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Analysis of Agile Manufacturing Enablers: A Case Study

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Abstract

The purpose of this paper is to strategically select and focus the right Agile Manufacturing Enablers (AMEs) for agility enhancement. A methodology is proposed using Interpretive Structural Modeling - Fuzzy Matriced Impacts Croises Multiplication Appliquee au Classement analysis to analyze the AMEs considering their driving and dependence power. The proposed methodology was applied to an Indian electrical hardware manufacturing company. It was concluded that the effort and focus should be streamlined towards information visibility and transparency, devolution of authority, and adaptability for enhancing its agility.

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1. Introduction

Agile Manufacturing (AM) has gained tremendous recognition and acceptability among the manufacturing engineers since the last decade. AM has evolved as a revolutionary way of manufacturing and assembling the products based on rapidly changing market and customer demands [1]. AM includes both management and technological enablers. The focus on management based AM enablers are given more importance by the researchers in comparison to technology based AM enablers [2]. Although alignment among competitive drivers, agility capabilities and providers are all very critical in making an enterprise agile, it is difficult for an enterprise to achieve

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agility because of the lack of an efficient approach for agile development planning [3]. There exists a need to comprehensively model the agile system with key enablers as well as to find the interdependency that exists between the agile enablers in an unpredictable environment [4]. Therefore, it is essential that the right AMEs should be selected to enhance the agility level of manufacturing system in general and of AM in specific. Their current status should be assessed and gap should be identified so that efforts would be streamlined to reach the desired level of performance along these selected AMEs. This selection of AMEs is manufacturing environment specific as priority of competitive strategies, internal and external business environment, and nature of the product are the basic and relevant input for the analysis. It is complicated in nature as all the interactions in terms of their driving and dependence power have to be captured considering the manufacturing environment. The proposed methodology using ISM-FMICMAC analysis is the systematic analysis of AMEs to select the right AMEs where the company must focus and put effort. The benchmarking approach should be developed for right AMEs for successful implementation of AM and its agility. This is an approach that has not been attempted before. A case study has been carried out to explain the salient features of the proposed methodology. Thus, the research gap has been filled.

This paper is organized as follows: the literature review on agile manufacturing and agile manufacturing enablers are in section 2 and section 2.1 respectively. The proposed methodology for successful implementation of AM is presented in Section 3. The ISM and Fuzzy MICMAC analysis for analyzing AMEs are discussed in section 3.1 and section 3.2 respectively. The application of proposed methodology in an Indian manufacturing company is presented in section 4. The results and managerial implications of the case company are discussed in section 5 and section 6 presents conclusions.

2. Agile Manufacturing Enablers

The purpose of this paper is to identify the agile manufacturing enablers (AMEs) and then define the domain of each enabler so that right AMEs can be selected in a specific manufacturing environment. Many researchers had carried out various studies related to AMEs, agile enablers and agility which may be specific or generic in nature. They also carried out various analysis using different tools and techniques. Avazpour et al [5] developed a framework based on the fuzzy multiple criteria decision making approach to identify the most appropriate agility enablers to be implemented by companies. They applied it in a subsidiary company of the National Iranian Gas Company and concluded that team building is the best agility enablers. Aravindraj and Vinodh [6] developed a 40-criteria agility assessment model and was applied to an Indian relays manufacturing organization. The present agility level of the case organization was determined which was used for the gap analysis and agility improvement proposals. Mishra et al [7] developed a fuzzy based integrated agility appraisal module, incorporated the variations in the Decision Makers' (DMs) risk bearing attitudes and analyzed the effects of variations in DMs' attitudes toward agility estimation. Gurd and Ifandoudas [8] used an action research approach in a single organization to investigate the practicality and usefulness of an agility-focused balanced scorecard (BSC) system. Vinodh and Aravindraj [9] identified AMEs and used multi grade fuzzy and fuzzy logic approaches for the agility assessment and the results were benchmarked. Based on the literature survey in AM [10] and discussion held with experts in Indian manufacturing environment, various enablers have been identified those promote AM and have been grouped (i.e. Adaptability (ADP); Product and Process Automation (PPA); Supply Chain Integration (SCI); Core Competency (CCT); Supply Chain Key Partner's Alacrity (SCP); Devolution of Authority (DOA); Information Visibility and Transparency (IVT); Manufacturing Management (MFM); Customer Relationship Management (CRM); Supplier Relationship Management (SRM); Human Resource Management (HRM)).

Adaptability (ADP): It is the capability of a system to respond to both predictable and unpredictable changes. The changes are not restricted to technology (i.e. new and better technologies), business environment, customer requirements, socio-economic, products and services, risk etc.

Product and Process Automation (PPA): It is the capability of a system to design, produce parts and develop processes with the aim to reduce the lead-times. Use of automated and computer-aided-technologies like Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Process Planning (CAPP), automated material handling, packaging etc. lead to reduced design-to-manufacture time.

Supply Chain Integration (SCI): It refers to the ability of integrating the operations/activities along the supply chain through respective core-competencies or specializations of various stakeholders. It is achieved through mutual trust, management of inter-relations and intra-relations, integrated procurement, logistics and distribution systems.

Core Competency (CCT): It is the ability of an organization to develop and sustain expertise in a specific domain. Strong R&D, knowledge of latest domain technologies, multi-skilled and enthusiastic work-force, “first time right” design, emphasis on quality maintenance etc., are antecedents for developing core competency in AM.

Supply Chain Key Partner's Alacrity (SCP): It refers to the willingness of supply chain partners for active participation, ability to share and take risks, venture into new markets and collaborate with other strategic partners, earn goodwill and reputation etc.

Devolution of Authority (DOA): It refers to the ability to define and delegate decision making powers for reducing delays across various dimensions. Improvised organizational structure, creating cross-functional teams, quality circles, auditors and consultants etc. are some of the ways of decentralizing the decision making process.

Information Visibility and Transparency (IVT): It refers to the ability to capture and share accurate and real-time information along various stake holders in the right form/details. This will provide intelligent business platform to analyze, forecast and prepare plans for AM.

Manufacturing Management (MFM): It refers to the management of manufacturing activities through a robust manufacturing planning and control, production methodologies. It also includes efficient waste management, concurrent engineering for “first time right” design/manufacturing plan and managing the product life cycle. Customer Relationship Management (CRM): It is the ability to maintain a positive and sustainable relationship with the customer by satisfying their ever increasing requirements by maintaining appropriate level of responsiveness. There should be a strong integration between customer relationship management and AM.

Supplier Relationship Management (SRM): It refers to the management the supplier base. The processes like supplier development, supplier switching, supplier selection, supplier certification, supplier evaluation etc. come under this. There should be a natural fit supplier relationship management and AM.

Human Resource Management (HRM): It relates to the management of human resource through training, development, compensation, recognition, rewards etc. for motivating them and promoting organizational learning.

From the above discussion, it is evident that agility enhancement is the need of the hour. To achieve this, a manufacturing company should assess the current status of agility performance, determine the agility performance gap, select the right AMEs and streamline efforts along those AMEs. It is very difficult for a manufacturing organization to focus and put efforts to all enablers. The AMEs should be classified considering the interactions (in terms of driving and dependence power) between AMEs to choose the right set of AMEs for enhancing the organizational agility. The interactions between AMEs are qualitative in nature and it should be captured taking judgments from team of multiple experts. Therefore in this study, a methodology proposed using ISM and FMICMAC analysis taking judgments from team of multiple experts to classify and select the right set of AMEs for enhancing organizational agility.

3. Proposed methodology for enhancing agility

The methodology initiates with identifying and defining the relevant AMEs for the specific environment. The importance of each AME should be captured on the basis of the multiple experts' judgment. For analyzing and establishing the relationship between AMEs, the ISM integrated with FMICMAC algorithm is proposed (see in section 3.1 and section 3.2).

Although number of enablers have impact either directly or indirectly or both ways on the agility performance of a manufacturing system, but it is not possible for an organization to focus on all the enablers at a time or never a wise choice in order to enhance agility performance level. Therefore, it is essential to identify the AM enablers which have high driving and low dependence power on the agility performance so that manufacturing companies can streamline their efforts accordingly. As the proposed methodology has got the ability to capture the multiple experts' judgments for identifying the right enablers on the basis of driving and dependence power, the obtained results will be more reliable. However, the proposed methodology cannot quantify the impact level of each AME and their combinations on the agility performance. Moreover, it does not also provide information regarding the future course of actions for a manufacturing organization, once the selected AMEs is improved to a desired level.

3.1. ISM for analyzing AMEs

ISM methodology has the ability to analyze the AMEs and to show the direction of relationships in manufacturing environment [11]. ISM presents a hierarchical structure that depicts the direct and indirect linkages between the various components in a system based on primacy, precedence, and causality over and among each other [12]. In the current study the relationships between the AMEs have to be studied in terms of driving and dependence powers for successful adoption of AM. Therefore, ISM methodology is adopted to know these relationships among the AMEs and develop a structural framework of AMEs. The ISM methodology used in the study is discussed below:

- Step 1 The contextual relationships (i.e. V: AME 'i' leads to AME 'j'; A: AME 'j' leads to AME 'i'; X: AME 'i' leads to AME 'j' and AME 'j' leads to AME 'i' and O: No relationship between AME 'i' and AME 'j') between AMEs are established considering the experts' judgment to develop Structural Self-Interaction Matrix (SSIM).
- Step 2 The Initial Reachability Matrix (IRM) is developed by converting SSIM into a binary matrix, substituting V, A, X and O by 1 and 0.
- Step 3 The Final Reachability Matrix (FRM) is created from IRM and transitivity (if AME "i" is related to AME 'j' and AME 'j' is related to AME 'k', then AME 'i' is related to AME 'k'.) in the contextual relations.
- Step 4 Driving and dependence power of each AME is determined by summing the elements along the rows and columns of FRM respectively. They are ranked on the basis of driving and dependence powers.
- Step 5 The different levels are developed by segregating FRM taking into account of the reachability and antecedent sets. The AME(s) occupies the top-level in the ISM hierarchy where the reachability and intersection sets are same. The top-level AMEs is taken out from the initial set of AMEs and the process is carried out in similar manner until all AMEs are assigned to a level.
- Step 6 A lower triangular matrix is obtained from step 5. This matrix is used to develop digraph. If there is a relationship between two AMEs, this is shown by an arrow which points between them. The structural model of AMEs is obtained by removing the transitivity links in the digraph and considering the level partitions and FRM. It is checked for conceptual accuracy and if it is not found to be conceptually accurate, then the process should be repeated from step 1.
- Step 7 Based on the driving and dependence powers obtained in the Step 4, Fuzzy MICMAC analysis is carried out (see section 3.2).

3.2. Fuzzy MICMAC analysis for analyzing AMEs

The use MICMAC analysis has been reported in the literature. Although MICMAC analysis can classify various factors (i.e. enablers, barriers and criteria) of a problem, there is a limitation in the process. Since the relationships between AMEs are recorded in terms of binary values (either 0 or 1), there is no enough degree of freedom for experts in expressing the strength of relationship between the factors which could be either very weak, weak, medium, strong or very strong [13]. One can find the use of Fuzzy MICMAC analysis in recent literatures [14-18] which are used in different areas to get more accurate and better analysis. The objective of the FMICMAC analysis is to divide the AMEs into four quadrants namely autonomous, dependent, linkage and driver. The division of quadrants is made on the basis of driving and dependence power of AMEs. Driving powers of an AME shows the influence level to other AMEs whereas the dependence powers of an AME represents the degree of influence by other AMEs. The steps mentioned below are to be followed to obtain above mentioned four quadrants [19, 20]:

- Step 1 Develop Binary Direct Relationship Matrix (BDRM) putting 0's in all the diagonal elements along in FRM. The relationships of BDRM should be relooked using fuzzy number as no relationship: 0; very low: 0.1; low: 0.3; medium 0.5; high 0.7; very high: 0.9 and full: 1 to develop fuzzy Direct Relationship Matrix (FuDRM).

- Step 2 The FuDRM's power is raised by fuzzy matrix multiplication (rule: $C = \max_k \{ \min (a_{ik}, b_{kj}) \}$ where $A = [a_{ik}]$, $B = [b_{kj}]$) to get final converged matrix (i.e. stabilized or cyclic in their variation with certain periodicity).
- Step 3 The driver dependence diagram is to be plotted to classify the AMEs into four groups (i.e. driver, autonomous, dependent and linkage).

4. Application of proposed methodology in an Indian Manufacturing Company

The proposed methodology was applied to an Indian electrical hardware manufacturing company for analyzing the AMEs. As per company's policy, to protect its confidentiality, to maintain good relationship with the senior executives and to conduct further research, name of the company is not disclosed and it is named as 'X' in this paper. The company is a large scale manufacturer and a prominent supplier for many manufacturing companies in India and abroad. The case company has a turnover more than INR 20 billion and has adopted the agile manufacturing to become more and more customer centric. Although the company has certain standard products manufactured but its major business is to offer highly customized and innovative products. With respect to its supply chain environment, it has developed an excellent supply base close to its manufacturing plant. In order to attain its own manufacturing excellence, it has been investing significant effort and resources specifically in research and development, and employee skill development. It is well known for its order winning capability and organizational culture. It also produces wide variety of products in comparison to its competitors. Characterized with these features, the company X is able to be aggressive in taking risk along many competitive dimensions to attract and retain its customer base. However, the company X does not have systematic evidence established to improve its agility. Therefore, the proposed approach is an interest to company to get right direction for optimum utilization of its resources and efforts for enhancing agility. It was decided to form a cross functional team which consists of six experts drawn from manufacturing, purchasing, logistics, marketing, finance and human resource development department of the case company. All the six experts have professional degree and have a sound knowledge on agility and business environment as they have more than 7-10 years of experience in the case company. A detailed discussion was held with them. When discussed with the experts regarding the AMEs, there were different aggressive opinions among the experts. The above proposed methodology and its objectives were explained to the experts and were asked to give their opinions at two stages. The company experts were motivated with the proposed methodology and agreed to cooperate but repeatedly cautioned not to reveal the identity of the company. The eleven AMEs as mentioned in previous section were discussed with the team of experts to check for accountancy, relevancy, and significance. Finally, it was concluded that the eleven AMEs were significant for the company's AM. The relationships among 11 AMEs were explored with the help of a questionnaire administered to the experts. The questionnaire consists of 55 questions to collect the qualitative opinions about the relationship between the AMEs. For collecting the qualitative opinions, six experts were asked to choose one among the following four types of relationships (i.e. V, A, X and O) between the AMEs (see Step 1 in section 3.1). Depending upon the choice made, the contextual relationships were developed among the AMEs in order to develop SSIM. The IRM was developed by substituting V, A, X and O by 1 and 0. The transitivity of the contextual relation and IRM are considered to develop FRM. The driving and dependence power of each AME is calculated to develop FRM. The ranking of each AME in terms of driving and dependence power were made. The level partition of AMEs is performed by developing the reachability and antecedent sets for each AME from the FRM. Three iterations are carried out to assign each AME to a level and by the process, three levels are formed. ISM model of AMEs for the case company was developed and shown in Figure 1. FMICMAC analysis was carried out revisiting driving and dependence power of each AME and the non-zero cells were replaced by fuzzy numbers depending the driving and dependence power of the corresponding AMEs on the basis of collective judgments of six experts. By the process, FuDRM was formed. The FuDRM's power was raised by fuzzy matrix multiplication to get converged matrix. Finally FMICMAC Driver Dependence Diagram of AMEs was developed on the basis of and is shown in Figure 2.

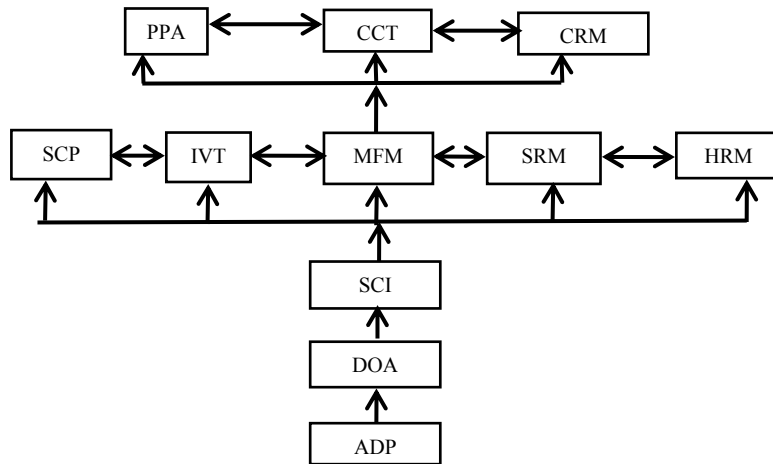


Figure 1: Structural model of AMEs

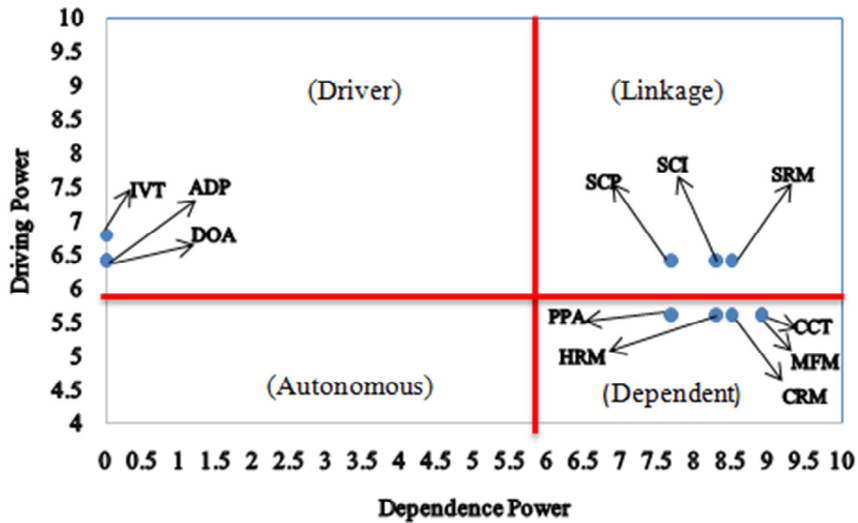


Figure 2: FMICMAC Driver Dependence Diagram for AMEs of the case company

5. Results and discussions

The results obtained after application of the proposed methodology in the case company is mentioned in section 3. These results are interpreted under two sections (i.e. development of structural model and AME classification). Each section is discussed in detail below.

5.1. Development of structural model

The developed structural model (see Figure 1) was discussed with the experts and was accepted. In the current study, AMEs were leveled across five levels in five iterations. ADP, DOA and SCI are at the base of the hierarchy of structural framework (see Figure 2). The case company should put effort to acquire capability along these three AMEs which will in turn leads to agility enhancement. The AMEs (i.e. SCP, IVT, MFM, SRM, and HRM) are at II

level. The AMEs positioned in this level should be addressed tactically in the AM implementation process. The AMEs (i.e. PPA, CCT and CRM) are positioned in the level-I and have high dependence power with different driving powers. The AMEs positioned in this level have the long standing and should be treated strategically in order to achieve the excellence in AM implementation. Thus, the ISM model developed presents a directional framework for the case company in successfully implementing AMs and gives clear mental picture of what experts think about the relationship between AMEs.

5.2. AMEs Classification

All the 11 AMEs were classified into three clusters (i.e. driver, dependent and linkage quadrant) using FMICMAC analysis on the basis of driving and dependence powers. No AMEs had weak driving and dependence power. Therefore, the autonomous quadrant had no AMEs. All the 11 AMEs are distributed in other three quadrants as mentioned below.

Driver quadrant (High driving power, Low dependence power): The AMEs i.e. IVT, DOA, and ADP were in driver/ independent cluster which means that these three AMEs have high influence on rest of the 8 other AMEs and these were also placed on bottom side of the developed ISM. Therefore, these three AMEs have to be addressed at first and the case company should put effort first to enhance them.

Dependent quadrant (Low driving power, High dependence power): The AMEs i.e. PPA, HRM, CRM, CCT and MFM were clustered in the dependent quadrant. This signifies that these AMEs' were mainly dependent on the other AMEs having the capacity to drive the AM. It is not easy to enhance directly but through other AMEs.

Linkage quadrant (High driving power, High dependence power): Out of 11 AMEs chosen, 3 AMEs (i.e. SCP, SCI and SRM) were grouped in this cluster having both high driving and high dependence power. Typically these can be attributed as unstable because they have feedback effect i.e. they get affected by their own action and so are difficult to manage. However, these AMEs cannot be ignored and have to be closely monitored regarding their status in making decisions.

5.3 Selection of AMEs for successful implementation of AM

From structural model, it was observed that DOA, ADP and SCI were at the bottom of the hierarchy which indicates that these three AMEs had high driving power. The IVT, DOA, and ADP were also found in driver quadrant. Therefore four AMEs (i.e. DOA, ADP, IVT and SCI) should be selected for successful implementation of AM in the case organization. Therefore, these four AMEs have to be addressed at first. The case company should analyze their current performance and evaluated the performance gap (i.e. difference between expected performance and current performance). On the basis of the performance gap along these AMEs, the case company should put effort to enhance them. The performance these AMEs should be evaluated periodically. It was also suggested to adopt benchmarking approach to enhance the performance for these selected four AMEs. Although this obtained result was for the case company but the current study may be used for selection of AMEs in any specific manufacturing environment.

6. Conclusions

The proposed methodology is generic in nature and easy to implement considering multiple experts' judgment. Hence, it can be applied to any manufacturing companies for enhancing its organizational agility capturing the relevant inputs specific to the manufacturing environment. The proposed methodology is applied to an Indian electrical hardware manufacturing company to streamline its efforts so that agility level can be enhanced effectively. The Adaptability (ADP) was concluded as the most influencing AME from the structural model followed by DOA and SCI whereas from FMICMAC analysis, the Devolution of Authority (DOA) along with the other two enablers (i.e. IVT and ADP) were found in driver cluster (i.e. high driving and low dependence power). Therefore, these four AMEs were considered as the prerequisite for implementing AM in the case company. The present performance of these four AMEs in the case company was discussed and was found to be reasonably good. But the performance gap exists when their performances were compared with their benchmarked values. Moreover, the current study may be

used as a basis to investigate more details regarding agile manufacturing in general and agile manufacturing enablers in specific. Also, like every study, the present study has some shortcomings. However, these shortcomings are the future research directions and these have outlined further research directions:

- Empirical study on the strength of relationship among AMEs as well as on the agility performance should be carried using structural equation modeling and it should be established in various manufacturing environment to develop a theoretical framework.
- Total Interpretive Structural Modeling (TISM) may be used to study and analyze the linkage relationship between AMEs. Study should be carried out on the quantification of the impact level of each relevant enabler and their combinations on the agility performance. The impact of dynamic behavior of AMEs on agility should also be studied and analyzed using Bayesian networks.

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