and equipments	**V**	**V**	**V**	**A**	**V**	**O**			
5	Innovations and use of advanced Manufacturing technologies	**V**	**V**	**V**	**A**	**V**				
6	Focus on Cost reduction & increasing Profitability	**A**	**A**	**O**	**A**					
7	Employee training and Participatory teamwork	**V**	**V**	**V**						
8	Control of Emission and Pollution	**A**	**V**							
9	Energy optimization	**A**								
10	Process control									

2.2 Development of Reachability matrix

The following substitution rule has been used to prepare the Initial Reachability matrix.

a) If (m,n) entry in SSIM is V: Replace V with 1 in (m,n) and put 0 in (n,m)

b) If (m,n) entry in SSIM is A: Replace A with 0 in (m,n) and put 1 in (n,m)

c) If (m,n) entry in SSIM is X: Replace X with 1 in (m,n) as well as in (n,m)

d) If (m,n) entry in SSIM is O: Replace O with 0 in (m,n) and put 0 in (n,m)

The Initial Reachability matrix is prepared based on the above substitution rule. This is given in Table 3.

Table 3: Initial Reachability Matrix

Metrics No.	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	0	1	0	1	1	1
2	0	1	0	0	0	1	0	1	1	0

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3	1	1	1	1	0	0	0	1	1	1
4	1	1	0	1	0	1	0	1	1	1
5	0	1	0	0	1	1	0	1	1	1
6	0	0	0	0	0	1	0	0	0	0
7	1	1	1	1	1	1	1	1	1	1
8	0	0	0	0	0	0	0	1	1	0
9	0	0	0	0	0	1	0	0	1	0
10	0	1	1	0	0	1	0	1	1	1

Final Reachability Matrix is prepared by using the concept of Transitivity. It states that if there are two metrics p and q such that p affects q and q affects r, then as per transitivity p will also affect r. This is illustrated in Fig. 2.

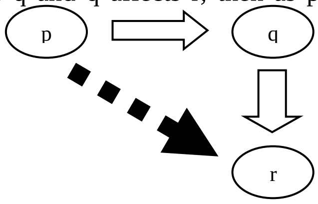


Fig. 2: Concept of Transitivity

The Final Reachability matrix is shown in Table 4. Symbol (*)reflects the Transitivity.

Table 4: Final Reachability Matrix

Metrics No.	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	0	1	0	1	1	1
2	0	1	0	0	0	1	0	1	1	0
3	1	1	1	1	0	1*	0	1	1	1
4	1	1	1*	1	0	1	0	1	1	1
5	0	1	1*	0	1	1	0	1	1	1
6	0	0	0	0	0	1	0	0	0	0
7	1	1	1	1	1	1	1	1	1	1
8	0	0	0	0	0	1*	0	1	1	0
9	0	0	0	0	0	1	0	0	1	0
10	1*	1	1	1*	0	1	0	1	1	1

2.3 Level Partitioning

Level partitioning is used to detectthe levels (hierarchy) in which the metrics are to be placed. This is done by using the Final Reachability matrix. It comprises of Reachability set, Antecedent set and Intersection set. The Reachability set consists of the metric itself and all other metrics that it helps to accomplish. The Antecedent set comprises of the metric itself and other metrics that facilitates to realize it. The intersection set is obtained by including the common metrics between Reachability set and Antecedent set. Top-level metrics have identical reachability set and intersection set - they are placed at the top of the ISM hierarchy. Top-level metrics are then removed from the iteration and next level metrics are evaluated from the remaining ones till the final iteration is completed. I[st]levelIteration is shown in table 5.

Table 5: I[st] level of Iteration

Metrics No.	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,6,8,9,10	1,3,4,7,10	1,3,4,10	
2	2,6,8,9	1,2,3,4,5,7,10	2	
3	1,2,3,4,6,8,9,10	1,3,4,5,7,10	1,3,4,10	
4	1,2,3,4,6,8,9,10	1,3,4,7,10	1,3,4,10	

5	2,3,5,6,8,9,10	5,7	5	
6	6	1,2,3,4,5,6,7,8,9,10	6	I
7	1,2,3,4,5,6,7,8,9,10	7	7	
8	6,8,9	1,2,3,4,5,7,8,10	8	
9	6,9	1,2,3,4,5,7,8,9,10	9	
10	1,2,3,4,6,8,9,10	1,3,4,5,7,10	1,3,4,10	

Similarly, iteration steps II to VI are calculated. Iteration I to VI are represented in Table 6.

Table 6:Final Iteration (I-VI)

Metrics No.	Reachability Set	Antecedent Set	Intersection Set	Level
6	6	1,2,3,4,5,6,7,8,9,10	6	**I**
9	9	1,2,3,4,5,7,8,9,10	9	**II**
8	8	1,2,3,4,5,7,8,10	8	**III**
2	2	1,2,3,4,5,7,10	2	**IV**
1	1,3,4,10	1,3,4,7,10	1,3,4,10	**V**
3	1,3,4,10	1,3,4,5,7,10	1,3,4,10	**V**
4	1,3,4,10	1,3,4,7,10	1,3,4,10	**V**
10	1,3,4,10	1,3,4,5,7,10	1,3,4,10	**V**
5	5	5,7	5	**VI**
7	5,7	7	7	**VI**

2.4 Development of Conical matrix and determination of drive and dependence power

A conical matrix is formed by clubbing together the metrics which are at the same level. The drive and dependence power of metrics are calculated by adding up the 1's in the rows and columns. Table 7 shows the drive and dependence power of each metrics.

Table 7: Drive and dependence power in Final Reachability matrix

Metrics	6	9	8	2	1	3	4	10	5	7	Drive Power
6	1	0	0	0	0	0	0	0	0	0	1
9	1	1	0	0	0	0	0	0	0	0	2
8	1	1	1	0	0	0	0	0	0	0	3
2	1	1	1	1	0	0	0	0	0	0	4
1	1	1	1	1	1	1	1	1	0	0	8
3	1	1	1	1	1	1	1	1	0	0	8
4	1	1	1	1	1	1	1	1	0	0	8
10	1	1	1	1	1	1	1	1	0	0	8
5	1	1	1	1	0	1	0	1	1	0	7
7	1	1	1	1	1	1	1	1	1	1	10
Dependence Power	10	9	8	7	5	6	5	6	2	1	

2.5 MICMAC analysis

The identified metrics has been classified into four categories (I to IV) namely Autonomous, Dependent,Linkage and Independent categories. This is represented in Fig. 3. It reflects that there exists no metrics in category I. Four metrics namely [6], [9], [8] and [2] are in category II. They have high dependence power but comparatively low drive power. Metrics [3] and [10] are in category III and are important linkages between II and IV. Metrics [7], [1], [4] and [5] are Independent metrics- these have high drive power but weak dependence power.

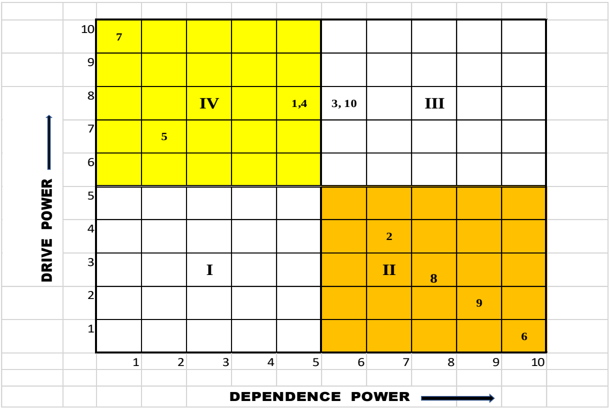


Fig. 3: MICMAC ANALYSIS

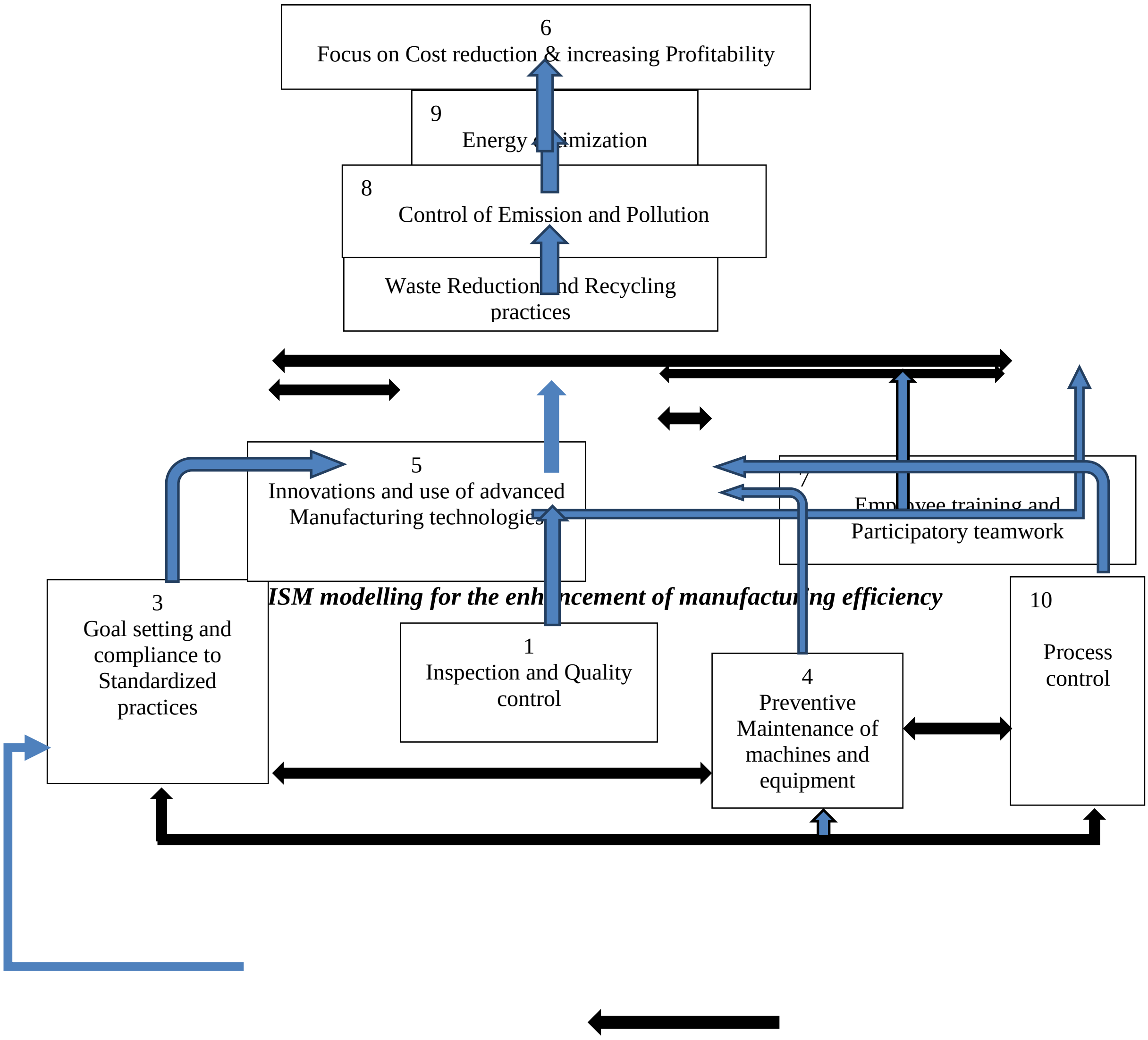
2.6ISM modelling for the enhancement of manufacturing efficiency

Based on the interactions among the metrics an ISM model is developed. This is shown in Fig. 4. It represents the metrics in the hierarchy (Level I to VI). The model also represents the mutual relationships and interactions among these metrics.

3Result and Discussion

The ISM model highlights the need for having a multi-disciplinary and holistic view for the enhancement of manufacturing efficiency. An efficient manufacturing platform wishes the adoption of innovations and emphasis on Employee training. The followings are important highlights as obtained from the above analysis.

- Metric [6] namely Focus on Cost reduction & increasing Profitability is placed at the top in the hierarchy (level I) and is therefore the top-level metric. This is influenced by next level metric [9] namely energy optimization placed at level II. This highlights the key role of energy optimization in reducing cost and thereby increasing profitability. Metrics in the succeeding levels are [8], [2], [3,1,4,10], [5,7]
- Metrics [3], [1], [4] and [10] are in the same level (level V) and they are highly interactive. The management must find better ways of implementing preventive maintenance, inspection and quality control, process control and ensure compliance towards standardized practices
- Metrics [5] namely Innovations &use of advanced Manufacturing technologiesand [7] namely Employee training & Participatory teamwork are at the base of the ISM model. These two metrics have high drive power and low dependence. By virtue of high drive power these metrics are responsible for channelizing other metrics towards the enhancement of manufacturing efficienc



ISM modelling for the enhancement of manufacturing efficiency

4. Conclusion

The present study is aimed towards the enhancement of manufacturing efficiency usingISM modelling. Meaningful insights obtained from the analysis can help the managers in deciding upon the ways for enhancing manufacturing efficiency which is indispensable for the business excellence. For enhancing manufacturing efficiency, organizations need to monitor various tangible and intangible resources and metrics. Organizations need to have a holistic approach involving all stakeholders for augmenting manufacturing efficiency in their operations. Future work may be carried out through the development of modelling using industry specific parameters or by using other MCDM techniques.

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