

Modeling agility of supply chain

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Abstract

Agility is the fundamental characteristic of a supply chain needed for survival in turbulent and volatile markets, which are becoming norms as product life cycles shorten and environmental forces create additional uncertainty resulting in higher risk in the supply chain management. Agility further helps in providing the right product, at the right time to the consumer, which is the main objective of any supply chain. In the present paper, using interpretive structural modeling, interrelationships of the variables, influencing supply chain agility, have been derived. These variables have been categorized according to their driving power and dependence. This methodology provides a means by which order can be imposed on the complexity of such variables. The insight from model would help supply chain managers in strategic planning for improving supply chain agility. © 2006 Elsevier Inc. All rights reserved.

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1. Introduction

Supply chain management (SCM) helps firms in integrating their business by collaborating with other value chain partners to meet the unpredictable demand of the end user. An integrated supply chain or seamless supply engineered to cope with uncertainty can profitably satisfy customer demand, while non-integrated manufacturing processes, non-integrated distribution processes and poor relationships with suppliers and customers are the recipes of business failure for trading firms. In the era of time-based competition, supply chain must have ability to meet the demands of customers for ever-shorter delivery times and to synchronize supply during the peaks and troughs of the demand. To have this ability supply chain must be responsive to the needs of the market. Responsiveness requires speed and high level of maneuverability, which is also termed as agility.

Agility is business-wide capability that embraces organizational structures, information systems and in particular, minds sets (Christopher, 2000). Agility means using market knowledge and virtual corporation to exploit profitable opportunities in a volatile marketplace (Mason-Jones & Towill, 1999).

Table 1 provides various ways in which agility has been defined in literature.

Christopher (2000) has identified a number of characteristics that a supply chain must have in order to be “truly agile”(Fig. 1):

- *Market sensitive* — it is closely connected to end-user trends.
- *Virtual* — it relies on shared information across all supply chain partners.
- *Network-based* — it gains flexibility by using the strengths of specialist players.
- *Process integration* — it has a high degree of process interconnectivity between the network members.

In the literature, frameworks based on other characteristics of supply chain agility have been also suggested. For example Bal, Wilding, and Goundry (1999) have proposed virtual teaming model for introducing agility in a supply chain. Yusuf, Sarhadi, and Gunasekaran (1999) have presented a conceptual model for the design of agile manufacturing system based on the four key dimensions of strategies, technology, people, and

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Table 1
Definition of agility

S.N.	Authors	Definition of agility
1	Goldman, Nagel, & Preiss, 1995	Agility means delivering value to customers, being ready for change, valuing human knowledge and skills, and forming virtual partnership.
2	Fliedner & Vokurka, 1997	Agility is an ability to produce a broad range of low-cost, high quality products with short lead times in varying lot sizes, built to individual customer specification.
3	Katayama & Bennett, 1999	Agility relates to the interface between the company and the market. Agility acts as a pillar to improve competitiveness and the business prospects.
4	Christopher, 2000	Agility is defined as the ability of an organization to respond rapidly to changes in demand, both in terms of volume and variety.
5	Mason-Jones et al., 2000	Agility means using market knowledge and virtual corporation to exploit profitable opportunities in a volatile market place.
6	Tolone, 2000	Agility implies effectively integrating supply chain and forging close and long term relationship with customers and suppliers.
7	Van Hoek, Harrison, & Christopher, 2001	Agility is all about customer responsiveness and market turbulence and requires specific capabilities that can be achieved using 'lean thinking'.
8	Aitken, Christopher, & Towill, 2002	Agility is an ability to have visibility of demand, flexible and quick response and synchronized operations.
9	Stratton & Warburton, 2003	Innovative products and unstable demand typify agile supply drivers.

system. Meade and Sarkis (1999) have used four dimensions to measure the agility of a manufacturing system. These are cooperating to enhance competitiveness, enriching customer, mastering change and uncertainty, and leveraging the impact of people and information.

Tolone (2000) has supported the role of real time and asynchronous collaboration technology for allowing manufacturers to increase their supply chain agility. Prater, Biehl, and Smith (2001) have used case studies to show how firms have successfully made a tradeoff between vulnerability and supply chain agility.

Svensson (2001) has stated that lean, responsive, and agile supply chains require satisfactory or high levels of perceived trust of companies towards suppliers and customers. Power, Sohal, and Rahman (2001) have identified some of the factors critical for successful agile organizations in managing their supply chains. Stratton and Warburton (2003) have explored the role of inventory and capacity in developing agile supply chain for an apparel manufacturer. Lau, Wong, Pun, and Chin (2003) have developed an infra-structural framework for the design and development of an agile supply chain system, which is characterized by its ability to cope with unpredictable changes related to the management of suppliers and flow of parts within the value chain of the entire production network. Yusuf, Gunasekaran, Adeleye, and Sivayoganathan (2004) have presented a conceptual model for assessing the capability of an agile supply chain, which consists of four dimensions: value

chain practice, competitive objectives, impact of change drivers, and business performance.

Literature on supply chain agility describes the dependence of agility on the characteristics of some performance variables but influence of interrelationships among the variables on the supply chain agility has been hardly taken into account in the literature.

Therefore there is a need to identify variables influencing supply chain agility and to develop generally applicable framework, which establishes interrelationships.

2. Identification of supply chain agility variables

The case supply chain pertains to auto business and the system consists of Auto company, suppliers, and dealers (distributors) (Fig. 2).

The company has a nationwide network to facilitate the customers. This network includes 352 dealers and their workshops, 1545 authorized service centers covering 898 cities and towns. There are 12 joint ventures (production facilities) in the company network; each of the joint ventures has its own computer systems to cater for production planning, scheduling and material scheduling. The top management in the company network is committed to integration of production facilities in order to take advantage of supply chain efficiencies. All the dealers in the supply chain are connected via extranet. These dealers provide real-time information about market conditions and demand. Based on the sales forecast and dealer orders, production plans are formulated. These plans percolate in the supply chain through communication to the suppliers to enable them to plan their production in advance. Latest IT tools such as extranet, EDI and e-mails are used to communicate these plans to the suppliers.

In the proposed ISM, to identify supply chain agility variables, and to establish mutual relationship, brainstorming sessions were conducted with experts from the trading partners of the supply chain.

Initial meeting was held with the management of supply chain. In this meeting, 5 experts from the company and its trading partners had been identified. These five experts had more than ten years of experience in the area of purchasing and supply chain management. Literature related to agility of supply chain had been circulated among the experts. Within a period of fifteen days, a brainstorming session was organized to identify the variables. Initially, only four variables as mentioned by Christopher were considered. Later on during brain storming session, experts from the case supply chain expressed their views to include more number of variables for agility improvement of their supply chain. In all, twenty-six variables had been identified in this session. The number was reduced to fifteen as some variables were of same nature. The literature related to these fifteen variables had been circulated among the experts. After seven days, a session was organized to establish the relationship among the variables. Since the relationships among all variables could not be established in this session, so another meeting was conducted to complete this task.

The purpose of the brainstorming sessions was to *identify relationships among supply chain variables*. For this experts

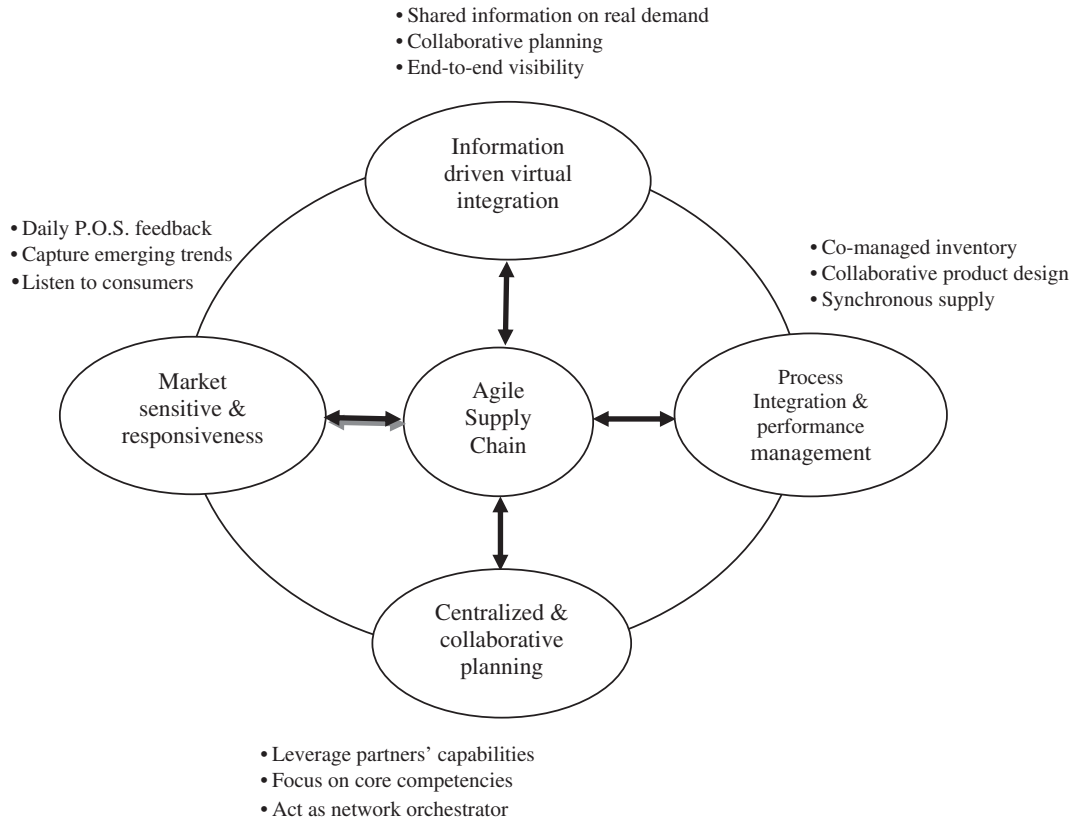


Fig. 1. Characteristics of agile supply chain (modified from Harrison et al., 1999).

were asked about the mutual relationship among variables (how a particular variable helps to achieve the other variables?).

After five days, the list of variables and interrelationship diagram were circulated among the experts for any further modification. A total of 15 variables have been identified for developing a framework for agility improvement of case supply chain. Identified variables are:

2.1. Market sensitiveness (MS)

The most important characteristic that makes a supply chain agile in nature is market sensitiveness (Christopher, 2000). By market sensitive it is meant that the supply chain is capable of reading and responding to real demand (Christopher

& Towill, 2001). The market sensitiveness of a supply chain is affected by level of collaboration among its trading partners, and its ability of using IT tools. Collaboration improves trust among trading partners, which motivates them to share business information and to work on the same data (Agarwal & Shankar, 2002a).

2.2. Delivery speed (DS)

Delivery speed from a market perspective is defined as ability to quickly meet delivery target (Vickery, Calantone, & Droge, 1999). Here delivery speed refers to the ability to deliver products or services faster than other competitors (Handfield & Pannesi, 1992). This definition also includes the

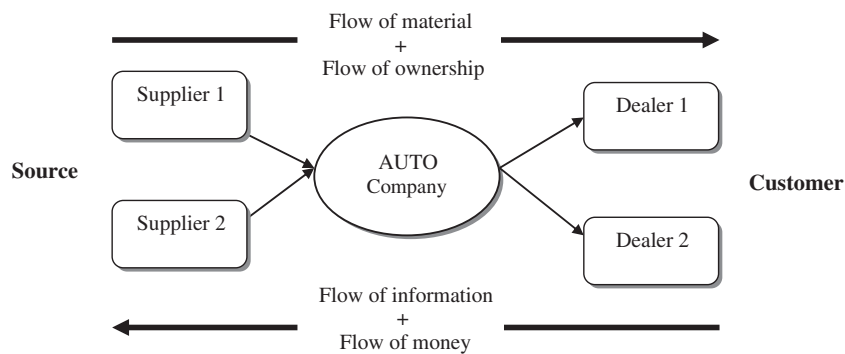


Fig. 2. Supply chain system.

time to bring new products to market, time to manufacture an existing product, and time to deliver a product to the customer (Jayaram, Vickery, & Droge, 1999; Tersine & Himmingbird, 1995).

2.3. Data accuracy (DA)

Data accuracy (DA) is one of the important factors, which influence the performance of a supply chain. It is defined as the accuracy of the data used by different trading partners in making their planning decision (Zhao, Xie, & Leung, 2002). In a supply chain, most of the retailers do not know their demand with certainty and they make their inventory decisions based on demand forecasts. With inaccurate forecasts, the quality of materials ordered does not match the demand. These errors in the retailer's forecasts are passed to the supplier in the form of distorted orders. The demand variability can be checked if data accuracy is maintained along the supply chain (Lee, Padmanabhan, & Wang, 1997).

2.4. New product introduction (NPI)

Ability to introduce new product has become very important for supply chains that want to have a competitive superiority. Initially quality was the model to follow in terms of competitive strategy; however, more recently, new product introduction has emerged as the winning strategy. This is especially important in a business (e.g., car) where product life cycles are relatively short (three years or less). Introducing a new product into the market can certainly bring significant benefits, including greater market share and higher price premiums, which will consequently result in higher profitability (Jayaram et al., 1999). Conversely, delaying the introduction of new products into the market can lead to negative consequences such as lower market share, lower margins, and may be most critical, the loss of customers' goodwill.

2.5. Centralized and collaborative planning (CCP)

Effective supply chain integration and synchronization among partners can eliminate excess inventory, reduce lead times, increase sales, and improve customer service (Agarwal & Shankar, 2002b; Anderson & Lee, 1999). Companies are now moving towards collaborative SCM in an effort to reduce the information imbalances that result in the dreaded "bullwhip effect" (Lee et al., 1997), while increasing their responsiveness to market demands and customer service (Mentzer, Foggin, & Golicic, 2000).

The result of collaborative SCM is not only the reduction of waste in the supply chain, but increased responsiveness, customer satisfaction, and competitiveness among all members of the partnership. Thus, collaborative SCM systems allow organizations to progress beyond mere operational-level information exchange and optimization and can transform a business and its partners into more competitive organizations (Christopher & Jittner, 2000).

2.6. Process integration (PI)

Shared information between supply chain partners is achieved by means of *process integration*. 'Process integration' means collaborative working between buyers and suppliers, joint product development, common systems and shared information (Christopher, 2000). This extended form of co-operation in the supply chain is becoming ever more prevalent as companies focus on managing their core competencies and outsource all other activities. In this new world of integration, a greater reliance on suppliers and alliance partners becomes inevitable and, hence, a new style of relationship is essential. In the 'extended enterprise' as it is often called, there can be no boundaries and an ethos of trust and commitment must prevail. Along with process integration comes joint strategy determination, buyer–supplier teams, transparency of information and even open-book accounting.

2.7. Use of IT tools (UIT)

The use of information technology to share data between buyers and suppliers is, in effect, creating a *virtual* supply chain. Virtual supply chains are information based rather than inventory based. Conventional logistics systems are based upon a paradigm that seeks to identify the optimal quantities of inventory and where it should be located. Complex formulae and algorithms exist to support this inventory-based business model. Paradoxically, what we are now learning is that once we have visibility of demand through shared information, the premise upon which these formulae are based no longer holds. Electronic Data Interchange (EDI) and the Internet have enabled partners in the supply chain to act upon the same data (i.e., actual sales figures) rather than to rely on the distorted and noisy picture that emerges in an extended supply chain (Lee, So, & Tang, 2000).

2.8. Lead time reduction (LTR)

Lead time reduction is the elapsed time from order to delivery. Lead-time reduction within the supply-production-distribution chain is the mechanism for time-based competition.

Management of time, specifically lead-time, can be a competitive advantage. To gain control over lead-time, the first step is an analysis of the status quo. The flow of material and information must be identified and lead-time separated into its various elements or components. Managing time is the mirror image of managing quality, cost, innovation and productivity. Reducing waste time automatically improves the other measures of performance in a multiplier fashion (Tersine & Himmingbird, 1995).

Reducing lead times in the largest link of the value-added chain is necessary but not sufficient for reducing lead times for the entire value-added chain. A comprehensive lead-time reduction strategy should attack all bottlenecks in the system, beginning with those most inhibitive to throughput.

2.9. Service level improvement (SLI)

Service level improvement is always cited as a key objective of supply chain management. Enhancement in service level

provided to customer leads to improvement in the supply chain performance. To achieve improved level of service, it is important for supply chain managers to manage customer service strategically and develop supply chain capabilities to deliver service viewed as important by critical downstream customers.

Customer service is frequently cited as an important objective of supply chain management (SCM). [Ellram \(1990\)](#) describes SCM as a means of maximizing “efficient use of resources in achieving the supply chain’s customer service goals”. [Stevens \(1990\)](#) describes the aim of SCM as that of achieving a “balance between the goals off high customer-service and low inventory–investment/low unit-cost goals”.

2.10. Cost minimization (COM)

Cost minimization helps firms to reduce costs by identifying ways to make the interface between the firms more efficient and by helping firms and its trading partners to find additional ways to cut the manufacturing costs of the products. In the most of the cases, advantages from management accounting practice have limited scope within the boundaries of the firm. This limitation makes it difficult for the firm to take advantage of any cost-reduction synergies that exists across the traditional supply chain. Such synergies can only be achieved by coordinating the cost-reduction activities of multiple firms. The objective of inter-organizational cost management programs is to find lower-cost solutions than would be possible if the firm and its buyers and suppliers attempted to reduce costs independently ([Cooper & Slagmulder, 1998](#)).

The supply chains must strive to manage costs associated with their products/service delivery system, the goal should be to increase customer satisfaction not merely minimize supply chain cost. Traditional cost management systems often legitimize supply chain activities that result in localized cost minimization that inhibit the supply chain’s ability to meet customer expectations.

2.11. Customer satisfaction (CUS)

Customer satisfaction is the customer’s reaction to the value received from the purchase or utilization of the offering. Customer satisfaction represents the customer’s reaction to his or her perception of the value received as a result of using a particular product or service. That reaction will be influenced by the desired value (ideal standard) as well as by the perceived value of competitive offerings (industry norms, expectations based on use of competitor products). Thus customer satisfaction is influenced by the perception of the value delivered as well as by the perception of the value offered by competition.

Today customers are from every corners of the world; the supply chain strategy should have focus towards satisfying the customers. With out satisfied customer, the whole exercise of applying the supply chain strategy could be costly and futile ([Gunasekaran, Patel, & Tirtiroglu, 2001](#)). For improving performance, supply chain metrics must be linked to customer satisfaction ([Lee & Billington, 1992](#)). This measurement is needed to integrate the customer specification in design, to set

the dimensions of quality, for cost control, and as a feedback for the control of process.

2.12. Quality improvement (QI)

Quality improvement is recognized by Management of worldwide business enterprises as a requirement to succeed in the competitive international marketplace. They also realize that the involvement of suppliers is critical to improve quality and meet customer specifications. They cannot maximize value to customers if components from their suppliers are defective and late. To gain this productive involvement, they have been advised to develop relationships with suppliers. Indeed, the creation and enhancement of effective customer–supplier partnership is a major quality practice that has long been prescribed as an indispensable part of any organization total quality management system ([Gunasekaran & McGaughey, 2003](#)). However, the exact nature of these relationships and how they can be established remain un-clarified. The study proposes that manufacturers and suppliers with co-operative compared with competitive and independent goals discuss quality issues openly and develop trusting, long-term relationships which in turn increase the supplier’s contributions to total quality improvement efforts. According to [Beamon and Ware \(1998\)](#) improving the quality of all supply chain processes result in reduced costs, improved resource utilization, and improved process efficiency.

2.13. Minimizing uncertainty (MU)

Supply chain is always linked with an uncertain external environment by customer demand from one-side and raw material suppliers from other side ([Prater et al., 2001](#)). Traditionally, attention has been focused on uncertainty in customer demand; however, uncertainty is also inherent in market at supply side. The quality and quantity of raw material delivered from an external supplier may differ from those requested. Uncertainty propagates through the supply chain and leads to inefficient processing and non-value adding activities. [Mason-Jones and Towill \(1999\)](#) give significant importance to minimization of uncertainty to get internationally competitive performance.

2.14. Trust development (TD)

Trust is defined as the binding force in most buyer–supplier transaction ([Agarwal & Shankar, 2003](#)). It is especially critical when two situational forces are present in a transaction: uncertainty; and asymmetric product information. Many researchers have proposed that trust is essential for understanding interpersonal behavior and economic exchanges. Trust is perceived as a state of readiness for unguarded interaction with someone or something ([Ba, 2001](#)).

[Handfield and Bechtel \(2002\)](#) have stated that the primary relational requirement for improved responsiveness is the development of greater levels of trust between purchasing organizations and their suppliers. The nature of trust and the nature of business transaction often temper the relationships.

Trust among trading partners in inter-organizational relationships improves communication and dialogue and create common strategic visions (Heide & John, 1990).

2.15. Minimizing resistance to change (MRTC)

Resistance has been classically understood as a foundation cause of conflict that is undesirable and detrimental to the health of any enterprise (Waddell & Sohal, 1998). Resistance to change has long been recognized as a critically important factor that can influence the success or otherwise of an organizational change effort.

Similarly, resistance, among trading partners of supply chain, is an expression of reservation, which normally arises as a response or reaction to change. Management of SC normally witnesses this expression, as any trading partner's actions are perceived as attempting to stop, delay, or alter change (Handfield & Bechtel, 2002). Thus resistance is most commonly linked with negative trading partner attitudes or with counter-responsive behaviors. Resistance to change can be handled when there is trust development among trading partners and they are involved in the strategic planning.

3. Methodology

Interpretive structural modeling (ISM) is an interactive learning process in which a set of different and directly related elements is structured into a comprehensive systemic model (Warfield, 1974; Sage, 1977). The model so formed portrays the structure of a complex issue or problem, a system or a field of study, in a carefully designed pattern implying graphics as well as words. ISM methodology helps to impose order and direction on the complexity of relationships among elements of a system. In the literature various applications of ISM have been found which are depicted in Table 2.

Interpretive structural modeling (ISM) helps in identifying the inter-relationships among variables. It is a suitable modeling technique for analyzing the influence of one variable on other variables. It provides systemic approach for improving supply chain agility.

ISM is primarily intended as a group learning process. The method is interpretive as the judgment of the group decides whether and how the variables are related. It is structural as on the basis of relationship, an overall structure is extracted from the complex set of variables. It is a modeling technique as the specific relationships and overall structure is portrayed in a digraph model.

ISM starts with an identification of variables, which are relevant to the problem or issue and then extends with a group problem-solving technique. Then a contextually relevant subordinate relation is chosen. Having decided on the element set and the contextual relation, a structural self-interaction matrix (SSIM) is developed based on pair-wise comparison of variables. In the next step, the SSIM is converted into a reachability matrix and its transitivity is checked. Once transitivity embedding is complete a matrix model is obtained. Then, the partitioning of the elements and an extraction of the structural model, called ISM is derived.

Table 2
Applications of ISM

S.N.	Contributors	Areas in which ISM has been applied
1	Saxena et al., 1990	Energy conservation in Indian cement industry
2	Saxena, Sushil, & Vrat, 1992	Waste management in India
3	Sharma et al., 1995	Vendor selection
4	Mandal & Deshmukh, 1994	Knowledge management (KM) in manufacturing industries
5	Singh et al., 2003	Reverse logistics
6	Ravi & Shankar, 2005	IT-enabled supply
7	Jharkaria & Shankar, 2005	Improving decision making process among executives working in different functional areas
	Bolanos, Fontela, Nenclares, & Paster, 2005	

In this research, interpretive structural modeling (ISM) has been applied to develop a framework for a case supply chain to achieve the following broad objectives:

- to derive interrelationships among the variables affecting supply chain agility, and
- to classify the variables according to their driving and dependence power.

In the present paper, ISM has been applied to show the inter-relationships of different variables of supply chain agility.

Various steps involved in the ISM technique are illustrated in Fig. 3 (Singh, Shankar, Narain, & Agarwal, 2003).

To obtain correlation matrix for supply chain agility variables, questionnaires were sent to original equipment manufactures (OEM) and their suppliers. Out of the 760 questionnaires sent, 179 usable responses have been received, resulting in a 23.55% response rate. This response rate is considered adequate for such surveys (Malhotra & Grover, 1998). Cronbach's coefficient (α) for the questions related to supply chain agility variables is calculated to test the reliability and internal consistency of the responses. The value of α for this is found to be 0.85. Out of the 179 usable responses, original equipment manufactures (OEM) are 41% while suppliers are 59%.

The correlation matrix for the variables is used together with the experts' opinion, in defining the mutual relationships.

3.1. Structural self-interaction matrix (SSIM)

Variables of supply chain agility are already discussed in previous section and are: market sensitiveness (1), delivery speed (2), data accuracy (3), new product introduction (4), centralized and collaborative planning (5), process integration (6), use of IT tools (7), lead-time reduction (8), service level improvement (9), cost minimization (10), customer satisfaction (11), quality improvement (12), minimizing uncertainty (13), trust development (14), and minimizing resistance to change (15).

For analysing variables of supply chain agility, a contextual relationship of "leads to" type is chosen. This means that one variable leads to another variable.

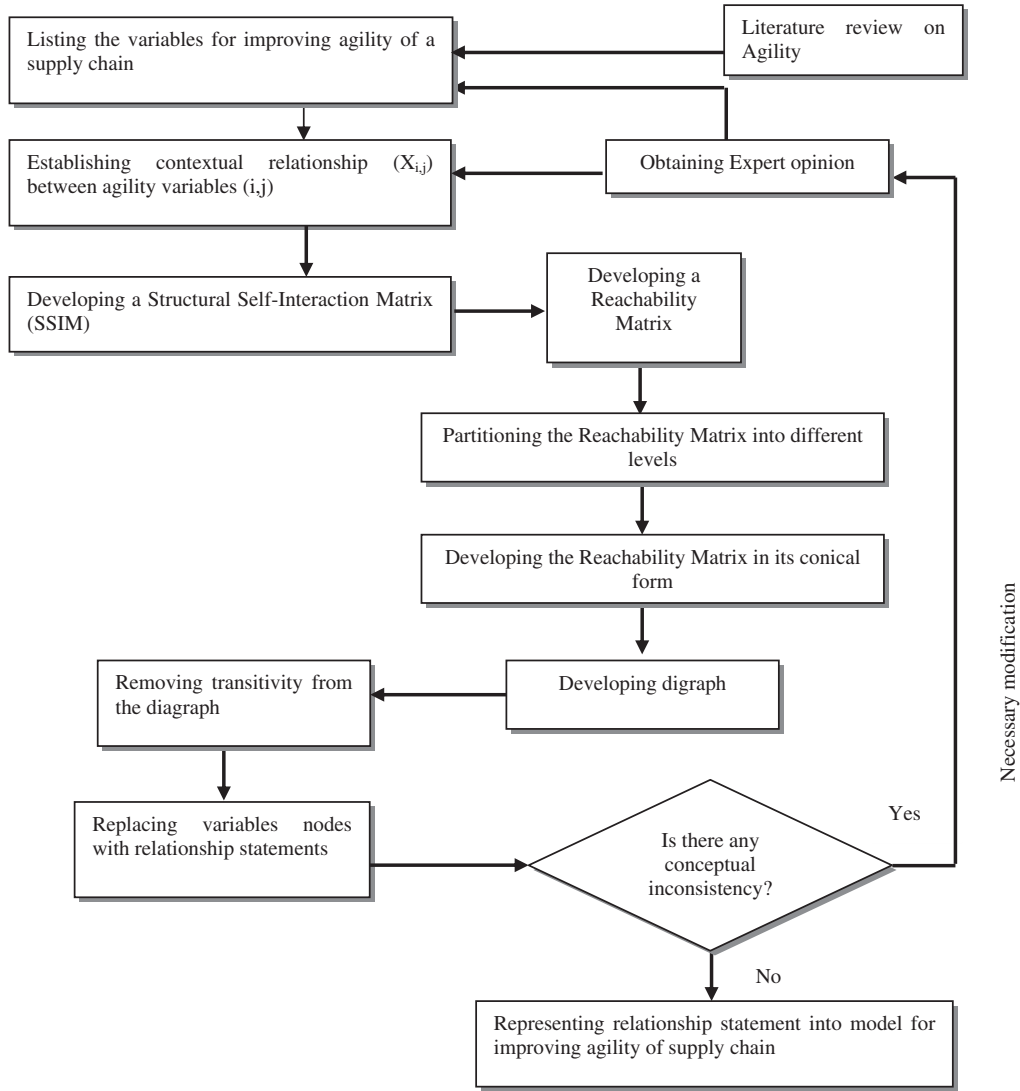


Fig. 3. Flow diagram for preparing ISM.

Keeping in mind the contextual relationship for each variable, the existence of a relation between any two sub-variables (*i* and *j*) and the associated direction of the relation

is questioned. Four symbols are used for the type of the relation that exists between the two sub-variables under consideration:

Table 3
Structural self-interaction matrix (SSIM)

Elements	15	14	13	12	11	10	9	8	7	6	5	4	3	2
1	A	A	A	O	V	O	O	V	A	A	A	V	A	V
2	A	A	A	O	V	O	V	A	A	A	A	O	A	
3	A	A	A	V	O	O	O	V	A	O	O	O	O	
4	A	A	A	O	V	O	O	O	A	A	A			
5	V	V	V	O	O	V	O	V	V	X				
6	V	V	V	O	O	V	O	V	V					
7	V	V	V	O	O	O	O	V						
8	O	O	O	V	V	V	V							
9	O	O	O	O	V	O								
10	O	O	O	O	X									
11	O	O	O	A										
12	O	O	O											
13	X	X												
14	X													

- V— variable *i* will help to achieve variable *j*;
- A— variable *j* will be achieved by variable *i*;
- X— variables *i* and *j* will help achieve each other; and
- O— variables *j* and *i* are unrelated.

The following statements explain the use of symbols V, A, X and O in SSIM (Table 3).

- (i) According to experts opinion market sensitiveness (1) and quality improvement (12) are unrelated; therefore O is assigned to cell at intersection of row of market sensitiveness (1) and column of quality improvement (12).
- (ii) Market sensitiveness (1) helps to achieve customer satisfaction (11); hence V is assigned to the cell at intersection of market sensitiveness (1) row and customer satisfaction (11) column.

(iii) Delivery speed (2) will be achieved by data accuracy (3); hence A is assigned in the cell at intersection of data accuracy row and delivery speed column.

Similarly, centralized and collaborative planning (5) helps in process integration (6), and process integration initiates centralized and collaborative planning, therefore X is assigned in the cell at intersection of centralized and collaborative planning row and process integration column.

Based on these contextual relationships the SSIM is developed (Table 3).

3.2. Reachability matrix

The SSIM format is transformed into a reachability matrix format by transforming the information in each entry of the SSIM into 1s and 0s in the reachability matrix.

The situations are as follows:

1. If the (i, j) entry in the SSIM is V, then 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, then the (i, j) entry in the matrix becomes 0 and the (j, i) entry becomes 1.
3. If the (i, j) entry in the SSIM is X, then the (i, j) entry in the matrix becomes 1 and the (j, i) entry also becomes 1.
4. If the (i, j) entry in the SSIM is O, then the (i, j) entry in the matrix becomes 0 and the (j, i) entry also becomes 0.

Following these rules, initial reachability matrix for the variables is prepared as shown in Table 4.

1* entries are included to incorporate transitivity to fill the gap if any in the opinion collected during development of structural self-instructional matrix. The Final reachability matrix is presented in Table 5.

3.3. Partitioning the reachability matrix

The matrix is partitioned, by assessing the reachability and antecedent sets for each variable (Warfield, 1974). The

Table 4
Initial reachability matrix

Elements	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	0	1	0	0	0	1	0	0	1	0	0	0	0
2	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0
3	1	1	1	0	0	0	0	1	0	0	0	1	0	0	0
4	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
5	1	1	0	1	1	1	1	1	0	1	0	0	1	1	1
6	1	1	0	1	1	1	1	1	0	1	0	0	1	1	1
7	1	1	1	1	0	0	1	1	0	0	0	0	1	1	1
8	0	1	0	0	0	0	0	1	1	1	1	1	0	0	0
9	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
10	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
11	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
13	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1
14	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1
15	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1

Table 5
Final reachability matrix

Elements	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	0	1	0	0	0	1	1*	1*	1	1*	0	0	0
2	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0
3	1	1	1	1*	0	0	0	1	1*	0	1*	1	0	0	0
4	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
5	1	1	1*	1	1	1	1	1	1*	1	1*	1*	1	1	1
6	1	1	1*	1	1	1	1	1	1*	1	1*	0	1	1	1
7	1	1	1	1	0	0	1	1	1*	1*	1*	1*	1	1	1
8	0	1	0	0	0	0	0	1	1	1	1	1	0	0	0
9	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
10	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
11	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
13	1	1	1	1	0	0	0	1*	1*	0	1*	1*	1	1	1
14	1	1	1	1	0	0	0	1*	1*	0	1*	1*	1	1	1
15	1	1	1	1	0	0	0	1*	1*	0	1*	1*	1	1	1

reachability set consists of the element itself and other elements, which it may help to achieve, whereas the antecedent set consists of the element itself and other elements, which may help achieving it. Then the intersection of these sets is derived for all the elements. The elements for which the reachability and intersection sets are same are the top-level elements in the ISM hierarchy. The top-level elements of the hierarchy would not help to achieve any other element above their own level in the hierarchy. Once top-level elements are identified, it is separated out from the rest of the elements. Then, the same process is repeated to find the next level of elements. These identified levels help in building the digraph and final model. In the present case, the variables along with their reachability set, antecedent set, intersection set and the levels are shown in Table 6. The process is completed in nine iterations (Tables 6–13) as follows:

In Table 6, the element 10 (cost minimization), element 11 (customer satisfaction), and element 12 (quality improvement) are found at level I. Thus, they will be positioned at the top of hierarchy of the ISM model.

After removing elements 10, 11 and 12 from Table 6, we get second and third column of Table 7.

In Table 7, the element 4 (new product introduction) and element 9 (service level improvement) are put at level II. Thus, it will be positioned at the level II in the ISM model. After removing elements 4 and 9 from Table 7, the second and third columns of Table 8 are obtained. The process is repeated till Table 14.

In Table 15, elements 10 (cost minimization), 11 (customer satisfaction), and 12 (quality improvement) are put at level I. These elements will be positioned at the top of ISM in the digraph. Elements 4 (new product introduction) and 9 (service level improvement) are at level II. Delivery speed (element 2) comes at level III. Element 8 (lead-time reduction) is at level IV. Market sensitiveness (element 1) and data accuracy (element 3) emerge at level V and VI, respectively. Seventh iteration brings minimizing uncertainty (element 13), trust development (element 14), and minimizing resistance to

Table 6
Iteration I

Element (P_i)	Reachability set: $R(P_i)$	Antecedent set: $A(P_i)$	Intersection $R(P_i) \cap A(P_i)$	Level
1	1,2,4,8,9,10,11,12	1,3,5,6,7,13,14,15	1	
2	2,9,11	1,2,3,5,6,7,8,13,14,15	2	
3	1,2,3,4,8,9,11,12	3,5,6,7,13,14,15	3	
4	4,11	1,3,4,5,6,7,13,14,15	4	
5	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	5,6	5,6	
6	1,2,3,4,5,6,7,8,9,10,11,13,14,15	5,6	5,6	
7	1,2,3,4,7,8,9,10,11,12,13,14,15	5,6,7	7	
8	2,8,9,10,11,12	1,3,5,6,7,8,13,14,15	8	
9	9,11	1,2,3,5,6,7,8,9,13,14,15	9	
10	10,11	1,5,6,7,8,10,11	10,11	I
11	10,11	1,2,3,4,5,6,7,8,9,10,11,13,14,15	10,11	I
12	11,12	1,3,5,7,8,11,12,13,14,15	11,12	I
13	1,2,3,4,8,9,11,12,13,14,15	5,6,7,13,14,15	13,14,15	
14	1,2,3,4,8,9,11,12,13,14,15	5,6,7,13,14,15	13,14,15	
15	1,2,3,4,8,9,11,12,13,14,15	5,6,7,13,14,15	13,14,15	

Table 7
Iteration II

Element (P_i)	Reachability set: $R(P_i)$	Antecedent set: $A(P_i)$	Intersection $R(P_i) \cap A(P_i)$	Level
1	1,2,4,8,9	1,3,5,6,7,13,14,15	1	
2	2,9	1,2,3,5,6,7,8,13,14,15	2	
3	1,2,3,4,8,9	3,5,6,7,13,14,15	3	
4	4	1,3,4,5,6,7,13,14,15	4	II
5	1,2,3,4,5,6,7,8,9,13,14,15	5,6	5,6	
6	1,2,3,4,5,6,7,8,9,13,14,15	5,6	5,6	
7	1,2,3,4,7,8,9,13,14,15	5,6,7	7	
8	2,8,9	1,3,5,6,7,8,13,14,15	8	
9	9	1,2,3,5,6,7,8,9,13,14,15	9	II
13	1,2,3,4,8,9,13,14,15	5,6,7,13,14,15	13,14,15	
14	1,2,3,4,8,9,13,14,15	5,6,7,13,14,15	13,14,15	
15	1,2,3,4,8,9,13,14,15	5,6,7,13,14,15	13,14,15	

change (element 15) at level VII. Final iteration brings out level VIII elements as centralized and collaborative planning (5), process integration (6), and use of IT tools (7).

3.4. Developing conical matrix

A conical matrix is developed by clustering variables in the same level, across rows and columns of the final reachability matrix, as shown in Table 16.

Table 8
Iteration III

Element (P_i)	Reachability set: $R(P_i)$	Antecedent set: $A(P_i)$	Intersection $R(P_i) \cap A(P_i)$	Level
1	1,2,8	1,3,5,6,7,13,14,15	1	
2	2	1,2,3,5,6,7,8,13,14,15	2	III
3	1,2,3,8	3,5,6,7,13,14,15	3	
5	1,2,3,5,6,7,8,13,14,15	5,6	5,6	
6	1,2,3,5,6,7,8,13,14,15	5,6	5,6	
7	1,2,3,7,8,13,14,15	5,6,7	7	
8	2,8	1,3,5,6,7,8,13,14,15	8	
13	1,2,3,8,13,14,15	5,6,7,13,14,15	13,14,15	
14	1,2,3,8,13,14,15	5,6,7,13,14,15	13,14,15	
15	1,2,3,8,13,14,15	5,6,7,13,14,15	13,14,15	

4. Development of digraph

Based on the conical form of reachability matrix, the initial digraph including transitive links is obtained. After removing indirect links, the final digraph is obtained, as shown in Fig. 4.

From Fig. 4, it is observed that centralized and collaborative planning (5), process integration (6), and use of IT tools (7) play significant driving role in improving agility for supply chain and they come at the base of ISM hierarchy. Cost minimization (10), customer satisfaction (11), and quality improvement (12)

Table 9
Iteration IV

Element (P_i)	Reachability set: $R(P_i)$	Antecedent set: $A(P_i)$	Intersection $R(P_i) \cap A(P_i)$	Level
1	1,8	1,3,5,6,7,13,14,15	1	
3	1,3,8	3,5,6,7,13,14,15	3	
5	1,3,5,6,7,8,13,14,15	5,6	5,6	
6	1,3,5,6,7,8,13,14,15	5,6	5,6	
7	1,3,7,8,13,14,15	5,6,7	7	
8	8	1,3,5,6,7,8,13,14,15	8	IV
13	1,3,8,13,14,15	5,6,7,13,14,15	13,14,15	
14	1,3,8,13,14,15	5,6,7,13,14,15	13,14,15	
15	1,3,8,13,14,15	5,6,7,13,14,15	13,14,15	

Table 10
Iteration V

Element (P_i)	Reachability set: $R(P_i)$	Antecedent set: $A(P_i)$	Intersection $R(P_i) \cap A(P_i)$	Level
1	1	1,3,5,6,7,13,14,15	1	V
3	1,3	3,5,6,7,13,14,15	3	
5	1,3,5,6,7,13,14,15	5,6	5,6	
6	1,3,5,6,7,13,14,15	5,6	5,6	
7	1,3,7,13,14,15	5,6,7	7	
13	1,3,13,14,15	5,6,7,13,14,15	13,14	
14	1,3,13,14,15	5,6,7,13,14,15	13,14	
15	1,3,13,14,15	5,6,7,13,14,15	13,14,15	

are variables, which depend on other variables for agility improvement. These variables have appeared at the top of the hierarchy. Effective centralized and collaborative planning (5), process integration (6), and use of IT tools (7) provide an environment which help in reducing uncertainty, developing trust among trading partners and minimizing resistance to change. This helps in improving data accuracy (3) and market sensitiveness (1).

Effective lead-time reduction (8) is achieved with improved level of data accuracy and market sensitiveness. Delivery speed (2) for supply chain enhances as a result of effective lead-time reduction. Minimizing uncertainty helps management to concentrate on introducing new and innovative products in the market. Delivery speed provides better service level, which results into improved level in customer satisfaction (11). Lead-time reduction minimizes all sort of waste including time; therefore experts feel that improvement in quality level (12) can be achieved with effective lead-time reduction. Improvement in customer satisfaction level is also achieved with better quality level.

Trust development (element 14) also influences data accuracy (element 3). Improved level of trust among trading partners helps in providing accurate data at various links of the supply chain (Ellram, 1991). Minimizing resistance to change among trading partners helps in improving market sensitiveness. Lead-time reduction (8) influences cost minimization (10). This implies that a sound strategic planning for lead-time reduction is a prerequisite to effective cost minimization. Use of IT tools (7) is helpful in centralized and collaborative planning (5), and process integration (6). Experts feel that use of IT tools, centralized and collaborative planning, and process integration help to develop integration of links within the supply chain.

Table 11
Iteration VI

Element (P_i)	Reachability set: $R(P_i)$	Antecedent set: $A(P_i)$	Intersection $R(P_i) \cap A(P_i)$	Level
3	3	3,5,6,7,13,14,15	3	VI
5	3,5,6,7,13,14,15	5,6	5,6	
6	3,5,6,7,13,14,15	5,6	5,6	
7	3,7,13,14,15	5,6,7	7	
13	3,13,14,15	5,6,7,13,14,15	13,14,15	
14	3,13,14,15	5,6,7,13,14,15	13,14,15	
15	3,13,14,15	5,6,7,13,14,15	13,14,15	

Table 12
Iteration VII

Element (P_i)	Reachability set: $R(P_i)$	Antecedent set: $A(P_i)$	Intersection $R(P_i) \cap A(P_i)$	Level
5	5,6,7,13,14,15	5,6	5,6	
6	5,6,7,13,14,15	5,6	5,6	
7	7,13,14,15	5,6,7	7	
13	13,14,15	5,6,7,13,14,15	13,14,15	VII
14	13,14,15	5,6,7,13,14,15	13,14,15	VII
15	13,14,15	5,6,7,13,14,15	13,14,15	VII

From the ISM, it is also observed that while planning for SC improvement, management of the supply chain should deploy strategies for an effective use of IT tools, centralized and collaborative planning, and process integration.

5. MICMAC analysis

The objective of MICMAC analysis (Mandal & Deshmukh, 1994; Saxena, Sushil, & Vrat, 1990; Sharma, Gupta, & Sushil, 1995) in this study is to identify and to analyze the variables according to their driving power and dependence power towards supply chain agility.

In the Table 17, an entry of “1” along the columns and rows indicates the dependence and driving power, respectively.

The variables are categorized into ranks. For example, element 4 has fourth rank in dependence and ninth in driving power; while element 2 has third rank in dependence and eighth rank in driving power. When variables are placed according to their driving and dependence power, variables are grouped into four clusters. Four clusters are presented in Fig. 5.

First cluster includes variables that have weak driver power and weak dependence. These variables are relatively disconnected from the system, with which they have only few links, which may be strong. These are autonomous variables. Second cluster consists of variables that have weak driving power but strong dependence. These are termed as dependent variables. Variables in third cluster have strong driving power and strong dependence. These variables fall into the category of independent or linkage variables. These variables are unstable. Any action on these variables will have an effect on others and also a feed back effect on themselves. Fourth cluster includes independent variables having strong driving power but weak dependence. Use of IT tools (7), centralized and collaborative planning (5), process integration (6), minimizing uncertainty (13), trust development (14) and minimizing resistance to change (15) come under category IV and therefore categorized as independent drivers. There is no linkage variable having strong driving and strong dependence power. Market

Table 13
Iteration VIII

Element (P_i)	Reachability set: $R(P_i)$	Antecedent set: $A(P_i)$	Intersection $R(P_i) \cap A(P_i)$	Level
5	5,6,7	5,6	5,6	VIII
6	5,6,7	5,6	5,6	VIII
7	5,6,7	7	7	

Table 14
Iteration IX

Element (P_i)	Reachability set: $R(P_i)$	Antecedent set: $A(P_i)$	Intersection $R(P_i) \cap A(P_i)$	Level
7	7	7	7	IX

sensitiveness (1), data accuracy (3), and cost minimization (10) are autonomous variables and are kept under cluster I. Delivery speed (2), new product introduction (4), lead-time reduction (8), service level improvement (9), customer satisfaction (11), and quality improvement (12) are kept under the cluster of dependent variables.

6. Discussion

The results of the study indicate that supply chain agility depends on customer satisfaction, quality improvement, cost minimization, delivery speed, new product introduction, service level improvement, and lead-time reduction. The top-level variables, having weak driving power, have strong dependence on other variables. Christopher and Towill (2001), Van Hoek et al., (2001), and Mason, Cole, Ulrey, and Yan (2002) have reported that agility of supply chain is influenced by quality improvement, cost minimization, lead-time reduction, and service level improvement. These variables depend on other variables like information enrichment, networking and collaboration across the supply chain (Christopher, 2000). Bottom level variables use of IT tools, centralized and collaborative planning, and process integration are considered as strong drivers of supply chain agility (Yusuf et al., 2004). These variables help to achieve improvement in variables like minimizing uncertainty, trust development, and minimizing resistance to change (Prater et al., 2001). Data accuracy, and market sensitiveness are the middle level variables. Performance of these variables can only be improved when improvement in bottom level variables is achieved (Katayama and Bennet 1999; Power et al., 2001; Yusuf et al., 2004). Improvement in middle level variables helps to achieve top-level variables. Improved level of top-level variables helps

Table 16
Conical form of reachability matrix

Elements	10	11	12	4	9	2	8	1	3	13	14	15	5	6	7
10	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
11	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
4	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
9	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
2	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0
8	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
3	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0
13	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0
14	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
15	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1

to enhance supply chain agility. Therefore, management of the case supply chain should focus its attention to build up a strong network of trading partners through better use of IT tools, centralized and collaborative planning, and process integration. They should adopt strategies to achieve better quality, higher service level, improved customer satisfaction, fast delivery and, new product introduction.

Similar inter-dependent action plans could emerge out of the combinations of these variables. For example, data accuracy (element 3), market sensitiveness (element 1) and lead-time reduction (element 8) are variables having a medium driver power and medium dependence. These variables need consistent attention of the management in enhancing supply chain agility. Management should always keep a watch on the level of these variables. Slight variation in the level of these variables may severely affect the agility of the supply chain.

Variables like use of IT tools (element 7), centralized and collaborative planning (element 5), process integration (element 6), minimizing uncertainty (element 13), trust development (element 14), and minimizing resistance to change (element 15) are agility variables having strong driving power. These variables

Table 15
Levels of SC agility variables

Element (P_i)	Reachability set: $R(P_i)$	Antecedent set: $A(P_i)$	Intersection $R(P_i) \cap A(P_i)$	Level
1	1,2,4,8,9,10,11,12	1,3,5,6,7,13,14,15	1	V
2	2,9,11	1,2,3,5,6,7,8,13,14,15	2	III
3	1,2,3,4,8,9,11,12	3,5,6,7,13,14,15	3	VI
4	4,11	1,3,4,5,6,7,13,14,15	4	II
5	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	5,6	5,6	VIII
6	1,2,3,4,5,6,7,8,9,10,11,13,14,15	5,6	5,6	VIII
7	1,2,3,4,7,8,9,10,11,12,13,14,15	5,6,7	7	IX
8	2,8,9,10,11,12	1,3,5,6,7,8,13,14,15	8	IV
9	9,11	1,2,3,5,6,7,8,9,13,14,15	9	II
10	10,11	1,5,6,7,8,10,11	10,11	I
11	10,11	1,2,3,4,5,6,7,8,9,10,11,13,14,15	10,11	I
12	11,12	1,3,5,7,8,11,12,13,14,15	11,12	I
13	1,2,3,4,8,9,11,12,13,14,15	5,6,7,13,14,15	13,14,15	VII
14	1,2,3,4,8,9,11,12,13,14,15	5,6,7,13,14,15	13,14,15	VII
15	1,2,3,4,8,9,11,12,13,14,15	5,6,7,13,14,15	13,14,15	VII

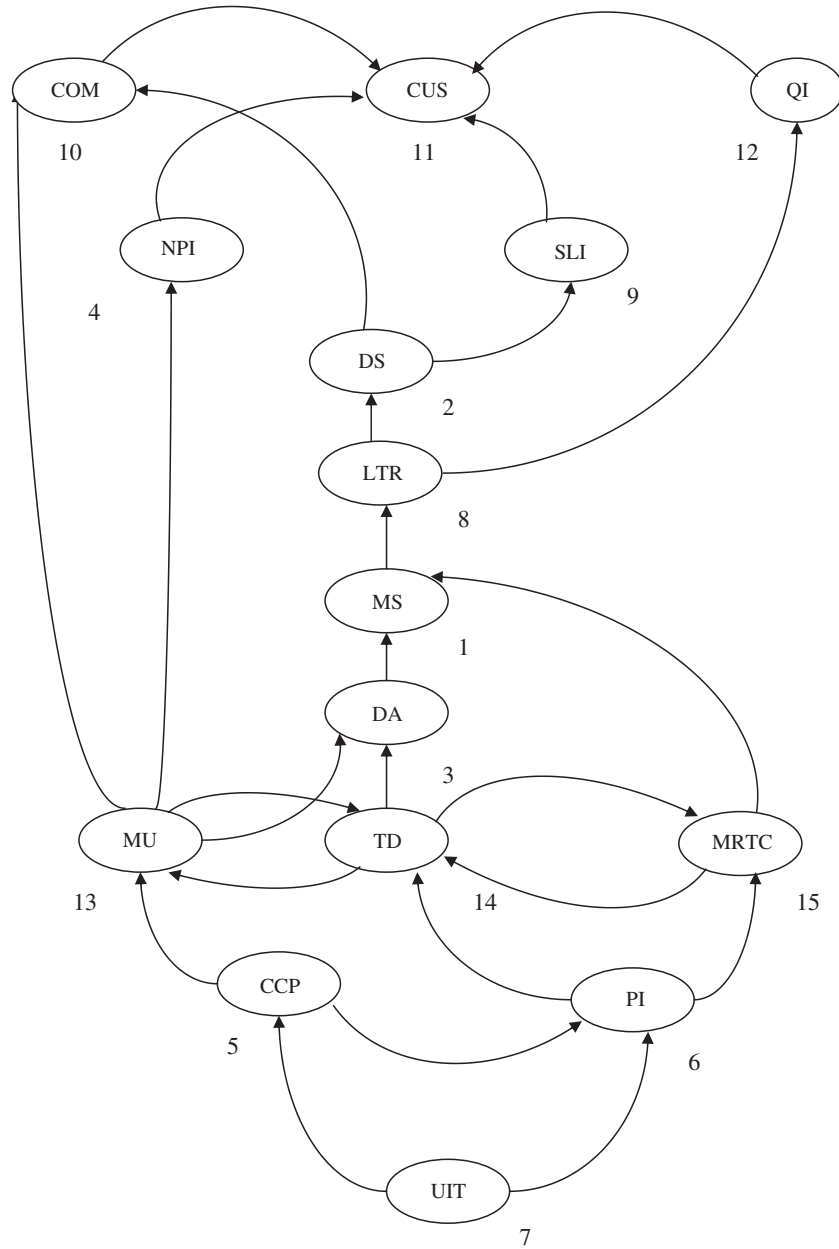


Fig. 4. ISM-based model of the variables for improving supply chain agility after removing indirect links.

have the capability to condition the whole supply chain and can be called independent elements or drivers of supply chain agility.

7. Limitations and scope for future work

In the present work only fifteen variables are identified for modeling the agility of a supply chain. More number of variables affecting supply chain agility can be identified to develop ISM. The experts’ help have been sought to analyze driving and dependence power of the variables of supply chains agility. Here the framework developed depends upon the opinion of few supply chain experts and has some element of bias. Through ISM, a relationship model among supply chain agility variables has been developed. This model has not been statistically validated. LISREL software can be used to examine

the relationships derived from this model. Structural equation modeling (SEM), also commonly known as linear structural relationship approach has the capability of testing the validity of such hypothetical model. Therefore, it may be applied in the future research to test the validity of this model.

8. Conclusion

To formulate strategies for building agility in supply chain, it is important for the management of a supply chain to understand characteristics and interrelationship of variables. In the proposed model, data accuracy is affected by other variables such as use of IT tools, centralized and collaborative planning, process integration, minimizing uncertainty, reducing resistance to change, and development of trust. However, it acts as a driver for market

Table 17
Driving power and dependence in reachability matrix

Elements	10	11	12	4	9	2	8	1	3	13	14	15	5	6	7	Driving power	Ranks
10	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	VIII
11	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	VIII
12	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2	VIII
4	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2	VIII
9	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2	VIII
2	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	3	VII
8	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	6	VI
1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	8	V
3	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	8	V
13	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	11	IV
14	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	11	IV
15	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	11	V
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15	I
6	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	14	II
7	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	13	III
Dependence Ranks	7	15	9	9	11	10	9	8	7	6	6	6	2	2	3		
	VI	I	IV	IV	II	III	IV	V	VI	VII	VII	VII	IX	IX	VIII		

sensitive supply chain and thus helps to quickly respond to the market demand. Strategy to cope up with resistance to change among trading partners helps to improve market sensitiveness, which supports supply chain agility. Ability to introduce new product in the market is governed by capability to visualize and manage the uncertainties. Uncertainty could be better managed if supply chain has centralized and collaborative planning which need to be supported by the effective use of IT tools. Trust among trading partners could be developed by process integration and centralized and collaborative planning. Trust development among trading partners helps to generate reliable data at each stage of the supply chain. All three variables namely, use of IT tools, centralized and collaborative planning, and

process integration are significant drivers hence they must be at the top priority for an agile supply chain.

Lead-time reduction is another important variables for agility of a supply chain. It is driven by the market sensitiveness of the supply chain. Lead-time reduction helps to make delivery fast, which further improves service level. New product introduction and service level improvement enhance the customer satisfaction level. Increase customer satisfaction level would help to improve the market share of supply chain business. Lead-time reduction would also help to improve quality level by reducing different types of waste. Customer satisfaction improves with better quality level. Quality improvement is captured in the present model by considering the customer satisfaction level,

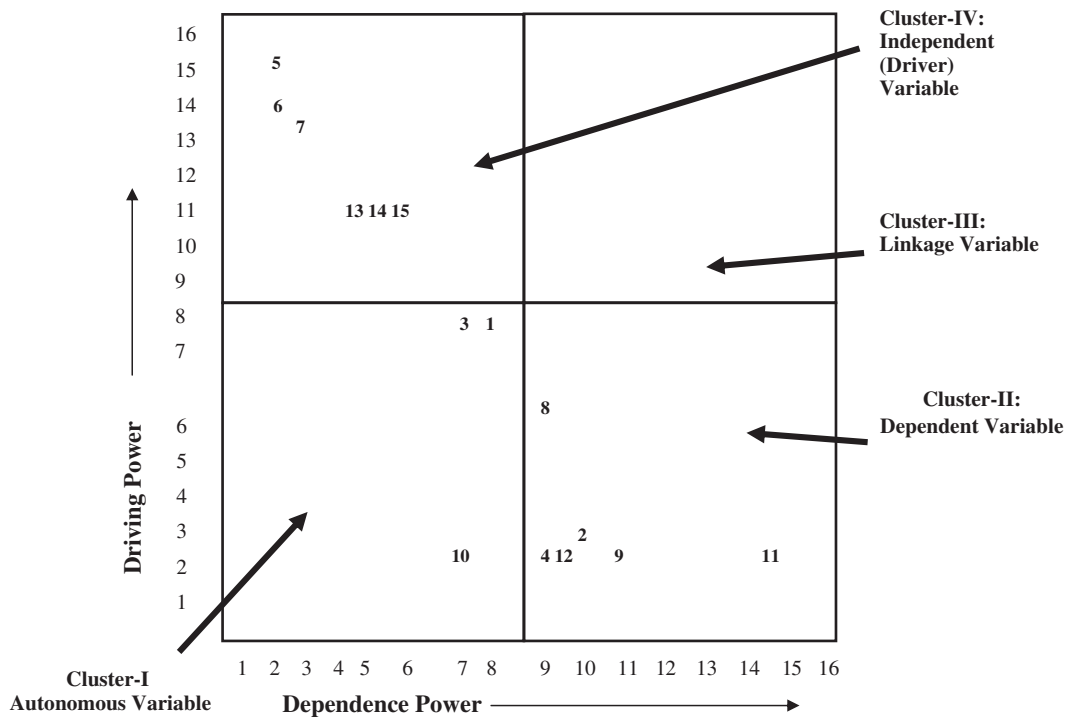


Fig. 5. Cluster of variables for improving supply chain agility.

which is also necessary to gain market share. Variables like use of IT tools, centralized and collaborative planning and process integration have relatively low dependence and thus appears at bottom level of hierarchy in ISM. This implies that use of IT tools, centralized and collaborative planning, and process integration play significant role and work as the driver in effective supply chain integration. Integrated supply chain is capable of responding to customer demand in a volatile market.

ISM developed in this paper acts as a tool for top management to understand the variables of an agile supply chain. Though ISM is developed on the basis of perception of the experts of supply chains, the results are quite generic and helpful for the top management to drive the efforts towards the roots of the problem. ISM approach leads us to the variables where fruitful results in terms of market share improvement can be achieved. ISM developed in this paper is not specific to any sector and specific model for any other sector may differ slightly from the model developed in this paper.

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