DEVELOPMENT OF FRAMEWORK FOR ANALYZING FLEXIBILITY IN SUPPLY CHAIN

R. K Singh[1] & P. B Sharma[2]

Abstract: *In present era of global competition, organizations are trying to improve the effectiveness of the whole chain of organizations involved from raw material to delivery of final product to consumer. In this regard, supply chain management is playing crucial role. Uncertainty and variation in customers' needs call for flexibility in the supply chain. Supply chain flexibility gives an account of inter-organizational relationships. In many industries supply chain flexibility is becoming a more and more important concept for gaining competitive advantages. By the design and use of strategic supply chain networks, significant improvements of supply chain flexibility can be achieved to improve overall flexibility of supply chain. Without analyzing the supply chain flexibility adequately, it is difficult to manage and organize the flow of material and information necessary for coordination in supply chain. This paper aims to find the main flexibility factors in supply chain and development of structural framework by using interpretive structural modeling approach (ISM).*

Keywords: Supply chain management, flexibility, ISM, Coordination, Responsiveness

[1] Associate Professor,IIFT, Delhi-110016,Email-rksdce@yahoo.com
[2] Vice Chancellor,Delhi Technological University,Delhi-110042

Introduction

In globalized economy, market has become highly uncertain. Requirements of customers are fast changing in terms of cost, quality and delivery. Therefore to sustain in such an environment, organizations need to have flexible supply chain.Supply chain is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers. Supply chains exist in both service and manufacturing organizations. Figure 1 shows a simple supply chain for a single product, where raw material is procured from suppliers, transformed into finished goods in a single step, and then transported to distribution centers, and then to retailers and ultimately, to customers. Realistic supply chains have multiple end products with shared components, facilities and capacities. Various modes of transportation may be considered, and the bill of materials for the end items may be both deep and large. Complexity of the chain may vary greatly from industry to industry and firm to firm (Chopra and Meindl, 2003).

Figure1. A Supply Chain Network

Flexibility is the ability of a system to perform proactive and reactive adaptations of its configuration in order to cope with internal and external uncertainties. Increasing complexity of the value-added processes and the shortening of response times to demand changes are the main causes for having flexibility in supply chains (Wilding, 1998). A fast response to changing demands is necessary for competitive advantage in today’s markets. Customers expect their needs to be satisfied at the time of their expression. Companies therefore must have quick response times to changing needs, in order to gain or hold market-shares (Talluri et al., 2004). Thus, flexibility is necessary to stay in this competitive environment.The complexity of business processes is increasing as companies attempt to respond to their customers’ needs with an increasing number of highly customized products. At the same time, the offered products themselves are becoming increasingly complex. This complexity results from the different embedded technologies. A single company can no longer produce or handle these technologies alone. The general trend of outsourcing and decreasing the vertical range of manufacturers intensifies the need of flexibility.

The objective of this paper is to identify different attributes of flexibility and develop a structural relationship between them. This paper is organized as follows. Section 2 discusses literature review. Section 3 discusses research methodology. It is followed by results and discussions and finally concluding remarks.

2. Literature Review

In today's scenario, survival and growth of the organization depend on competitiveness of the supply chain. Consumers are highly sophisticated. They demand customized quality products, timely delivery and low cost. Therefore in order to compete in this scenario, organizations and their respective supply chain need to be more flexible. Flexibility reflects the ability of a system to respond rapidly to changes that occur inside and outside the system. Vickery et al. (1999) defined five supply chain flexibilities which include product, launch, volume, access and responsiveness flexibility. They considered flexibility dimensions that directly impact firms' customers and share responsibilities of two or more functions along the supply chain. Information plays a key role in decision making regarding changes in customers' needs, delivery dates, storage and transportation [Duclos et al (2003), D'Souza and Williams (2000), Martinez and Perez (2005)].The promptness and the degree to which the supply chain changes its speed, destinations and volumes in response to changes in customer demands gives the benefits of mass customization and positive relationship between each node of the supply chain [Das and Abdel-Malek (2003), Garavelli (2003), Lummus et al.(2003)].Motivation and growth of employees [Efstathiads et al.(2002)] and adoption of TQM culture in the organization leads to better understanding among the workers in the organization thereby developing sound relationship with the suppliers and distribution personnel. Combination of the entire flexibilities give rise to supply chain flexibility should be seen as a tool for competitive advantage to the company and gaining success in all areas as well as satisfying customers.

Present study tries to develop a framework for managing the flexibility in the supply chain. For this, twenty nine enablers of flexibility in supply chain have been identified. For developing the framework, interpretive structural modeling (ISM) has been used. These enablers have been categorized into seven groups. These groups are:

- Information flow flexibility
- Suppliers' Flexibility
- Organizational Flexibility
- Production System Flexibility
- Transportation and Warehousing Flexibility
- Product Design and Development Flexibility
- Flexible Supply Chain

These groups along with the enablers have been shown in the Table 1.

Table 1: Enablers of flexibility in supply chain

Suppliers' Flexibility	**References**
Ability to meet changes in volume requirement on short notice	Kumar et al.(2008)
Ability to alter the supply of products in line with customers' demand	Duclos et al.(2003)
Ability to change delivery dates of raw materials to the suppliers	Duclos et al.(2003) Kumar et al.(2008)
Transportation and Warehousing Flexibility	**References**
Ability to serve distinct customers' shipping requirements	Koste and Malhotra (1999)
Ability to vary warehouse space	Martinez and Perez (2005) Garavelli (2003)
Ability to vary transportation carriers	Garavelli (2003)
Production System Flexibility	**References**
Ability to reconfigure assets (equipments) in line with customer needs	D'Souza and Williams (2000)
Ability to change processes as demand changes	Das and Abdel-Malek (2003)
Ability to adjust capacity	Das and Abdel-Malek (2003)
ability to produce parts in different ways	Vickery et al.(1999)
Ability to produce a part by alternate routes through the system	Duclos et al.(2003) Martinez and Perez (2005)
Ability to reduce the machine downtime	Lummus et al(2003)
Organizational Flexibility	**References**

Flexibility of top management	Koste and Malhotra (1999) Lummus et al.(2003)
Motivation and growth of employees	Efstathiads et al .(2002)
Training and empowerment of employees	Efstathiads et al .(2002)
Development of multiskills and capabilities of workforce	D'Souza and Williams (2000)
Ability to form personal links with other nodes	Duclos et al. (2003)
Cultural Flexibility	D'Souza and Williams (2000)
Information Flow Flexibility	**References**
Ability to get point of sales data	D'Souza and Williams (2000)
Ability to synchronize information systems with supply chain partners	Duclos et al. (2003) D'Souza and Williams (2000)
Ability to share information across internal departments	Duclos et al (2003) D'Souza and Williams (2000)
Ability to pass information along the supply chain	Duclos et al (2003) Martinez and Perez (2005)
Product Design and development Flexibility	**References**
Ability to introduce and design new product	Vickery et al.(1999) Martinez and Perez (2005)
Ability to mass customize	Lummus et al.(2003)
Postponement of final product	Martinez and Perez (2005)
Flexible supply Chain	**References**
Ability to change the volume	Duclos et al.(2003) Martinez and Perez (2005)
Ability to change delivery time	Duclos et al.(2003) D'Souza and Williams (2000)
Ability to change design of product	Martinez and Perez (2005)
Ability to adapt processes to specific products	Duclos et al.(2003)

3. Research methodology

To develop structural relationship between different groups of flexibility in supply chain, interpretive structural modeling is used.

3.1. Interpretive structural modeling

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 and to impose order and direction on the complexity of the relationships among elements of a system. It is very difficult to handle all the enablers of a complex problem if the number of enablers is large. ISM develops collective understanding of relationships among the enablers. ISM 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 digraph model. It is primarily intended as a group learning process, but it can also be used individually. Jharkharia and Shankar (2005) applied ISM for understanding the barriers in IT – enablement of supply chains. Singh et al. (2007a, b) applied ISM for improving SMEs competitiveness and for implementation of advanced manufacturing technologies (AMTs) in firms. The various steps involved in the ISM technique are:

(1) Identification of elements, which are relevant to the problem or issues, this could be done by any group problem solving technique.

(2) Establishing a contextual relationship between elements with respect to which pairs of elements will be examined.

(3) Developing a structural self -interaction matrix (SSIM) of elements, which indicates pair-wise relationship between elements of the system.

(4) Developing a reachability matrix from the SSIM, and then checking the matrix for transitivity. Transitivity of the contextual relation is a basic assumption in ISM which states that if element A is related toB and B is related to C, then A will be necessarily related to C.

(5) Partitioning of reachability matrix into different levels.

(6) Based on the relationships given above in the reachability matrix draw a digraph, and remove transitive links.

(7) Convert the resultant digraph into ISM, by replacing element nodes with statements.

(8) Review the ISM model to check for conceptual inconsistency, and make the necessary modifications.

Above described steps, which lead to the development of ISM model, are discussed below.

3.1.1. Structural self-interaction matrix (SSIM)

For analyzing the criteria a relationship of "leads to" is chosen here. For developing contextual relationships among variables, expert opinions based on various management techniques such as brainstorming, nominal group technique, idea engineering, etc. were considered. For expressing the relationship between different critical factors, four symbols have been used to denote the direction of relationship between the parameters i and j (here i, j):

(1) V: parameter i will lead to parameter j;

(2) A: parameter j will lead to parameter i;

(3) X: parameter i and j will lead to each other; and

(4) O: parameters i and j are unrelated.

Considering above notations, SSIM is developed in Table 2.

Table 2: Structural self-interaction matrix

S.No.	Factors	1	2	3	4	5	6	7
1	Information Flow Flexibility		V	V	V	V	V	V
2	Suppliers' Flexibility			X	X	V	V	V
3	Organizational Flexibility				X	V	V	V
4	Production System Flexibility					V	V	V
5	Transportation and Warehousing Flexibility						O	V
6	Product Design and development Flexibility							V
7	Flexible supply Chain							

3.1.2. Initial Reachability matrix

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

(1) 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.

(2) 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.

(3) 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.

(4) 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.

Following above rules, the initial reachability matrix for the critical success factors is shown in Table 3.

Table 3: Initial Reachability matrix

S.No.	Factors	1	2	3	4	5	6	7
1	Information Flow Flexibility	1	1	1	1	1	1	1
2	Suppliers' Flexibility	0	1	1	1	1	1	1
3	Organizational Flexibility	0	1	1	1	1	1	1
4	Production System Flexibility	0	1	1	1	1	1	1
5	Transportation and Warehousing Flexibility	0	0	0	0	1	0	1
6	Product Design and development Flexibility	0	0	0	0	0	1	1
7	Flexible supply Chain	0	0	0	0	0	0	1

3.1.3. Final reachability matrix

The final reachability matrix is obtained by incorporating the transitivity as enumerated in Step (4) of the ISM methodology. This is shown in Table 4. In this, the driving power and dependence of each factor are also shown. The driving power of a particular factor is the total number of factors (including itself), which it may help achieve while the dependence is the total number of factors, which may help achieving it. On the basis of driving power and dependencies, these factors will be classified into four groups of autonomous, dependent, linkage and independent (driver) factors.

Table 4: Final Reachability Matrix

S.No.	Factors	1	2	3	4	5	6	7	D.P.
1	Information Flow Flexibility	1	1	1	1	1	1	1	7
2	Suppliers' Flexibility	0	1	1	1	1	1	1	6
3	Organizational Flexibility	0	1	1	1	1	1	1	6
4	Production System Flexibility	0	1	1	1	1	1	1	6
5	Transportation and Warehousing Flexibility	0	0	0	0	1	0	1	2

6	Product Design and development Flexibility	0	0	0	0	0	1	1	2
7	Flexible supply Chain	0	0	0	0	0	0	1	1
	Dependence	1	4	4	4	5	5	7	

3.1.4. 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 above their own. Once the top-level element is identified, it is separated out from the other elements. Then by the same process, the next level of elements is found. These identified levels help in building the diagraph and final model. From Table 5, it is seen that the performance improvement 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 (Tables 5-8).

Table 5: Iteration 1

Factors	Reachability set	Antecedent set	Intersection set	Level
1	1,2,3,4,5,6,7	1	1	**I**
2	2,3,4,5,6,7	1,2,3,4	2,3,4	
3	2,3,4,5,6,7	1,2,3,4	2,3,4	
4	2,3,4,5,6,7	1,2,3,4	2,3,4	
5	5,7	1,2,3,4,5	5	
6	6,7	1,2,3,4,6	6	
7	**7**	1,2,3,4,5,6,7	**7**	

Table 6: Iteration 2

Factors	Reachability set	Antecedent set	Intersection set	Level
1	1,2,3,4,5,6	1	1	**II**
2	2,3,4,5,6	1,2,3,4	2,3,4	
3	2,3,4,5,6	1,2,3,4	2,3,4	
4	2,3,4,5,6	1,2,3,4	2,3,4	
5	**5**	1,2,3,4,5	**5**	
6	**6**	1,2,3,4,6	**6**	

Table 7: Iteration 3

Factors	Reachability set	Antecedent set	Intersection set	Level
1	1,2,3,4	1	1	
2	**2,3,4**	1,2,3,4	**2,3,4**	
3	**2,3,4**	1,2,3,4	**2,3,4**	
4	**2,3,4**	1,2,3,4	**2,3,4**	**III**

Table 8: Iteration 4

Factors	Reachability set	Antecedent set	Intersection set	Level
1	**1**	1	**1**	**IV**

3.1.5. Classification of factors

In this section, the critical success factors described earlier are classified into four clusters (Figure 2). This classification is similar to that made by Mandal and Deshmukh (1994). The first cluster consists of the "autonomous factors" that have weak driving power and weak dependence. These factors are relatively disconnected from the system, with which they have only few links, which may not be strong. The "dependent factors" constitute the second cluster which has weak driving power but strong dependence. Third cluster has the "linkage factors" that have strong driving power and strong dependence. These factors are unstable due to the fact that any change occurring to them will have an effect on others and also a feedback on themselves. Fourth cluster includes the "independent factors" having strong driving power but weak dependence. The driving power and dependence of each of these factors are shown in Table VI. In this table, an entry of "1" added along the columns and rows indicates the dependence and driving power, respectively. Subsequently, the driver power-dependence diagram is constructed as shown in Figure 2. For illustration, the factor five having a driving power of 2 and dependence 5 is positioned at a place corresponding to driving power of 2 and dependency of 5 in the Figure 2. Similarly all other factors considered in this study are positioned on different quadrants depending on their driving power and dependency.

3.1.6. Formation of ISM-based model

From the final reachability matrix (Table 4), the structural model is generated by means of vertices or nodes and lines of edges. If there is a relationship between the flexibility factors i and j this is shown by an arrow which points from i to j. This graph is called a directed graph or digraph. After removing the transitivities as described in ISM methodology, the digraph is finally converted into ISM as shown in Figure 3.

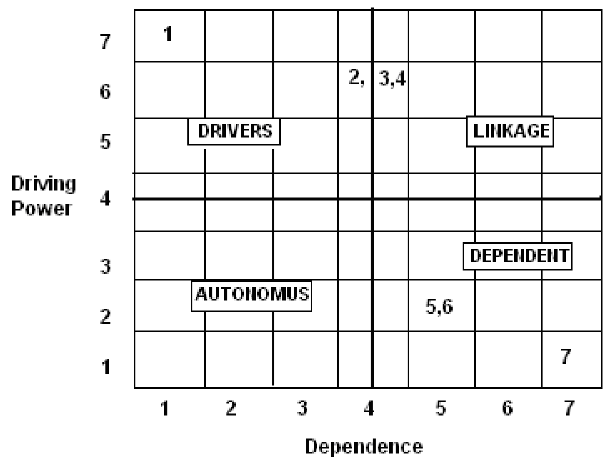

Figure 2: Driving Power and Dependence diagram

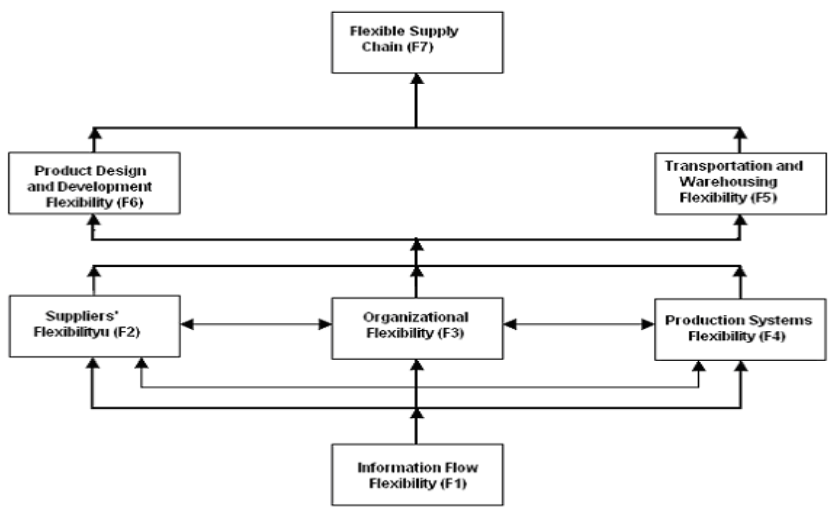

Figure 3: ISM based model for enablers of supply chain flexibility

4. Results and discussion

The main objective of the ISM model in this research is to develop a digraph of factors that would help to increase flexibility in supply chain. These various flexibilities are analyzed to judge the performance of supply chain according to their driving power and dependencies. The driver power-dependence matrix provides the information about the interrelationship among the factors. Some of the observations are:

1. The driver power-dependence matrix shows that there is no autonomous factor for flexibility in supply chain.
2. Information flow flexibility has the strong driving power and is capable to lead the organization to achieve the desired objective independently.
3. Suppliers' flexibility, Organizational flexibility and Production system flexibility have strong driving power and medium dependence. Thus they also acts as driver next to Information flow flexibility. They are categorized as linkage variables.
4. Dependence increases as we move from Transportation and Warehousing flexibility to Product design and development flexibility till Flexible supply chain. Flexible supply chain has the highest dependence and represents the ultimate goal to be achieved in the supply chain.

5. Conclusions

In today's scenario, the demand of the customer changes very rapidly and there is lots of complexities in the products. Also, the competition is very high. So, in order to survive, flexibility is necessary in the supply chains which allow them to adapt to market uncertainties. This paper has identified important enablers of flexibility in supply chain. These enablers are categorized into seven flexibility sub-groups and ISM approach has been applied to develop a structural relationship between these groups for managing flexibility in supply chain. Information flow flexibility has emerged as major driving force for flexibility in supply chain. It implies that organization should focus on generating accurate information and its availability at the right time.

References

1. Chopra S and Meindl P (2003), "Supply chain management, strategy, planning, and operations", Upper Saddle River, New Jersey.
2. Das SK and Abdel-Malek L (2003)," Modeling the flexibility of order quantities and lead times in supply chains", International Journal of Production Economics, Vol. 85, pp.171–181.
3. D'Souza, D.E. and Williams, F.P. (2000),"Towards a taxonomy of manufacturing flexibility dimensions", Journal of Operation Management, Vol. 18 No.5, pp.577-93.
4. Duclos LK, Vokura RJ and Lummus RR (2003), "A conceptual model of supply chain flexibility", Industrial Management and Data System, Vol.106 No.6, pp. 446–456.
5. Efstathiades, A., Tassou, S.A. and Antoniou, A. (2002),"Strategic planning, transfer and implementation of advanced manufacturing technologies (AMT), development of an integrated process plan",Technovation,Vol.22 ,pp. 201-12.

6. Garavelli CA (2003),"Flexibility configurations for the supply chain management, International Journal of Production Economics, Vol.85, pp. 141–153.
7. Jharkharia, S. and Shankar, R. (2005), "IT-enablement of supply chains: understanding the barriers", The Journal of Enterprise Information Management, Vol. 18 No. 1, pp. 285-309.
8. Koste, L.L. and Malhotra, M.K. (1998)," A theoretical framework for analyzing the dimensions of manufacturing flexibility ", Journal of Operation Management, Vol. 18 No.1, pp.75-93.
9. Kumar P, Shankar R and Yadav S.S. (2008)," Flexibility in global supply chain: modelling the enablers", Journal of Modelling in Management, Vol. 3 No. 3, pp. 277-297.
10. Lummus R, Duclos LK and Vokurka RJ (2003)," Supply chain flexibility: building a new model", Global Journal of Flexible System Management, Vol. 4 No.4, pp 1–13
11. Mandal, A. and Deshmukh, S.G. (1994), "Vendor selection using interpretive structural modeling (ISM)", International Journal of Operations & Production Management, Vol. 14 No. 6, pp. 52-9.
12. Martinez AM and Perez M (2005), "Supply chain flexibility and firm performance. A conceptual model and empirical study in the automotive industry", Inter--national Journal of Operations and Production Management, Vol.25 No.7, pp. 681–700.
13. Sage, A.P. (1977), "Interpretive structural modeling: methodology for large- scale population density", Small Business Economics, Vol. 6, pp. 291-7.
14. Singh, R.K., Garg, S.K. and Deshmukh, S.G. (2007a), "Interpretive structural modeling of factors for improving SMEs competitiveness", International Journal of Productivity and Quality Management, Vol. 2 No. 4, pp. 423-40.
15. Singh, R.K., Garg, S.K., Deshmukh, S.G. and Kumar M (2007b), "Modelling of critical success factors for implementation of AMTs development for competitiveness", Journal of Modelling in Management, Vol. 2 No. 3, pp. 232-250.
16. Talluri S, Cetin K and Gardner AJ (2004),"Integrating demand and supply variability into safety stock evaluations", International Journal of Physical Distribution Logistics Management, Vol. 34 No.1, pp.62–69.
17. Vickery S, Canlantone R and Droge C (1999)"Supply chain flexibility: An empirical study", Journal of Supply Chain Management, Vol.35 No.1, pp 16-24.
18. Warfield, J.N. (1974), "Developing interconnection matrices in structural modeling", IEEE Transactions on Systems, Man and Cybernetics, Vol. 4 No. 1, pp. 81-7.
19. Wilding R (1998)," The supply chain complexity triangle- uncertainty generation in the supply chain", International Journal of Physical Distribution and Logistics Management, Vol. 28 No.8, pp.599–618.