



**Proceedings of GLOGIFT 08**  
June 14-16, 2008  
Stevens Institute of Technology  
Hoboken, NJ, pp. 262-273

## MODELING THE ENABLERS OF AGILE MANUFACTURING SYSTEM

Pravin Kumar\*, Ravi Shankar\*\* and Surendra S Yadav\*\*\*

### ABSTRACT

*Free trade policies, globalization of economy, and continuous changes in technology have increased competition among the manufacturers. Identification of customer need and its rapid fulfillment become more important for manufacturers as well as suppliers. The needs for flexible, rapid, cost effective and high quality product development have led to the concept of agile manufacturing. In this paper, various enablers of agile manufacturing system have been analyzed and interrelationships have been developed using ISM (interpretive structural modeling). These enablers are classified with different driving powers and dependencies. This paper may help the manufacturers and suppliers for rapid product development by identifying the enablers as drivers and dependence and integrating the entire systems.*

**Keywords:** Agility, Flexibility, Lean Manufacturing, and Concurrent Engineering

---

### Introduction

Agility means using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile marketplace (Naylor *et al.*, 1997). Agile manufacturing system (AMS) is intended to improve the competitiveness of manufacturers in continuous changing market conditions. There is requirement of complete integration of systems from supplier to customer to design, develop and manufacture the products rapidly and cost effectively. Agility becomes a tool to respond rapidly to continuous and unpredicted changes in market driven by customer designed products and services (Cho *et al.* 1996). The concept of flexible and more responsive manufacturing led to the new concept of agile manufacturing system (Gunasekaran and Yusuf, 2002). The concept of agile manufacturing was first time launched in 1991 at Lehigh University.

Agile manufacturing is a combination of flexible and responsive manufacturing systems. Flexible manufacturing shows the ability to change the entire systems according to changes in customer requirements. Agility should not be confused with leanness. Lean manufacturing has focus on elimination of waste and large inventories. Lean leads to high productivity and quality, but it does not necessarily imply being responsive. But, lean manufacturing reduces the cost of production by eliminating the waste. There is equal importance of cost and responsiveness for AMS. Yusuf *et al.* (1999) incorporated cost and quality into agile competitive bases.

---

\* Research scholar, Department of Management Studies, Indian Institute of Technology Delhi, Vishwakarma Bhavan, Shaheed Jeet Singh Marg, P.O. Hauz Khas, New Delhi- 110016, Email- pravin\_papers@rediffmail.com, Phone: +91 9818273764

\*\* Asian Institute of Technology, Bangkok

\*\*\* Professor and Head, Department of Management Studies, Indian Institute of Technology Delhi, Vishwakarma Bhavan, Shaheed Jeet Singh Marg, P.O. Hauz Khas, New Delhi- 110016, E mail:ssyadav@dms.iitd.ac.in

## *Modeling the Enablers of Agile Manufacturing System*

Gupta and Mittal (1996) stressed on both responsiveness as well as leanness of manufacturing system. They gave more priority to responsiveness than cost effectiveness. De Vor and Mills (1995) defined AMS as “ability to thrive in a competitive environment of continuous and unanticipated change and to respond quickly to rapidly changing markets driven by customer-based valuing of products and services.

The main drivers of agile manufacturing systems are: short product life cycle; tough competition due to globalization of business, region-wise customization of products and services, advancement in manufacturing technologies and equipments, global sourcing, advanced information technology, increasing customer awareness about products, improved global logistics, and inter-organizational relationships. Thus for survival in global market an entire manufacturing system must be agile.

A number of research works concerning the agile manufacturing are available. However, Very little effort has been made to present all the enablers of agile manufacturing and its impact on each other. Gunasekaran (1998) emphasized seven enablers of AMS: virtual enterprise formation tools/metrics, physically distributed manufacturing architecture and teams, rapid partnership formation tools/metrics, concurrent engineering, integrated product/production/information system, rapid prototyping and e-commerce. He reviewed the literature works available on agile manufacturing and made good effort to collect all the enablers but in changing market scenario there is need to re-examine the enablers with mutual interactions. This paper re-examines the enablers of AMS in present business scenario and shows the hierarchy of enablers with mutual interaction to achieve the required agility.

The remainder part of paper is arranged as following: section 2 deals with the enablers of AMS; section 3 presents the ISM methodology and model development; section 4 presents discussion and conclusion.

### **Enablers of Agile Manufacturing System**

Total 14 enablers have been incorporated to develop ISM model; these enablers are: (i) manufacturing flexibility; (ii) strategic production planning; (iii) concurrent engineering; (iv) automation in manufacturing; (v) rapid prototyping; (vi) integrated information system; (vii) multi-functional workforce; (viii) rapid partnership and supplier development (ix) virtual enterprise formation; (x) product decision; (xi) market information system; (xii) product mix; (xiii) product postponement and; (xiv) agile manufacturing system. The brief discussions about these enablers are given below:

#### **Manufacturing Flexibility**

Sethi and Sethi (1990) defined manufacturing flexibility in terms of ability of reconfiguration of manufacturing resources to produce different products of acceptable quality level efficiently. Swafford *et al.* (2006) defined manufacturing flexibility as the ability of manufacturing system to adapt its capabilities to produce quality products timely and cost effective manner to respond to changing product characteristics, material supply, and demand, or to employ technological process enhancements. Manufacturing flexibility continues to be a concern for companies as they strive to meet the changing demands of their customer (Krause *et al.*, 2007). Avittathur and Swamidass (2007) divided the evolution of manufacturing flexibility concept into four phases from concept development to supplier buyer integrations.

#### **Strategic Production Planning**

There are a number of uncertainties related to production activities such as fluctuation in demand, introduction of new products or customization of existing products. To respond the demand

uncertainties, a manufacturer should have multiple options such as outsourcing, subcontracting, overtime production, daily wages workers, expansion of plants etc. To introduce new product into the market within short notice, there is requirement of generic machines and multi-skilled personals with advanced technologies and strong research and development department. For customization of existing products the decoupling point in the manufacturing or assembly should be shifted to last stage.

### **Concurrent Engineering**

Concurrent engineering also called simultaneous engineering was coined in US in 1989. It means a way of work where the various engineering activities in the product development, process development and field support development are integrated and performed as much as possible in parallel rather than in sequential order. Mehdad and Rook (1997) emphasized the need of multifunctional team and emerging techniques such as computer-aided design and computer-aided manufacturing (CAD/CAM), computer-aided engineering (CAE), computer-aided process planning (CAPM), design for manufacturing (DFM), design for assembly (DFA), and quality function deployment (QFD). Graham and Ragade (1994) highlighted the need of design improvement and concurrently to check the suitability for manufacturing.

### **Automation in Manufacturing**

Automation is an integration of knowledge of various fields such as mechanical, electronics, computer and information technology. It is very helpful to reduce production lead-time, improve quality, and lower the manufacturing cost. Some of the important technologies which have been frequently used are: flexible manufacturing system (FMS), group technology (GT), cellular manufacturing, computer aided quality control (CAQC), computer numerical control (CNC), direct numerical control (DNC), automated guided vehicle (AGV), automated storage and retrieval system (AS/RS), etc.

### **Rapid Prototyping**

Rapid Prototyping (RP) is a combination of technology, which converts directly a design file into a prototype, which is used in analysis during the design development phase with least time. Rapid prototyping is able to produce a prototype in shorter lead-time with less material wastage. This valuable benefit of the technology makes it worth for agile manufacturing (Kumar and Kumar, 2006).

Prototyping is a process of analysis of product design before putting it into real use. Rapid prototyping has been used in the production of three-dimensional object by stereolithography. Wang *et al.* (2002) mentioned its utilization in their research work "conceptual approach for managing design recourses".

### **Integrated Information System**

Several research articles have been published on the use of information technology (IT) within an organization (Katayama and Bennett, 1999; Powell and Dent-Micallef, 1997; Palvia, 1997). Information systems flexibility can be defined as the ability of an organization's collective information system to adapt and support changing requirements of the business functions such as product development, sourcing, manufacturing and logistics, and other strategic goals. Sethi and King (1994) developed a concept called CAPITA (competitive advantage provided by and information technology application), which measures the firm's competitive benefits gained through the use of a single information technology application (Kumar *et al.*, 2007).

### **Multi-functional Workforce**

The need of frequent changing in roles and responsibilities shows the requirement of multi-functional workforce so that during new demand or in changing circumstances existing workforce can be employed for any work due to time constraints. Christian (2001) termed it as people flexibility; and its components are employee skill flexibility, skills replaceability, and employee skills utilization.

#### ***Rapid Partnership & Supplier Development***

A single manufacturing organization can not be expert of all the business activities such as supply chain, government policy, trade regulations and legislation, legal formalities, and competitor's action. Thus, strategic alliances have become a need for manufacturers in today's business environment. Rapid partnership with these service providers has become an influencing factor for agility (Gunasekaran, 1998).

Integrated-sourcing flexibility in supply chain management improves the organization's ability to deliver products and services in a timely and effective manner (Tan et al., 1996). Sourcing flexibility is the ability to change sourcing decisions such as the number of suppliers per part and delivery schedule. Sourcing flexibility facilitates a faster response when there is uncertainty; therefore, it has a positive impact on manufacturing flexibility (Gupta and Somers, 1996). Sourcing flexibility may support the arms-length relationship with suppliers, but strategic partnership with flexibility is more beneficial to cover various uncertainties in supply chain. Manufacturers always try to find the reliable suppliers and establish strategic relationships with them (Kumar et al., 2007).

#### ***Virtual Enterprise Formation***

Virtual enterprise is temporary integration of organizations on basis of core competencies having focus on speed to market, cost reduction and quality (Abair, 1995). An organization may not be successful alone to respond rapidly to changing market. Therefore temporary alliance based on core competencies can help to achieve improved flexibility and responsiveness of organizations (Gunasekaran and Yusuf, 2002). Medhat and Rook (1997) highlighted three factors for partnership: pre-qualifying partners, evaluation of product design and capability of potential partners, selecting the optimal number of partners for manufacturing of a particular product.

#### ***Product Decision***

Product decision is based on market information, availability of resources, product mix and delayed product differentiation. In push-based system, production decision is based on long term forecasting while pull-based system is demand driven (Simchi-Levi et al., 2002). There should be strong information channel to know the changing market behavior.

#### ***Market Information System***

Market information system is a base for agile manufacturing system. Agility means dancing on the tune of market. Therefore, strong market information system is required to know the changing customer needs and its behavior with competitor's strategies. It is also very helpful to forecast the demand and to customize the product according to customer requirements.

#### ***Product Mix***

Product mix is a set of similar or dissimilar products of various configurations and specifications provided by same manufacturer. This may help to satisfy the diversified demand of customers. Product mix is very helpful to design and produce new or customized product with short lead-time. For example, Maruti-Suzuki started to produce Marui-800 model at beginning and now producing new model of car in every 2-4 years according to requirement of Indian market.

### Product Postponement

He and Kusiak (1995) used product postponement strategy to achieve agility in manufacturing. Product postponement is delay in time when a product gets its identity. Using high level of part commonality at early stages of the manufacturing process can delay the product differentiation. For example, in an apparel industry, traditionally, the manufacture of clothing starts with the dyeing of the yarn followed by the knitting of the garment. This process may result in out of stock of desired color and over inventory of unpopular color. In a market characterized by very short product life cycles, this mismatch of inventory and customer demand cannot be corrected using a traditional manufacturing approach. The typical result is the end of season markdown. Benetton uses the bleached yarn and delay dyeing until information on the preferred colors became available through EDI to reduce the inventory size (Kumar *et al.* 2007).

### Agile Manufacturing System

Agile manufacturing system is a function of all the enablers as mentioned above. Manufacturing system is highly responsible to produce customized, low cost, and high quality product to meet exact demand of market within short period of time.

### ISM Methodology and Model Development

Interpretive structural modeling (ISM) is an interactive learning process, which systemizes the different and directly related elements into a structured system (Warfield, 1974; Sage, 1977). It transforms a complex problem into visible, well-defined models serving the purposes (Sage, 1977). It helps in identifying the inter-relationships among variables. It also helps to impose order and direction on the complexity of relationships among elements of a system. It is very difficult to handle all the enablers of a complex problem, like agile manufacturing system involving 14 enablers in this paper. ISM develops a collective understanding of relationships among the enablers. ISM is used by a number of researchers in different fields that are tabulated in Table 1.

It is a modeling technique in which the specific relationships of the variables and the overall structure of the system under consideration are presented in a directed graph model. ISM is primarily intended as a group learning process, but it can also be used individually.

Table 1: ISM Applications

Researchers	Applications
Mandal and Deshmukh (1994)	Vendor selection.
Jharkharia and Shankar (2005)	IT enablement of supply chain.
Ravi and Shankar (2005)	Reverse logistics.
Faisal et al. (2006)	Risks mitigation in supply chain.
Qureshi et al. (2007)	Logistics outsourcing relationships.

The various steps involved in the ISM technique are:

- (1) Identification of elements or factors that are relevant to the problem- this could be done by survey or any group problem-solving technique;
- (2) Establishing a contextual relationship between the elements with respect to which pairs of elements would be examined;
- (3) Developing a structural self-interaction matrix (SSIM) of elements, this indicates pair-wise relationship between elements of the system;
- (4) Developing a reachability matrix from the SSIM, and checking the matrix for transitivity –

*Modeling the Enablers of Agile Manufacturing System*

transitivity of the contextual relation is a basic assumption in ISM which states that if element A is related to B and B is related to C, then A is necessarily related to C;

- (5) Partitioning of the reachability matrix into different levels;
- (6) Based on the relationships given above in the reachability matrix, drawing a directed graph (digraph), and removing the transitive links;
- (7) Converting the resultant digraph into an ISM-based model by replacing element nodes with the statements; and
- (8) Reviewing the model to check for conceptual inconsistency, and making the necessary modifications.

**Structural Self-Interaction Matrix (SSIM)**

For analyzing the enablers a contextual relationship of “leads to” is used. To develop contextual relationships among enablers, expert opinions based on various management techniques such as brainstorming, nominal group technique, idea generation, etc. were considered. For expressing the relationship between different enablers to improve the agility of manufacturing system, four symbols have been used to denote the direction of relationship between the parameters i and j (here  $i < j$ ):

- (1) V: enabler i will lead to enabler j;
- (2) A: enabler j will lead to enabler i;
- (3) X: enabler i and j will lead to each other; and
- (4) O: enabler i and j have no relationship.

**Reachability Matrix**

The SSIM has been converted into a binary matrix, called the initial reachability matrix by

Table 2: Structural Self- Interaction Matrix (SSIM)

↙ Enablers	14	13	12	11	10	9	8	7	6	5	4	3	2
1. Manufacturing Flexibility	V	O	O	O	A	O	O	O	A	O	A	A	V
2. Strategic Production Planning	V	O	O	A	A	A	A	A	A	A	A	A	
3. Concurrent Engineering	V	O	O	A	A	O	O	O	A	A	A		
4. Automation in Manufacturing	V	O	O	A	A	O	O	O	A	X			
5. Rapid Prototyping	V	O	O	O	A	O	O	O	A				
6. Integrated Information System	V	A	A	A	A	O	V	O					
7. Multi-functional Workforce	V	O	O	O	O	V	O						
8. Rapid Partnership & Supplier Devlt.	V	O	O	O	A	O							
9. Virtual Enterprise Formation	V	O	O	A	A								
10. Product Decision	V	A	A	A									
11. Market Information System	V	V	V										
12. Product mix	V	O											
13. Product Postponement	V												
14. Agile Manufacturing System													

substituting V, A, X and O by 1 and 0 as per the case. The substitution of 1s and 0s are as per the following rules:

- If the (i, j) entry in the SSIM is V, the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0.

- If the (i, j) entry in the SSIM is A, the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry becomes 1.
- If the (i, j) entry in the SSIM is X, the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry also becomes 1.
- If the (i, j) entry in the SSIM is O, the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry also becomes 0.

The initial reachability matrix for the enablers is shown in Table 3. After incorporating the transitivity as described earlier in step (4) of the ISM methodology, the final reachability matrix with driving

Table 3: Initial Reachability Matrix

Enablers	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Manufacturing Flexibility	1	1	0	0	0	0	0	0	0	0	0	0	0	1
2. Strategic Production Planning	0	1	0	0	0	0	0	0	0	0	0	0	0	1
3. Concurrent Engineering	1	0	1	0	0	0	0	0	0	0	0	0	0	1
4. Automation in Manufacturing	1	0	1	1	1	0	0	0	0	0	0	0	0	1
5. Rapid Prototyping	0	0	1	1	1	0	0	0	0	0	0	0	0	1
6. Integrated Information System	1	0	1	1	1	1	0	1	0	0	0	0	0	1
7. Multi-functional Workforce	0	0	0	0	0	0	1	0	1	0	0	0	0	1
8. Rapid Partnership & Supplier Devlt.	0	0	0	0	0	0	0	1	0	0	0	0	0	1
9. Virtual Enterprise Formation	0	0	0	0	0	0	0	0	1	0	0	0	0	1
10. Product Decision	1	0	1	1	1	1	0	1	1	1	0	0	0	1
11. Market Information System	0	0	1	1	0	1	0	0	1	1	1	1	1	1
12. Product mix	0	0	0	0	0	1	0	0	0	1	0	1	0	1
13. Product Postponement	0	0	0	0	0	1	0	0	0	1	0	0	1	1
14. Agile Manufacturing System	0	0	1	0	0	0	0	0	0	0	0	0	0	1

power and dependence for each enabler is shown in Table 4. Driving power for an enabler is the total number of enablers (including itself) to which it may help to achieve. On the other hand dependence is the total number of enablers (including itself), which may help achieving it.

Table 4: Final Reachability Matrix

Enablers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Drivers
1. Manufacturing Flexibility	1	1	0	0	0	0	0	0	0	0	0	0	0	1	3
2. Strategic Production Planning	0	1	0	0	0	0	0	0	0	0	0	0	0	1	2
3. Concurrent Engineering	1	1	1	0	0	0	0	0	0	0	0	0	0	1	4
4. Automation in Manufacturing	1	1	1	1	1	0	0	0	0	0	0	0	0	1	6
5. Rapid Prototyping	1	0	1	1	1	0	0	0	0	0	0	0	0	1	5
6. Integrated Information System	1	1	1	1	1	1	0	1	0	0	0	0	0	1	8
7. Multi-functional Workforce	0	0	0	0	0	0	1	0	1	0	0	0	0	1	3
8. Rapid Partnership & Supplier Devlt.	0	0	0	0	0	0	0	1	0	0	0	0	0	1	2
9. Virtual Enterprise Formation	0	0	0	0	0	0	0	0	1	0	0	0	0	1	2
10. Product Decision	1	0	1	1	1	1	0	1	1	1	0	0	0	1	9
11. Market Information System	1	0	1	1	1	1	0	1	1	1	1	1	1	1	12
12. Product mix	1	0	1	1	1	1	0	1	1	1	0	1	0	1	10
13. Product Postponement	1	0	1	1	1	1	0	1	1	1	0	0	1	1	10
14. Agile Manufacturing System	1	0	1	0	0	0	0	0	0	0	0	0	0	1	3
<b>Dependence</b>	10	5	9	7	7	5	1	6	6	4	1	2	2	14	

### Modeling the Enablers of Agile Manufacturing System

These driving power and dependencies will be used in the classification of enablers into the four groups of autonomous, dependent, linkage and independent (driver) enablers in MICMAC analysis.

#### Level Partitions

From the final reachability matrix, the reachability and antecedent set for each factor are found. The reachability set consists of the element itself and other elements to which it may help achieve, whereas the antecedent set consists of the element itself and the other elements, which may help achieving it. Then the intersection of these sets is derived for all elements.

The element for which the reachability and intersection sets are same is the top-level element in the ISM hierarchy. The top-level element of the hierarchy would not help achieve any other element. Once the top-level element is identified, it is separated out from the other elements. Then the same process finds the next level of elements. These identified levels help in building the directed graph and final model. From Table 5, it is seen that the agile manufacturing system

Table 5: Iteration 1

Enablers	Reachability set	Antecedent set	Intersection set	Level
1. Manufacturing Flexibility	1, 2, 14	1, 3, 4, 5, 6, 10, 11, 12, 13, 14	1, 14	
2. Strategic Production Planning	2, 14	1, 2, 3, 4, 6	2	
3. Concurrent Engineering	1, 2, 3, 14	3, 4, 5, 6, 10, 11, 12, 13, 14	3, 14	
4. Automation in Manufacturing	1, 2, 3, 4, 5, 14	4, 5, 6, 10, 11, 12, 13	4, 5	
5. Rapid Prototyping	1, 3, 4, 5, 14	4, 5, 6, 10, 11, 12, 13	4, 5	
6. Integrated Information System	1, 2, 3, 4, 5, 6, 8, 14	6, 10, 11, 12, 13	6	
7. Multi-functional Workforce	7, 9, 14	7	7	
8. Rapid Partnership & Supplier Devlt.	8, 14	6, 8, 10, 11, 12, 13	8	
9. Virtual Enterprise Formation	9, 14	7, 9, 10, 11, 12, 13	9	
10. Product Decision	1, 3, 4, 5, 6, 8, 9, 10, 14	10, 11, 12, 13	10	
11. Market Information System	1, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14	11	11	
12. Product mix	1, 3, 4, 5, 6, 8, 9, 10, 12, 14	11, 12	12	
13. Product Postponement	1, 3, 4, 5, 6, 8, 9, 10, 13, 14	11, 13	13	
14. Agile Manufacturing System	1, 3, 14	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 3, 14	I

Table 6: Iteration 2

Iteration	Enablers	Reachability set	Antecedent set	Intersection set	Level
ii	2	2	1, 2, 3, 4, 6	2	ii
ii	8	8	6, 8, 10, 11, 12, 13	8	ii
ii	9	9	7, 9, 10, 11, 12, 13	9	ii
iii	1	1	1, 3, 4, 5, 6, 10, 11, 12, 13	1	iii
iii	7	7	7	7	iii
iv	3	3	3, 4, 5, 6, 10, 11, 12, 13	3	iv
v	4	4, 5	4, 5, 6, 10, 11, 12, 13	4, 5	v
v	5	4, 5	4, 5, 6, 10, 11, 12, 13	4, 5	v
vi	6	6	6, 10, 11, 12, 13	6	vi
vii	10	10	10, 11, 12, 13	10	vii
viii	12	12	11, 12	12	viii
viii	13	13	11, 13	13	viii
ix	11	11	11	11	ix

is found at level I. Thus, it would be positioned at the top of the ISM hierarchy. This iteration is repeated till the levels of each factor are found out as shown in Tables 6. The identified levels aids in building the final model of ISM. Figure 2 shows levels of all the enablers in directed graph.

### MICMAC Analysis

The purpose of the MICMAC analysis is to analyze the driver power and the dependence power of the enablers. The enablers are classified into four clusters as shown in figure 2. The first cluster consists of the “autonomous enablers” that have weak driver power and weak dependence. These enablers are relatively disconnected from the system, with which they have only few links, which may be strong. Second cluster consists of the dependent enablers having weak driver power but strong dependence. Third cluster has the linkage enablers having both strong driving power and strong dependence. These enablers are highly unstable in the fact that any action on these enablers will have an effect on others and also a feedback on themselves. Fourth cluster includes the independent enablers having strong driving power but weak dependence. It is observed that enablers with a very strong driving power called the key enablers, falls into the category of independent or linkage enablers.

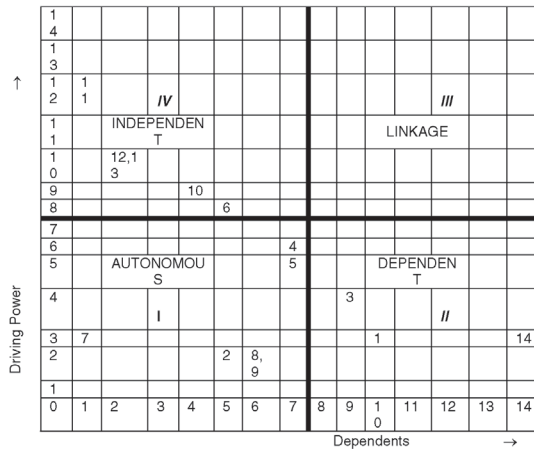


Figure 1: Driving power and Dependence Diagram

The driving power-dependence diagram is constructed on the basis of final reachability matrix, which is shown in Figure 1. For an example, it is observed from Table 4 that enablers 12 and 13 have a driver power of 10 and a dependence of 2. Therefore, in this Figure, it is positioned at a place corresponding to a driver power of 10 and a dependency of 2.

### Discussion and Conclusion

The main objective of the ISM model in this research was to develop a hierarchy of enablers that would help to increase agility of manufacturing systems. These variables must be considered in present manufacturing trends according to their driving power and dependencies. It has been observed that there are three basic categories of enablers: strategic, operational, and performance based. The strategic enablers lie in lower level of ISM hierarchy; operational enablers lie in middle level of the hierarchy whereas performance related enablers lie in top level of the hierarchy as shown in Figure 2.

To increase the agility of manufacturing system, market information system should be very strong so that quick information regarding change in demand related to volume and design of

### Modeling the Enablers of Agile Manufacturing System

the product can be passed to the manufacturer. A manufacturer should have a capacity to incorporate the changed design as soon as possible by providing product postponement, product mix, increasing commonality of components etc. An advanced technology is very helpful to achieve the required ability. These technologies are flexible manufacturing system, concurrent engineering, automated manufacturing, Just-in-time philosophy etc. The strategic production planning is based on the availability of these technologies.

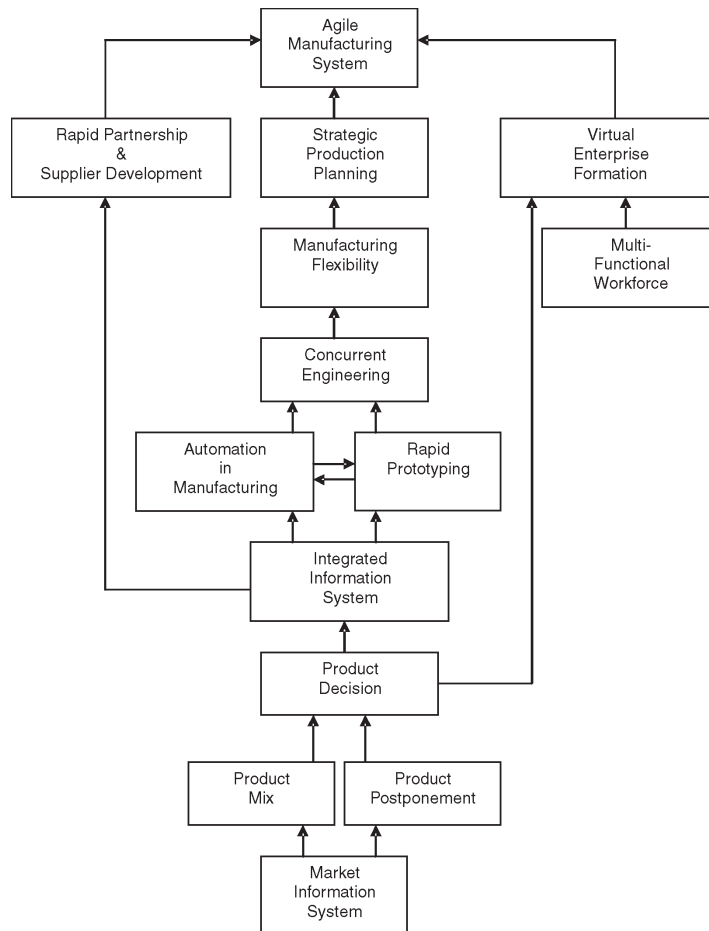


Figure 2: ISM based model for agility enablers in a manufacturing system

The relationship management also plays an important role in increasing the agility of manufacturing system. The ability of rapid partnership facilitates fast supply of components, technology and design. Multi-functional workforce helps to perform the situation based tasks within limited time.

Strategic production planning, automation in manufacturing, rapid prototyping, multi-functional workforce, rapid partnership and supplier development, and virtual enterprise formation are autonomous variables and have low driving power.

These enablers are relatively disconnected from the system, with which they have only few links, which may be strong. Manufacturing flexibility, concurrent engineering, and agile manufacturing system are highly dependent and have low driving power. There are no enablers

having high driving power with high dependency. Integrated information system, product design, market information system, and product postponement have high driving power with low dependencies and are very important to improve the agility of product development process.

## References

- Abair, R. A. (1995), Agile manufacturing: this is not just repackaging of material requirements planning and just-in-time. *Annual International Conference Proceedings- American Production and Inventory Control Society*, 196-198.
- Avittathur, B. and Swamidass, P. (2007), Matching plant flexibility and supplier flexibility: lesson from small suppliers of U.S. manufacturing plants in India. *Journal of Operations Management*, 25(3), 717-735.
- Cho, H., Jung, M. Y. and Kim, M. (1996), Enabling technologies of agile manufacturing and its related activities in Korea. *Computers & Industrial Engineering*, 30, 323-334.
- Christian, I., Ismail, H., Mooney, J., Snowden, S., Toward, M., Zhang, D. (2001), Agile manufacturing transitional strategies, manufacturing information systems. Proceedings of The Fourth SMESME International Conference, 1-9.
- De Vor, R. and Mills, J. (1995), Agile manufacturing. *American Society of Mechanical Engineers, Manufacturing Engineering Division, MED*, 2(2), 977.
- Faisal, M. N., Banwet, D. K. and Shankar, R. (2006), "Supply chain risk mitigation: modeling the enablers." *Business Process Management Journal*, 12 (4), 535-52.
- Graham, J. H., Ragade, R. K. (1994), Design support system for agile manufacturing. Proceedings of the *IEEE International Conference on Systems, Man and Cybernetics 1* 512-517.
- Gunasekaran, A. (1998), Agile manufacturing: enablers and an implementation framework. *International Journal of Production Research*, 36(5), 1223-1247.
- Gunasekaran, A. and Yusuf, Y. Y. (2002), Agile manufacturing: a taxonomy of strategic and technological imperatives. *International Journal of Production Research*, 40(6), 1357-1385.
- Gupta, U. G., Mittal, R. O. (1996), Quality, time, and innovation based performance measurement system for agile manufacturing. *Proceedings - Annual Meeting of the Decision Sciences Institute*, 3, 1511-1513.
- Gupta, Y.P. and Somers, T.M. (1996), Business strategy, manufacturing flexibility, and organizational performance relationships: a path analysis approach. *Production and Operations Management*, 5(3), 204-233.
- He, D.W. and Kusiak, A. (1995), The delayed product differentiation strategy in agile manufacturing. *IERC Proceedings 1995, 4th Annual Industrial Engineering Research Conference*. Norcross, GA, USA, 701-708.
- Jharkharia, S. and Shankar, R. (2005), IT enablement of supply chains: understanding the barriers. *Journal of Enterprise Information Management*, 18(1), 11-27.
- Katayama, H. and Bennett, D. (1999), Agility, adaptability and leanness: a comparison of concepts and a study of practice. *International Journal of Production Economics*, 60, 43-51.
- Krause, D.R., Handfield, R.B., and Tyler, B.B. (2007), The relationships between supplier development social capital accumulation and performance improvement. *Journal of Operations Management*, 25(2), 528-545.
- Kumar, A. and Kumar, P. (2006), Role of rapid prototyping in agile manufacturing. Proceedings of *RDFTME-2006*, 258-264.
- Kumar, P., Shankar, R., and Yadav, S.S. (2007), Flexibility in Global Supply Chain: A Review of Perspectives, Proceedings of Seventh Global conference on flexible system Management (*GLOGIFT-07*), 377-385
- Mandal, A. and Deshmukh, S.G. (1994), Vendor selection using interpretive structural modeling (ISM), *International Journal of Operations & Production Management*, 14(6), 52-59.
- Medhat, S. S. and Rook, J. L. (1997), Concurrent engineering - processes and techniques for the agile manufacturing enterprise. *IIE Conference Publication*, 435, 9-14.
- Naylor, J.B., Naim, M.M. and Berry, D. (1999), Leagility: integrating the lean and agile manufacturing paradigm in the total supply chain, *International Journal of Production*

*Modeling the Enablers of Agile Manufacturing System*

*Economics*, 62, 107-118.

- Palvia, Prashant C. (1997), Developing a model of the global and strategic impact of information technology. *Information and Management*, 32(5), 229-244.
- Powell, Thomas C., and Dent-Micallef, A. (1997), Information technology as competitive advantage: the role of human, business and technology resources. *Strategic Management Journal*, 18(5), 375-405.
- Qureshi, M. N., Kumar, D., and Kumar, P. (2007), Modeling the logistics outsourcing relationship variables to enhance shippers' productivity and competitiveness in logistical supply chain, *International Journal of Productivity and Performance Management*, 56, (8), 689-714.
- Ravi, V. and Shankar, R. (2005), Analysis of interactions among the barriers of reverse logistics, *Technological Forecasting and Social Change*, 72, 1011-29.
- Sage, A. P. (1977), Interpretive structural modeling: methodology for large-scale systems. *McGraw-Hill*, New York, NY, 91-164.
- Sethi, V. and King, William R. (1994), Development of measures to assess the extent to which an information technology application provides competitive advantage. *Management Science*, 40(12), 1601-1627.
- Sethi, A. K., and Sethi, S. P. (1990), Flexibility in Manufacturing: a survey. *The International Journal of Flexible Manufacturing Systems*, 2(4), 289-328.
- Simchi-Levi, D., Kaminsky, P., and Simchi-Levi, E. (2002), Designing and managing the supply chain: concepts, strategies and case studies, 2nd Edition, *Irwin/McGraw-Hill*.
- Swafford, P. M., Ghosh S., and Murthy, N. (2006), The antecedents of supply chain agility of a firm: scale development and model testing. *Journal of Operations Management*, 24(2), 170-188.
- Tan, Keah-choon., Kannan, V.R., and Handfield, R.B. (1996), Supply chain management: supplier performance and firm performance. *International Journal of Purchasing and Materials Management*. August, 2-9.
- Wang, F., Mill, J.J., and Devarajan, V. (2002), A conceptual approach for managing design resources, *Computer in Industries*, 47, 169-183.
- Warfield, J.N. (1974), Developing interconnection matrices in structural modeling. *IEEE Transactions on Systems, Man and Cybernetics*, 4 (1), 81-7.
- Yusuf, Y. Y., Sarhadi, M. S. and Gunasekaran, A. (1999), Agile manufacturing: the drivers, concepts and attributes. *International Journal of Production Economics*, 62(1-2), 23-32.