A systematic approach to evaluate supply chain management environment index using graph theoretic approach

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Abstract: The performance of a supply chain is characterised by its ability to remain market-sensitive without losing the integration through the chain. One of the difficulties in designing and analysing a supply chain is that its processes are governed by the strategic factors of the supply chain. With the emergence of a business era that embraces change as one of its major characteristics, increasing the market share and survival are becoming more and more difficult to ensure. The emphasis is on adaptability to changes in the business environment and on addressing market and customer needs proactively. This paper is identifying the supply chain management from the perspective of digraph approach. An attempt has been made to identify through literature review of 150 papers contain 65 factors and understanding the interrelationship among these factors, sub-factors to design a mathematical model using graph theory approach. This paper attempts to consider factors and sub-factors from a system point of view.

Keywords: supply chain management; SCM; supply chain management environment; SCME; service quality in supply chain; SQSC; graph theoretic approach; GTA.


Biographical notes: Tarun Kumar Gupta is an Associate Professor in Department of Mechanical Engineering at NGF College of Engineering and Technology, Palwal, Haryana, India. He is pursuing his PhD from YMCA University of Science and Technology, Faridabad, Haryana, India. His research interests are in the area of SCM, and graph theory. He has published technical papers in international journals and proceedings of national conferences.
1 Introduction

Enterprises are continuously paying attention in responding to the customer demand for maintaining competitive advantage over their rivals. Supply chain management (SCM) has gained attention as it focuses on material, information and cash flows from vendors to customers or vice-versa (Gupta and Singh, 2012b). SCM has been considered as the most popular operations strategy for improving organisational competitiveness in the 21st century (Gunasekaran et al., 2008). A supply chain is an integral process where in raw material is manufactured in to final product and delivers to customer through distribution channel (Beamon, 1999). SCM is a degree to which a manufacturer strategically collaborates with its supply chain partners and collaboratively manages intra and inter organisational process, in order to achieve effective and efficient flow of products and services, information, money and decisions to provide maximum value to the customers (Flynn et al., 2010). SCM is a big umbrella under which suppliers of supplier to end users are there. Everyone is a customer of its upstream so customer focus and customer satisfaction are the main key issues of SCM. Viewed from customer’s side it is the quality of product, value for money and post sales facilities (Grover et al., 2004). A key feature of present day business is the idea that it is the supply chains that compete, not companies and the success or failure of supply chains is ultimately determined in the marketplace by the end user, i.e., consumer. As competition moves beyond a single firm into supply chain, focus is shifting from management of internal practice alone (Kaynak and Hartley, 2008). Demanding competition in today’s global markets, introduction of products with short life cycles, and the discriminating expectations of customers have forced organisations to invest in, and focus attention on supply chains as system which is affected by the environment. SCM has increasingly become an inevitable challenge to most companies to be continuously survived and prospered in the global chain-based competitive environment.

The new age customers want customised products according to their tastes like automobile colour, interior, audio system, etc. The customer behaviour implies that dealers and manufacturers have to maintain adequate inventory to satisfy the customer (Mangal and Gupta, 2012). To improve profitability and efficiency, industries are seeking ways to achieve operational excellence, reduce operating cost and enhance customer service through efficient SCM. SCM is a network of facilities that produce raw materials, transform them into intermediate goods and then final product and deliver the product to customer through a distribution system (Lee and Billington, 1995). SCM can also be defined as a hierarchical and strategic approach to planning supply and demand, sourcing raw materials and components, making products and parts, tracking inventory and order fulfilment, and delivering to the customer and end user (Chow et al., 2008).
The ultimate aim of SCM is to satisfy the customer at optimum cost (Shah and Shrivastava, 2012; Kulkarni, 2005). Due to globalisation, liberalisation and advancement in the new technologies supply chain has become more complex, more global and a more critical business function than ever before (Shah and Shrivastava, 2012). Schiele et al. (2011) considered 166 buyers and suppliers and studied the supplier innovativeness, supplier pricing and buyers and suppliers relations. Lau et al. (2010) evaluates 251 manufacturing organisations of Hong Kong and conclude that there is a positive relationship between supplier and customer integration and product performance. Childhouse and Towill (2003) evaluate a supply chain in UK automotive industry and used ANOVA to analyse the relations of supplier and organisation. Prakash (2011) focus on competitive advantage and service quality of a supply chain of Indian automobile industry and use SPSS v13 and LISREL v 8.7 for analysis. Miguel and Brito (2011) develop a model after analysis the SCM based on four factors cost, quality, flexibility and delivery and use ANOVA for comparing all the four factors. Gumus and Guneri (2009) evaluate multi echelon inventory management in a SCM and used artificial neural network (ANN) to analyse the data. Kaynak and Hartley (2008) focused on quality management of SCM and used LISREL as analysis tool. Handfield et al. (1999) and Seth et al. (2006) focused on various SCM and evaluate the relations of supplier and organisations. Beamon (1999) measure the supply chain performance on the basis of cost, output and flexibility and draw a normal distribution curve. Thakkar et al. (2007) evaluate the buyer supplier relationship using ISM and graph theory. Singh et al. (2011) used graph theory to assess quality of manufacturing organisation. Singh et al. (2013) used graph theory to assess the vendor selection in a manufacturing organisation. Damperat and Jolibert (2009) study buyer-seller relationship in automobile supply chain and use CFA to analyse the data. Bozarth et al. (2009) study the SCM of machinery, electronics and transportation components manufacturing industries of seven countries and used SPSS v16.1 for analysis.

The purpose of this study is not just to identify the factors, but to group the factors and to develop a model using inheritance and interactions among factors identified to have a net effect on the SCM environment in quantitative term. In this paper, a technique using digraph and matrix approach has been suggested to quantify the presence of factors conducive to SCM. The graph theoretic representation is suitable for visual analysis, it can be computer processed and can be expressed as a mathematical entity, whereas the conventional representations, like block diagrams, cause and effect diagrams and flow charts, although providing visual analysis, do not depict interactions among factors and are not suitable for further analysis and cannot be processed or expressed in mathematical form, whereas, the digraph is the starting point for further analysis in the graph theoretical methodology (Grover et al., 2004).

The graph theory is an old technique and developed by Euler in 1736 when he solved the Konigsberg bridge problem. Subsequently, the graph theory has been applied in various fields like mechanical engineering (Agrawal and Rao, 1989; Gandhi and Agrawal, 1994; Wani and Gandhi, 1999; Sehgal et al., 2000; Rao, 2006b), reliability (Gandhi et al., 1991; Gandhi and Agrawal, 1992), automobile engineering (Venkataswamy and Agrawal, 1996, 1997), manufacturing engineering (Singh and Sekhon, 1996; Mukhopadhyay et al., 2000; Rao and Gandhi, 2002a, 2002b; Rao and Padmanabhan, 2007; Singh and Agrawal, 2008; Chakladar et al., 2008; Jangra et al., 2011a, 2011b), design (Al-Hakim et al., 2000), flexible manufacturing systems (Rao,
2006a), robotics (Rao and Padmanabhan, 2006), sociology (Rao and Gandhi, 2000), computer technology (Saha and Grover, 2011), economics (Yadav et al., 2010b), operation research (Dou et al., 2007, 2009), industrial engineering (Grover et al., 2004, 2005, 2006; Kulkarni, 2005; Prabhakaran et al., 2006; Qureshi et al., 2009; Singh et al., 2011), thermal engineering (Mohan et al., 2004; Yadav et al., 2010a), supplier-buyer relationship (Thakkar et al., 2007), rating of contractor (Darvish et al., 2009), SCM (Faisal et al., 2007; Wagner and Neshat, 2010; Singh et al., 2011), etc.

The scope of SCM has increased significantly. Most of available literature of SCM considers different factors as independent entity affecting SCM environment and evaluated either independently or in combination of the drivers of SCM, i.e., supplier-organisation or organisation-customer. Authors are not aware about the literature available which has considered all the drivers of a supply chain from supplier to customer and quantification of SCM environment in form of numerical index, considering the interdependencies and interrelationships among the system and sub system factors. The forces which are responsible for making a supply chain effective are its drivers that cover all the echelons, their inter-relationships and bonding. Next section represents the supply chain drivers and their considerable role.

2 Drivers of supply chain

The management of supply chain and the role and responsibilities of various persons involved differ from industry to industry. Due to which SCM has become a vital issue for manufacturing organisations, professionals and researchers. Also, to survive in today’s cut throat competition and to respond to the customer’s demands companies have no choice other than to offer high quality product and services. It is felt that to manage the supply chain effectively, entire structure of supply chain must be understood properly.

The main drivers of SCM are supplier, organisation, distributor, retailer and customer. Organisation has larger size and expending capacity among all these. Organisation is the main driver which selects its upstream and downstream except the customers, i.e., end users. Customer is the king of market and main driving force.

Figure 1 Drivers of supply chain

![Diagram of supply chain drivers](image)

SCM constitutes the series of interdependent upstream, manufacturing and downstream processes targeted at transforming raw materials into products to meet customer demand.
A systematic approach to evaluate supply chain management

A supply chain is an inter-linked set of relationships connecting customer to supplier, perhaps through a number of intermediate stages such as manufacturing, warehousing and distribution. The supply chain consists of suppliers, manufacturing centres, warehouses, distribution centres, and retail outlets, as well as raw materials, work-in-process inventory, and finished products that flow between the facilities. SCM is a set of approaches utilised to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that product can be produced and distributed in the right quantities, to the right locations, and at the right time, in order to minimise system wide costs while satisfying service level requirements. SCM revolves around efficient integration of suppliers, manufacturers, warehouses, and stores. It encompasses the firm’s activities at many levels, from the strategic level through the tactical to the operational level.

2.1 Role of supplier

Companies of all sizes are realising that they no longer have complete control over their market success. This is because they rely heavily on the performance of their supply chain trading partners. Market-leading retailers and original equipments manufacturers (OEMs) know this fact, and they are looking for partners that work to ensure their success. Many large companies are now insisting that their small and medium industrial suppliers help them to improve supply chain cost, responsiveness and reliability. These market heavy weights are measuring suppliers’ performance against key indicators and giving preferred status to those who perform well. This puts pressure on many small and medium manufacturers. Those that have not invested heavily in SCM practices or solutions beyond ERP to date are now driven to consider seriously making the investment. The business justification will rest on traditional cost savings and on revenue and customer compliance issues. Supply chain improvements will not only improve internal performance, but will also create benefits that will ripple through to customers and partners as well. Cost savings through reduced inventory levels (ILs), expediting, fulfilment and premium freight costs could allow a company to provide more favourable prices or terms to customers. Likewise, effective planning and execution can help companies and their customers adapt to the market’s demand shifts. When the company can purchase, produce and distribute the right products to the right channels in the right quantities at the right time, both supplier and customer will increase revenue capture by channel and region. Therefore, supplier plays an important role as it will help the organisation to achieve the excellence (Shah and Shrivastava, 2012). Closer long-term relationship with suppliers implies the use of joint quality planning and joint production planning between buyer and supplier (Theodorakioglou et al., 2010). In the area of manufacturing arena, supplier selection is a crucial strategic decision that has long-term impacts on a company’s profitability and efficiency (Muralidhar et al., 2010). Selection of appropriate suppliers in supply chain management strategy (SCMS) is a challenging issue because it requires battery of evaluation criteria/attributes, which are characterised with complexity, elusiveness, and uncertainty in nature (Ming-Lang et al., 2009). According to Choi and Hartley (1996), with a well-developed long-term relationship a supplier becomes a part of a well-managed supply chain and it will have a lasting effect on the competitiveness of the entire supply chain. Shah and Shrivastava (2012) had discussed the following role of a supplier.
improving transportation facilities, delivering performances
b proper stocking and fulfilling the requirements timely
c inventory and finance management
d proper communication with organisation and market.

Dowlatshahi (1998) stated that to improve communication the supplier should be involved in the early phases of product design. Supplier performance measures were based on the price variation rejects on receipt and on time delivery (Gunasekaran et al., 2004). The contribution of suppliers in delivering values to customers, hence, building competitive capabilities (quality, delivery, flexibility, and cost) has been well-recognised (Olhager and Prajogo, 2012).

2.2 Role of manufacturing organisation

For more than a decade, SCM has increased attention among the industries for achieving competitive advantage. Some of the benefits of SCM, which are predominantly discussed in the literature, include lower ILs (Closs et al., 1998; Pagel, 1999; Stank et al., 1999; Quinn, 2000), better responsiveness (Lalonde and James, 1994; Stank et al., 1999), and lower throughput time (Stank et al., 1999). Some key issues such as IT-enablement of supply chains, buyer-supplier relationships, and inventory management are at the core of the supply chain research and have been given a lot of attention in the literature (e.g., Monczka, 1996; Nielson, 1998; Bensaou, 1999; Pagel, 1999; Handfield and Nichols, 1999; Ballou et al., 2000; Handfield et al., 2000). There are, however, some other issues such as postponement (Anderson et al., 1997; Metz, 1998), attitude of major stakeholder of the supply chain (Ballou et al., 2000; Munson et al., 2000), top management commitment (Higginson and Alam, 1997), disparity in trading partners capability (Kwan, 1999; Sohal et al., 2001), etc., which influence these core issues. The literature on SCM has many references about these issues but lacks in providing enough empirical evidence of these relationships. Further, it is the people who often talk about supply chain strategies to cope-up with the ever-changing trends and expectations of market. Sometimes, the operational level processes involved in a supply chain are ignored, which results in unexpected inefficiencies in the system. The end goal of any company is a satisfied customer which is a guarantee of repeat order. The process of locating, obtaining and transporting the inputs needed to do this is the core function of SCM. Supply chain design in the manufacturing industry requires a great deal of focus on physical product and a broader supplier base. The business strategy does not matter, if the operations function cannot deliver, its game over. Despite years of experience with operations improvement methods such as lean and Six Sigma, many manufacturers aren’t able to conduct rapid, integrated operations transformations across a complex production system. Companies that can rapidly develop high performing production systems can also develop competitive advantage. Today’s supply chains have to be more nimble than ever before, able to respond quickly to the slightest changes in direction, more global, new products, greater risk of disruption, faster-paced, and more. All while meeting new demands for lower costs and increased productivity in a ferociously competitive global environment. Manufacturing organisation has investing capacity for research,
development and manufacturing. It is the trust, commitment and market reputation of the manufacturer which motivates distributor and retailer to invest and kept inventory. The increasing competition has driven firms to not only improve their internal operations, but also focus on integrating their suppliers into overall value chain processes (Olhager and Prajogo, 2012).

2.3 Role of distributor

In the ever-changing industry, distributors play an important role in the supply chain. From just-in-time procurement strategies to risk management, distributors can bring real value to customers. In today’s economic environment, distributors are being relied on heavily as our customers are more likely to order smaller volumes of products on a more frequent basis. Established partnerships with distributors provide for continuity and trust of supply. Wholesalers give distributors the opportunity to purchase in small quantities or can be relied on for special orders. Thus, distributors are not stuck tying up capital in inventory that otherwise might end up being dead stock. Distributors can also benefit by receiving shorter order lead times from wholesalers, which in turn help them turn product faster. While competition exists not only on the organisations but also on the supply chains, organisations are seldom worked alone and will form a lot of strategic partners or align with their suppliers so as to empower synergy. They will focus on their core competency and outsource the other business process or form partnership with each other. The main idea is to make sure that every party of the supply chain is more efficient and effective than its competitors of other supply chains. The performance of the supply chain is determined by the achievement of the collaboration of every party. Every person in the supply chain is not earning profit till the last customer is paying satisfactory. With this understanding, every organisation in the supply chain has to move out all the obstacles between them and find out a win-win scenario which emphasis a partnership relationship. However, most of research works concerning SCM put the emphasis on the aspect of responding to customer demands by a responsive strategy in correspondence to the front line demand (also called real demand), for example, Dell’s Virtual Integration Model (Magretta, 1998), Benetton and Zara’s Quick Response Model (Dapiran, 1992; Christopher et al., 2004) and the vendor managed inventory system between P and G and Wal-Mart (Vergin and Barr, 1999; Waller et al., 1999). Actually, the prime goal for these practices is to meet the customers’ value without sacrificing on inventory cost (Ketzenberg et al., 2000), to shorten the lead time (Lampel and Mintzberg, 1996; Pagh and Cooper, 1998), and to alleviate the bullwhip effect (Lee et al., 1997a, 1997b). Consequently, improvement in manufacturer-retailer relationships becomes a hot topic since Kumar (1996). It seems that the collaboration between manufacturer and retailer is the vital solution to manage demand uncertainty for having a good supply chain performance.

2.4 Role of retailer

To effectively deliver customer satisfaction, however, dominant retailers perform significant roles in providing the right products whenever and wherever customers want them. The closest to the end-customers are the retailers providing the link to the manufacturers and suppliers products. A dominant retailer acts as a leader and therefore
directly or indirectly affects other players in the chain including the manufacturers. This will discuss how retailers dominate the supply chain and its vital leadership roles in order to achieve its ultimate goal of customer satisfaction. The discussion focuses on dominant retailer’s roles; however, similar roles are also played by other dominant players in the supply chain, such as manufacturers or suppliers. Suppliers and manufacturers here are defined as the upstream players where retailers’ products are coming from. Both these players are assumed to deliver goods to the retailers and maybe used interchangeably.

The structure begins with a definition of a retailer in the supply chain. Then, a short discussion of how position of power in the industry is achieved by a retailer with examples of the dominant retailers in a number of leading industries. This will be followed by a discussion of the significant roles of a dominant retailer in the supply chain: leading the competition, value creation, stimulant of innovation, and price setter. Companies attempt to change their ways of doing business to find out new approaches to customers. Internationalisation and consolidation of retailing turned traditional retail industry upside down. Fast and efficient operational models and new technologies constantly challenge retailers. The term SCM is relatively new in the literature, appearing first in 1982. Supply chain is a set of institutions that moves goods from the point of production to the point of consumption. Retailing is the last step in a supply chain. Successful managing of supply chain will achieve significant savings and increased customer satisfaction. Retailing is responsible for matching the individual demands of the consumer with quantities of supplies produced by huge range of manufacturers.

SCM is to consider only strategically important suppliers in the value chain. Retailers cannot perform their role in supply chain without close interaction with other functions of supply chain. Companies in the retail industry resort to SCM to counter the increasing uncertainty and complexity of the marketplace and competitive situation to reduce inventory in the entire value chain. Efficient managing of retailers supply chain should support the satisfaction of end-users requirements. Retailers operate at the point closest to customers therefore are in best position to answer the questions when, where and how customers want particular product. SCM in retail industry is a challenge to implement and practice.

2.5 Role of customer

Customer is the main driving force of the market. He decides the future of the organisation. The customer service management process is the firm’s face to the customer. It provides the single source of customer information, such as product availability, shipping dates and order status. Real-time information is provided to the customer through interfaces with the firm’s functions, such as manufacturing and logistics. Whether it is the age of the ‘new consumer’, the experience economy or the era of post-modernism, it is clear that there has been a significant shift in most market-places. Fuelled by increasing market fragmentation, the desire to consume ‘experiences’ and increased market literacy, consumers are becoming increasingly discerning. It would be convenient to dismiss this as a ‘marketing problem’ and to ignore the logistics implications; but such fundamental shifts in consumer behaviour and the demand creation patterns they cause must be addressed by equally fundamental shifts in the way that demand is fulfilled. This has significant implications for SCM. It is time to understand the needs of the end-customer and to align supply chain strategy behind end-customer needs in the market-place.
When all the drivers work together for a specific purpose, create a working environment which is known as SCM environment. There are many factors which affect the environment of the SCM. In the next section, an effort has been done to identifying those factors which affects the SCM environment. It gives an insight to the relations, responsibilities, functional approaches, etc. and see the sights of SCM.

3 SCM environment-identification of factors

The environment in an organisation must reflect its effort to achieve its objectives (Grover et al., 2004). It is the SCM environment, which help to implement the SCM function and achieve success.

Table 1 Factors affecting supply chain

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<thead>
<tr>
<th>Group</th>
<th>Sub group</th>
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<td>Human factors (1)</td>
<td>Supplier</td>
<td><strong>Strategic supplier partnership</strong></td>
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<td>Li et al. (2002, 2005, 2006), Monczka et al. (1998),</td>
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<td>Zylbersztajn and Filho (2003), Flynn et al. (1994), Lamming</td>
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<td>and Hampson (1996), Buzell et al. (1975)</td>
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<td>Supplier quality management</td>
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<td>(1988), Saraph et al. (1989), Deming (1993), Flynn et al. (1994),</td>
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<td>and Flippini (1998), Dow et al. (1999), Das et al. (2000), Wilson</td>
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<td>Supplier performance</td>
<td>Seth et al. (2006), Viswanadham (2000)</td>
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<td><strong>Faster response time</strong></td>
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<td>Kocoglu et al. (2011)</td>
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<td>Trust on trading partner</td>
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<td>et al. (2001), Ruyter et al. (2001), Ganesan (1994), Handfield</td>
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<td>and Nicholas (1999), Kumar et al. (1995), Mariotti (1999),</td>
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<td>Monczka et al. (1998), Moorman et al. (1992), Morgan and Hunt (1994),</td>
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<td>et al. (2012), Dominic et al. (2013)</td>
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<td>Commitment of trading partner</td>
<td>Achim and Ritter (2003), Balsmeier and Voisin (1996), Burnell</td>
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<td>(1999), Crots et al. (2001), Ruyter et al. (2001), Hamel and Prahalad</td>
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<td>(1989), Handfield and Nicholas (1999), Kumar et al. (1995), Lee and</td>
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<td>Human factors</td>
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<td>Choi and Hartley (1996), Li et al. (2002, 2006)</td>
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<td>Risk management</td>
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### Table 1  
Factors affecting supply chain (continued)

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<td>Distributor and retailer</td>
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<td><strong>Time to market</strong></td>
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<td><strong>Service quality</strong></td>
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<td>Customer</td>
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<td><strong>Customer satisfaction</strong></td>
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<td><strong>Customer responsiveness</strong></td>
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<td>Beamon (1999), Ishii et al. (1988), Lee and Billington (1993), Newhart et al. (1993), Peterson et al. (2001), Towill et al. (1992), Li et al. (2006)</td>
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<td>Faster response time Beamon (1999), Kocoglu et al. (2011)</td>
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<td>Inventory level Viswanadham (2000)</td>
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<td>Lean system Li et al. (2002, 2006)</td>
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<td>Efficiency Beamon (1999), Li et al. (2006)</td>
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<td>Risk consideration Hahn and Kuhn (2012), Elahi et al. (2013)</td>
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<td>Cost of activity time Arnzen et al. (1995), Beamon (1999)</td>
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<td>Buy back contract Elahi et al. (2013)</td>
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<td>Revenue sharing Elahi et al. (2013)</td>
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<td>Capacity Krajewski and Ritzman (2002)</td>
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### Table 1  Factors affecting supply chain (continued)

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<thead>
<tr>
<th>Group</th>
<th>Sub group</th>
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| Product network (3)    | Product manufacturing concern            | **Process management**  
Saraph et al. (1989), Flynn et al. (1994), Crosby (1984),  
Ahire et al. (1996), Black and Porter (1996), Grandzol and  
Gershon (1997), Forza and Flippini (1998), Rungtusanatham  
et al. (1998), Samson and Terziovski (1999), Wilson and Collier  
**Business processes**  
Hicks et al. (2000)  
**Engineer to order**  
Hicks et al. (2000)  
**Production planning**  
Beamon (1999), Lee and Billington (1993), Li et al. (2005),  
Hicks et al. (2000)  
**Manufacturing systems**  
ABL (2001), Bindon and Jones (2001), Hepner et al. (2004),  
**Technology and organisation**  
**Partnership and collaboration**  
Sadler and Hines (2002), Spekman et al. (1998), Yu et al.  
**Resource utilisation**  
Viswanadham (2000)  
**Product/service design**  
Garvin (1988), Kaynak and Hartley (2008), Saraph et al. (1989),  
Flynn et al. (1994), Ahire et al. (1996), Black and Porter (1996),  
Adam et al. (1997), Easton and Jarrell (1998), Wilson and Collier  
(2000), Kaynak (2003), Hicks et al. (2000)  
**Recycling**  
Guide et al. (2000)  
**Environment friendly product**  
Guide et al. (2000)  
**Product development**  
Teller (2013)  |
Table 1  
Factors affecting supply chain (continued)

<table>
<thead>
<tr>
<th>Group</th>
<th>Sub group</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional dimension (4)</td>
<td>Quality concern</td>
<td>Quality of product</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Luning et al. (2002), Li et al. (2006)</td>
</tr>
<tr>
<td></td>
<td>Quality systems</td>
<td>Bindon and Jones (2001), Hepner et al. (2004), Sadler and Hines (2002)</td>
</tr>
<tr>
<td></td>
<td>Society perceptions</td>
<td>Peterson et al. (2001)</td>
</tr>
<tr>
<td>Policy</td>
<td>Strategy</td>
<td>Elahi et al. (2013), Hicks et al. (2000)</td>
</tr>
<tr>
<td></td>
<td>Procurement policy</td>
<td>Lee and Billington (1993), Hicks et al. (2000)</td>
</tr>
<tr>
<td></td>
<td>Marketing</td>
<td>Hicks et al. (2000)</td>
</tr>
<tr>
<td></td>
<td>Order Fulfilment</td>
<td>Teller (2013), Sahoo and Mishra (2013)</td>
</tr>
<tr>
<td></td>
<td>Logistics</td>
<td>Coyle et al. (2003), Krajewski and Ritzman (2002)</td>
</tr>
<tr>
<td></td>
<td>Efficiency</td>
<td>Krajewski and Ritzman (2002)</td>
</tr>
<tr>
<td></td>
<td>Traceability</td>
<td>Li et al. (2006)</td>
</tr>
</tbody>
</table>
Figure 2  Factor affecting supply chain
Extensive literature on SCM for the last three decades has motivated various authors to identify and classify SCM factors based on literature review. Beamon (1999) discussed and listed five factors to measure the supply chain performance. Kaynak (2003) identified ten factors which further modified by 11 and establish the relationship among them. Peterson et al. (2003) discussed five factors. Gunasekaran et al. (2004) classify the four categories of factors which further sub-divide into 12 factors and a framework was developed and discussed. Li et al. (2006) found mainly three factors which further subdivide into 12 factors. Kaynak and Hartley (2008) identified eight factors which affect the SCM and established the relation between them. Wu et al. (2012) discussed 12 factors for hi-tech industries of Taiwan and found that there is a positive relationship between trust and commitment.

The authors have referred to a large no. of papers for identification of factors. The various factors which help in creating a SCM environment, will lead to mathematical complexity in the analysis, these are identified and grouped under four broad categories as shown in Table 1.

All the factors discussed in Table 1 are shown in Figure 2.

SCM performance depends on a number of factors with the contribution of each factor towards its acceptability with various stakeholders. Four main factors are identified in Table 1. These four factors are taken as major factors for evaluation of any SCM environment. Various factors and sub-factors concerned are discussed below.

3.1 Human factors in SCM

These factors are directly related to the people who are interacting with SCM. The success of any supply chain depends upon the integrity of its drivers, i.e., supplier, organisation, distributor, retailer and customer. The people working for organisation and being served by organisation are a source of strength. Organisation is the main driving agent in the SCM. The internal structure of organisation consists two categories of human-employees and employers. The coordination between these two takes the organisation at newer heights. Employers always set the targets and invest the money with a clear quality vision and mission and employees try to achieve that goal with their full strengths.

3.1.1 Supplier

The first driver of SCM is supplier. A supplier is the person who helps the organisation to achieve its goal through on time delivery of quality product in right quantity (Singh et al., 2013). The evolution of supplier in the context of supply chain involves measures important at the strategic, operational and tactical level (Gunasekaran et al., 2004). The financial position of supplier must be sound enough so that he can enhance economic processes, manage risks and absorb market shocks. Suppliers who had participated early in initial technology sharing discussion, later contributed to setting goals regarding project outcomes always fulfils his commitment, makes a long-term association (Peterson et al., 2003). Supplier play an important role in assuring that incoming materials are defects free, which means that the buyer does not have to hold as much as safety stock as a contingency in case of defects in incoming materials (Kaynak and Hartley, 2008). Various sub-factors under supplier are strategic supplier partnership, supplier quality
A systematic approach to evaluate supply chain management

management, supplier performance, faster response time, trust on trading partner and commitment of trading partner.

1 Strategic supplier partnership – Strategic supplier partnership is defined as the long-term relationship between the organisation and its suppliers (McNeil and Wilson, 1997, Spekman et al., 1998). It is designed to leverage the strategic and operational capabilities of individual participating organisation to help them achieve significant ongoing benefits (Li et al., 2006). A strategic partnership emphasises direct, long-term association and encourages mutual planning and problem solving. Strategic partnership with suppliers enables the organisations to work more effectively with a few important suppliers who are willing to share responsibility for the success of the product (Li et al., 2006). Jie et al. (2007) stated that strategic supplier partnership usually occur with a few major suppliers who are willing to contribute with more responsibility for the success of the product. Strategically aligned organisations can work closely together to eliminate waste effort and time to save money (Balsmeier and Voisin, 1996). An effective supplier partnership can be a critical component of a leading edge supply chain (Noble, 1997).

2 Supplier quality management – It is fewer dependable on suppliers, reliance on supplier process control, strong interdependence of supplier and customer, purchasing policy emphasising quality rather than price, supplier quality control and supplier assistance in product development [Saraph et al., (1989), p.818].

3 Supplier performance – Supplier performance can be checked by service delivery, credibility, service completeness and intra-organisational communication (Seth et al., 2006). In other words, supplier performance is a measurement whether a supplier can fulfil order quantitatively and qualitatively.

4 Faster response time – When a customer gets response for his query on time, known as faster response time.

5 Trust on trading partner – It is the willingness to rely on a trading partner in whom one has confidence (Jie et al., 2008). Trust refers to a firm’s expectations that their partners will act to benefit their interest and would not act in an opportunistic manner even if there are short-term incentives to do so, regardless of their availability to monitor such behaviour (Kwon and Suh, 2005). Lack of trust is one of the major factors which highly affect SCM.

6 Commitment of trading partner – It is the willingness of each partner to exert effort on behalf of the relationship (Jie et al., 2008).

3.1.2 Employer

The second driver of SCM is employer. The employer is the main driving force in the supply chain as only he can invest money for various purposes like research, manufacturing, advertising, etc. Actually, it the employer who sets the target for the organisation and provides various resources, facilities and guidance to achieve them. Various sub-factors under employer are information sharing, information flow, information quality, information and material information and management leadership.
Information sharing – Flow of accurate information from one end to other end on time. The supply chain which works on shared information performs better than those do not have access to information related to their partner (Li et al., 2002). Some industries like Dell, Wal-mart are sharing information with their supplier and customer to decrease cost and improve service (Handfield and Nicholas, 1999). Information sharing has two aspects: quantity and quality, both aspects are fundamental for practices of supply chain and have been considered as independently constructed in the past SCM studied (Choi and Hartley, 1996). Shared information can vary from strategic to tactical in nature and from logistic activities to general market (Li et al., 2006).

Information flow – The extent to which critical and proprietary information is communicated to supply chain partner (Li et al., 2005).

Information quality – It refers to the accuracy, timeliness, adequacy, and credibility of information exchanged (Monczka et al., 1998; Moberg et al., 2002). Though sharing of information is very important, the significance of its impact on SCM depends on what information is shared, how it is shared and with whom it is shared (Li et al., 2006).

Material flow information – The extent to which all functions within the supply chain communicate information and transport material is material flow information (Jie et al., 2007). Mohr and Spekman (2004) state that information of material flow refers to extent to which critical and proprietary information is communicated to supply chain partner.

Management leadership – Saraph et al. (1989, p.818) discuss the management leadership as it is
   a acceptance of quality responsibility by top management
   b evaluation of top management on quality
   c participation by top management in quality improvement efforts
   d specificity of quality goals
   e importance attached to quality in relation to cost and schedule
   f comprehensive quality planning.

Management leadership is positively related to customer focus, training, employee relations, supplier quality management and product/service design (Kaynak and Hartley, 2008). Management can promote customer involvement by allow them for plant visits, by providing detailed information about product (Flynn et al., 1994).

3.1.3 Employee

The third driver of SCM is employee. Employee is the people who converts the dream of employer into reality by designing, manufacturing and selling the product, and establish the reputation of organisation. Various factors under employee are employee relations, training, safety, risk management and attitude.
1 Employee relations – Saraph et al (1989, p.818) discuss the employee relations factor as it is
   a implementation of employee involvement and quality circles
   b open employee participation in quality decisions
   c responsibility of employees for quality
   d employee recognition for superior quality performance
   e effectiveness of supervision in handling quality issues
   f ongoing quality awareness of all employees

Employee relations are directly related to quality data reporting and customer focus (Kaynak and Hartley, 2008). Those employees, who participate in decision making are recognised for better quality performance and aware for customer satisfaction, are like by the management.

2 Training – It is the provision of statistical training, trade training, and quality-related training for all employees [Saraph et al., (1989), p.818]. Kaynak’s (2003) indicate clearly that training is directly related to employee’s relations and quality data reporting. Training increase the healthy work environment and increase the involvement of employees, though only training will not sustain an improvement (Kaynak and Hartley, 2008).

3 Safety – Safety during processing, storing, transporting and using the product (ABL, 2001).

4 Risk management – The degree to which the effect of risks is minimised (Johnson and Scott, 1995).

5 Attitude – It is the favour or disfavour toward a person, place, thing, or event (Farmer, 1988).

3.1.4 Distributor and retailer

The next drivers of SCM are distributor and retailer. The distributor is that entity who helps organisation to sell the product into market through various retailers. Distributor may be called as authorised stockiest who store finish goods inventory because of trust, commitment and market reputation of parent organisation and supply the material to retailer according to demand. Retailer is the driver who really and directly faces the demand and reaction of customer. So feedback of retailer is very much important. Though reputation and service quality of retailer is very much important for customer but quality of product is also matter. Various sub-factors under distributor and retailer are competitive advantages, price, sales growth, time to market, lead time and service quality.

1 Competitive advantages – It is the extent to which an organisation is able to create a defensible position over its competitors (Porter, 1985; McGinnis and Vallopra, 1999). It comprises capabilities that allow an organisation to differentiate itself from its competitors and is an outcome of critical management decisions (Tracey et al., 1999). The dimensions of the competitive advantages are cost, quality, delivery, dependability, product innovation and time to market (Li et al., 2006).
Price – How much an organisation is capable of competing against major competitors based on low prices (Gunasekaran et al., 2004).

Sales growth – How much an organisation is capable to increase the sale and explore new markets (Gunasekaran et al., 2004).

Time to market – The extent to which an organisation is capable of introducing new products faster than major competitors (Li et al., 2005).

Lead time – It is the end to end delay in a business process (Viswanadham, 2000).

Service quality – Service quality in supply chain can be defined as how well an organisation meets or exceeds the customer expectations in unidirectional or bidirectional for each element of a supply chain, i.e., supplier, manufacturer, distributor, retailer and customer or end consumer (Gupta and Singh, 2012a). It is very important to consider the service provide by distributor and retailer before their selection for becoming a partner of SCM.

Customer plays an important role in the performance of supply chain (Lummus et al., 2001). Customer is the king of market and he decides good or bad. He is the main driving force. Robinson and Malhotra (2005) found that integration with customer is an important practice of SCM. Various sub-factors for customer factors are customer focus, customer satisfaction, customer responsiveness, customer relationship management (CRM), faster response time and responsiveness.

Customer focus – The entire practices that are employed for the purpose of managing customer complaints, building long-term relationships with customers, and improving customer satisfaction. Kaynak and Hartley (2008) stated that management provides the necessary action for quality training of customer to increase the faith of customer in the organisation. Hicks et al. (2000) discussed three stages of interaction with customer, i.e., marketing, preliminary design and after design.

Customer satisfaction – The ability to generate higher levels of customer satisfaction is regarded as an important differentiator and has therefore become a key element of many firms’ business strategies (Ellinger et al., 2012). Customer should be satisfied with the product or service which he received and it is the guarantee of repeat order. Customer satisfaction is a measure of how the products and services provided by a company meet or exceed customer expectations (Fornell, 1992; Olsen and Johnson, 2003). Christopher (1994) stated that there are three elements of customer satisfaction such as pre transaction satisfaction, transaction satisfaction and post transaction satisfaction.

Customer responsiveness – Customer responsiveness refers to accurately and insightfully giving customers what they need, want or do not yet know they want. It includes customer response time, lead time, order fill rate, back order and on time delivery.

CRM – It includes the complete practices which employed for managing customer complaints, building long-term relationships with customer and improving customer satisfaction (Tan et al., 1998; Claycomb et al., 1999). CRM is a key element of
supply chain practices (Noble, 1997; Tan et al., 1998). CRM allows an organisation to differentiate its product from competitors sustain customer loyalty and dramatically extend the value it provide to its customer (Magretta, 1998). Very good relations with customer are needed for successful implementation of SCM programmes (Li et al., 2006).

5 Faster response time – It is the amount of time between an order and its corresponding delivery (Beamon, 1999).

3.2 SCM inventory

SCM inventory (SI) is the finance involved in machinery, raw material, semi finished product, finish product, tooling and in complete supply chain, etc. Sub-factors under SI are investment and price.

3.2.1 Investment

Investment can be defined as the money involve in plant machinery, land, tooling, raw material, etc. Various sub-factors under investment are financial performances (FPs), IL, lean system (LS), efficiency and risk consideration (RC).

1 **FPs** – FP is a result of quality performance, inventory management and process management (Kaynak and Hartley, 2008). It is the return on investment, sales growth, profit growth, market share, and market share growth.

2 **IL** – It includes the level of finish product which is available to supply at every time and availability of safety stock of raw material.

3 **LS** – The practices of eliminating waste (cost, time, etc.) in a manufacturing system, characterised by reduced setup times, small lot sizes, and pull-production (Li et al., 2005).

4 **Efficiency** – Efficiency measures the utilisation of resources in the systems that are used to meet the system’s objectives (Beamon, 1999).

5 **RC** – If order quantity is more than demand then unsold inventory and if order quantity is less than demand then unmet demand.

3.2.2 Price

Price indicates the cost involved in manufacturing the product. It considers operation cost, inventory cost, waste cost, transportation cost, labour cost and profit. Various sub-factors under the price are cost, cost of activity time, buy back contract, revenue sharing, capacity and efficiency.

1 **Cost** – In today’s cut throat competition new industries are introducing with lesser price, so it becomes awkward for the manufacturing industries to remain their stake in the market and earn profits (Singh et al., 2013). It includes inventory cost and operational cost, risk cost, service cost and insurance cost (Beamon, 1999; Gunasekaran et al., 2004).
Product network (PN) indicates the various factors related to technology used for the product and manufacturing. Sub-factors under PN are product manufacturing concern and technology.

3.3.1 Product manufacturing concern

It indicates the different factors for manufacturing the product. Various sub-factors under this factor are process management, business processes, engineer to order (ETO), production planning, manufacturing methods, feeding methods and postponement.

1 Process management – Saraph et al. (1989, p.818) discussed the process management factor as it is
   a Clarity of process ownership, boundaries, and steps.
   b Less reliance on inspection.
   c Use of statistical process control.
   d Selective automation.
   e Foolproof process design. Preventive maintenance.
   f Employee self-inspection.
   g Automated testing.

Process management directly related to quality performance (Kaynak and Hartley, 2008). Process management reduce the variation thorough practice such as fool proofing, stabilising production schedule and equivalent preventive maintenance (Kaynak, 2003)

2 Business processes – Business process indicate the interaction with supplier and customers. Hicks et al. (2000) discussed three stages for business process namely marketing, invitation to tenders and activities after awarding the contract.

3 Engineers to order – Company build unique products designed to customer specifications. The characteristics of ETO companies are described in terms of their markets, products and the internal processes of their organisation (Hicks et al., 2000).
4 Production planning – It focuses on the planning of the production in advance, setup the targets and complete those timely and economically. The practice of moving forward one or more operations or activities (making, sourcing and delivering) to a much later point in the supply chain (Li et al., 2005).

5 Manufacturing systems – It refers to the manufacturing systems available to the organisation.

3.3.2 Technology

Various sub-factors under technology are technology and organisation, partnership and collaboration, resource utilisation, product/service design, recycling, environment friendly product and product development.

1 Technology and organisation – it is the market reputation of organisation, its product and technology used. The technology used by the organisation must be latest and customer friendly.

2 Partnership and collaboration – It refer to technical and financial assistance for increase market share. Collaborative supply chain partnership supports the development of flexibility, responsiveness and low cost/low volume manufacturing skill (Hoyt and Huq, 2000).

3 Resource utilisation – It refers to effective utilisation of resources available such as raw material, man power, electricity, etc.

4 Product/service design – Saraph et al. (1989, p.818) discussed the product/service design factor as it is
a thorough scrub-down process
b involvement of all affected departments in design reviews
c emphasis on producibility
d clarity of specifications
e emphasis on quality, not roll-out schedule
f avoid frequent redesigns.

Earlier product/service design activities took place primarily within the organisation but now main supplier and customers work together during product and service design (Kaynak and Hartley, 2008; Peterson et al., 2003). It is the management who limit the involvement of customer and supplier during product/service design.

5 Recycling – After completing its life cycle, the waste can be used for making new product without harming the environment.

6 Environment friendly product – The product should not be harmful to the environment during its usage, storage and decomposing.

7 Product development – It refers to development of new product or make existing product better and more useful for users at reasonable price.
Functional dimension of supply chain

3.4.1 Quality concern

Quality can be defined as fitness for use and conformance to specifications. Various sub-factors under functional area of supply chain are quality of product, quality in purchasing, quality system and quality data and reporting.

1 Quality of product – The quality of any product is solely depends on the raw material supplied by the supplier because if the raw material is not meeting the required level of expectations then there is no guarantee of good quality product (Singh et al., 2013). Quality also refers that how an organisation is capable of offering product quality and performance that creates higher value for customers (Rondeau et al., 2000).

2 Quality in purchasing – Raw material is used in a manufacturing organisation to convert it into finish goods that will be delivered to a customer; it is the responsibility of the purchasing department to ensure that the materials that arrive are of the correct quality and as per specifications.

3 Quality system – It indicates quality of all the systems followed.

4 Quality data and reporting – Saraph et al. (1989, p.818) discussed the quality data and reporting factor as it is the
   a use of quality cost data
   b feedback of quality data to employees and managers for problem solving
   c timely quality measurement
   d evaluation of managers and employees based on quality performance
   e availability of quality data.

5 Society perception – It indicates the requirement of the society from the product, maintenance and life (Peterson et al., 2001).

3.4.2 Policy

Policy refers to various decisions regarding the product. Various sub-factors under the policy are strategy, procurement policy, marketing and order fulfilment.

1 Strategy – This includes business models, strategic alliances, and partnership formation with the objective of developing a sustainable supply chain that is flexible and responsive to changing market requirements, but at the same time meets the environmental regulations (Hicks et al., 2000; Elahi et al., 2013).

2 Procurement policy – It refers to the policies used for procurement of raw material, tooling, etc. It may be through invitation of tenders or by some other methods (Hicks et al., 2000).
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3 Marketing – It refers to that how well an organisation has marketing team, how well organisation advertise his product and convert luxury item into need full item (Hicks et al., 2000).

4 Order fulfilment – It is the number of times when an organisation fulfils the order quantitatively and qualitatively (Teller, 2013). Better planning and coordination within and beyond the boundary of a manufacturing organisation can achieve reduction in order fulfilment time. Technology and human resource related issues also play an important role in reducing the order fulfilment time (Sahoo and Mishra, 2013).

3.4.3 Flexibility

It is the ability to adapt to their changing environment. Flexibility is vital to the success of the supply chain as the supply chain exist in an uncertain environment (Beamon, 1999). Various sub-factors under the flexibility are flexibility range and response flexibility. Flexibility means the tolerable deviation from actual one.

1 Flexibility range – Flexibility range is defined as the extent to which the operation can be changed (Slack, 1991). The practice of moving forward one or more operations or activities to a much later point in supply chain (Li et al., 2006).

2 Response flexibility – Response flexibility is defined as the ease (in terms of cost, time, or both) with which the operation can be changed (Slack, 1991).

3.4.4 Transport

Various factors under transport are delivery, logistic, capacity, efficiency and traceability.

1 Delivery – Delivery includes delivery speed, production lead time and delivery reliability.

2 Logistic – It refers to transportation of raw material and finish product timely and in required quantity.

3 Capacity – Capacity of the machine, capacity of shipment and delivery truck.

4 Efficiency – It consider operation cost, inventory cost, waste cost, transportation cost, labour cost and profit.

5 Traceability – It include latest and fast tracing systems which can used for tracing of raw material to finish goods.

There are various numbers of factors responsible for SCM environment creation. An attempt has been made to make interrelationship among the factors, sub-factors and to evaluate the environment of SCM. In the next article, graph theory is used to evaluate the SCM environment. If interaction are not direction dependent SCM environment is represented by an undirected graph, if direction dependent it is called a digraph representation.
Graph theory is a systematic methodology consisting of digraph representation, matrix representation and permanent function (Singh et al., 2013). The permanent function is obtained in a similar manner as determinant but unlike in a determinant where a negative sign appears in the calculation, is available permanent function positive sign replace these negative sign (Faisal et al., 2007).


Graph theory is a logical and system approach. A graph consists of a set of objects $V \{v_1, v_2, \ldots\}$ called vertices, and another set $E \{e_1, e_2, \ldots\}$; whose elements are called edges, such that edge $e_k$ is identified with an unordered pair $(v_i, v_j)$ of vertices. The vertices $v_i, v_j$ associated with edge $e_k$ are called end vertices of $e_k$. The most common representation of a graph is by means of a diagram, in which the vertices are represented as points and each edge as a line segment joining its end vertices.

### 4.1 Digraph representation

A digraph is direction assigned graph and used to represent the factors and their interdependencies in term of nodes and edges. The SCM digraph represents the SCM environments factors ($S_i$'s) through its Nodes and edges and their dependencies ($S_{ij}$'s). $S_{ij}$ indicates the degree of dependence of the $j^{th}$ factor on $i^{th}$ factor. The four broad factors identified in Section 3 and arrange in Table 1 form the SCM digraph. The factors are human factors (HF) ($S_1$), SI ($S_2$), product development (S3) and functional dimension (FD) ($S_4$). All these four factors are schematically represented in Figure 3.

### 4.2 Matrix representation

Variable permanent matrix (VPM – SCM) for SCM representing the digraph shown in Figure 3 is given below:
A systematic approach to evaluate supply chain management


\[
VPM - SCM_e (Level 1) = \begin{pmatrix}
1 & 2 & 3 & 4 \\
1 & S_1 & S_{12} & S_{13} & S_{14} \\
2 & S_{21} & S_2 & S_{23} & S_{24} \\
3 & S_{31} & S_{32} & S_3 & S_{34} \\
4 & S_{41} & S_{42} & S_{43} & S_4 \\
\end{pmatrix}
\]

Figure 3 Schematic representation of four attributes and their interdependencies for a system

The variable permanent factor for supply chain management (VPF-SCM) expression corresponding to four factor digraph is given by

\[
VPF - CSM_e = \text{per}_S^* = \prod_i S_i + \sum_{i,j} \sum_{k,l} \sum_{m,n} (S_{ij} S_{jk} S_{kl} S_{mn} + S_{ij} S_{im} S_{mj} S_{mn}) \prod_i S_i \\
+ \sum_{i,j} \sum_{k,l} \sum_{m,n} \sum_{o,p} (S_{ij} S_{jk} (S_{kl} S_{lp} + S_{kl} S_{lp} S_{mp})) \prod_i S_i \\
+ \left( \sum_{i,j} \sum_{k,l} \sum_{m,n} \left( (S_{ij} S_{jk} S_{kl} S_{lp}) + (S_{ij} S_{im} S_{mj} S_{mn}) \right) \right)
\]

The permanent function [equation (1)] is a mathematical expression in symbolic form. Equation (1) contain terms arranged in \( N + 1 \) group, where \( N \) is the number of elements, which is 4 in this case. The total number of terms are \( N! \), i.e., 4! or 24 in this case. The physical significance of various groups is explained below:

1. The first grouping indicates a set of \( N \) unconnected SCM elements, i.e., \( S_1, S_2, \ldots, S_N \).
2. The second grouping indicates the self-loops which is absent in this case.
3. The third grouping indicates a set of two element SCM loops (i.e., \( S_{ij} S_{il} \)).
4. The fourth grouping indicates a set of three element SCM loops (i.e., \(S_{ij}S_{jk}S_{ki}\) or its pair \(S_{ik}S_{jk}S_{ji}\)).

5. The fifth grouping consists of two subgroups. The first subgroup indicates a set of two element SCM loops (i.e., \(S_{ij}S_{ji}\) and \(S_{kl}S_{lk}\)). The second subgroup indicates a set of four element SCM loops (i.e., \(S_{ij}S_{jk}S_{kl}S_{li}\) or its pair \(S_{il}S_{lk}S_{jk}S_{ji}\)).

The variable permanent matrix for subsystems and sub-systems is written as

\[
VPM - SCM_e = \begin{pmatrix}
1 & 2 & 3 & \cdots & m \\
\begin{array}{cccc}
S_{11} & S_{12} & S_{13} & \cdots & S_{1m} \\
S_{21} & S_{22} & S_{23} & \cdots & S_{2m} \\
\vdots & \vdots & \vdots & \cdots & \vdots \\
S_{m1} & S_{m2} & S_{m3} & \cdots & S_{mm}
\end{array}
\end{pmatrix}
\]

4.3 Quantification of \(S_i\)'s and \(S_{ij}\)'s (diagonal and off diagonal elements)

Quantification of diagonal and off diagonal elements of VPM-SCME, i.e., \(S_i\)'s and \(S_{ij}\)'s is necessary for the evaluation of VPM-SCME. Table 2 suggests the equivalent value over a scale of 1–9 for the qualitative measure of an attribute.

<table>
<thead>
<tr>
<th>Qualitative measure of attributes</th>
<th>Assigned value of the attributes ((S_i))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exceptionally low</td>
<td>1</td>
</tr>
<tr>
<td>Very low</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>3</td>
</tr>
<tr>
<td>Below normal</td>
<td>4</td>
</tr>
<tr>
<td>Normal</td>
<td>5</td>
</tr>
<tr>
<td>Above normal</td>
<td>6</td>
</tr>
<tr>
<td>High</td>
<td>7</td>
</tr>
<tr>
<td>Very high</td>
<td>8</td>
</tr>
<tr>
<td>Exceptionally high</td>
<td>9</td>
</tr>
</tbody>
</table>

Similarly, the relative importance between the two characteristics or attributes is also assigned a value on a scale of 1–5 and is arranged into classes as mentioned in Table 3.

<table>
<thead>
<tr>
<th>Dependency effect of attribute (j) on attribute (i)</th>
<th>Assigned value of the attributes ((S_{ij}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very weak</td>
<td>1</td>
</tr>
<tr>
<td>Weak</td>
<td>2</td>
</tr>
<tr>
<td>Medium</td>
<td>3</td>
</tr>
<tr>
<td>Strong</td>
<td>4</td>
</tr>
<tr>
<td>Very strong</td>
<td>5</td>
</tr>
</tbody>
</table>
It may be mentioned that one may choose any scale, e.g., 0.0 to 1, 0 to 5, 1 to 5, 0 to 10, 1 to 10, 1 to 11, 0 to 50, 0 to 100, 1 to 100, 1 to 110, 0 to 1,000, 1 to 1,000, or any other scale for $S_i$ and $S_{ij}$. But the final ranking will not change, as these are relative values (Saha and Grover, 2011).

5 Methodology

The graph theoretic approach evaluates the supply chain performance in terms of a single numerical index. This takes into consideration the inheritance effect of factors and their interdependencies. The various steps in the proposed approach are presented here, which will help in evaluation process of the supply chain performance.

1 Identify various factors that affect supply chain performance. Different supply chains may have a different set of factors affecting supply chain performance depending on the type of supply chain.

2 Broadly group these factors (as four broad factors are framed in this study based on Table 1). For the application of this methodology, the factors are written in composite form to avoid mathematical complexity in the further analysis.

3 Logically develop a digraph between the factors depending on their interdependencies (similar to Figure 3). The nodes in the digraph represent factors while edges represent interaction among factors.

4 Identify the sub-factors affecting supply chain performance factors.

5 Identify the sub sub-factors affecting sub-factors.

6 Develop a sub-factor digraph considering inheritances and interactions among one of the groups of sub-factors. The nodes in the digraph represent sub-factors while edges represent interaction among sub-factors.

7 Develop sub-factor matrix with diagonal elements representing inheritances and the off diagonal elements representing interactions among them.

8 At the sub-system level use Tables 2 and 3. This will provide numerical values for inheritance of attributes and their interactions with the help of experts.

9 Find the value of permanent function for sub-factor.

10 Repeat Steps 6 to 9 for each sub-factor.

11 Similarly, repeat Steps 6 to 9 for each sub sub-factor.

12 Develop performance factor digraph and performance matrix at system level as explained in Steps 3 and 7.

13 At system level, the permanent value of each sub-factor (obtained in Step 9) provides inheritance of supply chain performance factor. The quantitative value of interactions among factors is obtained from Table 3 through proper interpretation by experts. This will form performance matrix at system level similar to equation (1).
Find the value of permanent function for the system. This is the value of the supply chain performance index. The performance of a supply chain can thus be evaluated based on the above-discussed methodology.

6 Example

An example is considered for the demonstration of the proposed methodology in a leading automobile industry of North India. To analyse the system using graph theory, a case consisting of four variables is considered. These variables are HF, SI, PN and FD. The interdependencies among these variables are developed with the help of expert opinion from automobile industry and academic. A small brain storming session was conducted where experts from the automobile industry and academia participated. The interdependency of these four attributes is shown in Figure 3. Based on interdependencies of these elements, sub-system and sub subsystem digraphs have been developed wherein these elements form a VPM for sub-system and sub subsystem. For example, SI factor, there are two sub-factors – investment and price. The sub-factor investment consists five sub sub-factors as FPs, IL, LS, efficiency (EF) and RC, the digraph for all these five sub sub-factors is shown in Figure 4 and VPM is given as

![Figure 4](image)

Figure 4 Digraph showing interdependency for sub-factor investment

![Figure 5](image)

Figure 5 Digraph showing interdependency for factor SI
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\[
\begin{pmatrix}
FP & IL & LS & EF & RC \\
FP & S_1 & S_{12} & 0 & 0 & S_5 \\
IL & S_{31} & S_2 & 0 & S_{24} & S_{25} \\
EF & S_{41} & S_{42} & S_{43} & S_4 & 0 \\
RC & 0 & 0 & S_{33} & 0 & S_5 \\
\end{pmatrix}
\]

\[VPM - SCM_{3}(Investment, level 3) = LS \begin{pmatrix}
S_1 & S_{12} & S_3 & S_{14} & 0 \\
S_{31} & S_{12} & S_3 & S_{14} & 0 \\
S_{41} & S_{42} & S_{43} & S_4 & 0 \\
0 & 0 & S_{33} & 0 & S_5 \\
\end{pmatrix}\] (M3)

For demonstration at system level, the values are assumed for above matrix and taken from Table 3 as

\[S_1 = 6, \quad S_2 = 7, \quad S_3 = 6, \quad S_4 = 8, \quad S_5 = 6\]

Similarly the values of \(S_i\) are taken from Table 2 as

\[S_{12} = 3, \quad S_{15} = 4, \quad S_{21} = 2, \quad S_{24} = 3, \quad S_{25} = 4, \quad S_{31} = 2, \quad S_{32} = 4, \quad S_{41} = 2, \quad S_{42} = 4, \quad S_{43} = 3, \quad S_{33} = 4.\]

\[
\begin{pmatrix}
FP & IL & LS & EF & RC \\
FP & 6 & 3 & 0 & 0 & 4 \\
IL & 2 & 7 & 0 & 3 & 4 \\
EF & 4 & 3 & 3 & 8 & 0 \\
RC & 0 & 0 & 4 & 0 & 6 \\
\end{pmatrix}
\]

\[VPM - SCM_{3}(Investment, level 3) = LS \begin{pmatrix}
6 & 3 & 0 & 0 & 4 \\
2 & 7 & 0 & 3 & 4 \\
4 & 3 & 3 & 8 & 0 \\
0 & 0 & 4 & 0 & 6 \\
\end{pmatrix}\] (M4)

The value of this VPM is 30172.

The minimum value of this VPM can be calculate as

\[
\begin{pmatrix}
FP & IL & LS & EF & RC \\
FP & 1 & 1 & 0 & 0 & 1 \\
IL & 1 & 1 & 0 & 1 & 1 \\
EF & 1 & 1 & 1 & 1 & 0 \\
RC & 0 & 0 & 1 & 0 & 1 \\
\end{pmatrix}
\]

\[Min. VPM - SCM_{3}(Investment, level 3) = LS \begin{pmatrix}
1 & 1 & 0 & 0 & 1 \\
1 & 1 & 0 & 1 & 1 \\
1 & 1 & 1 & 1 & 0 \\
0 & 0 & 1 & 0 & 1 \\
\end{pmatrix}\] (M5)

The minimum value of this VPM is 18.

The maximum value of this VPM can be calculate as

\[
\begin{pmatrix}
FP & IL & LS & EF & RC \\
FP & 9 & 5 & 0 & 0 & 5 \\
IL & 5 & 9 & 0 & 5 & 5 \\
EF & 5 & 5 & 9 & 0 & 9 \\
RC & 0 & 0 & 5 & 0 & 9 \\
\end{pmatrix}
\]

\[Maximum. VPM - SCM_{3}(Investment, level 3) = LS \begin{pmatrix}
9 & 5 & 0 & 0 & 5 \\
5 & 9 & 0 & 5 & 5 \\
5 & 5 & 9 & 0 & 9 \\
0 & 0 & 5 & 0 & 9 \\
\end{pmatrix}\] (M6)

The maximum value of this VPM is 200474.
Variable permanent matrix M4 gives the actual or current value of sub-factor investment. Similarly another VPM can be used for sub sub-factors like cost, cost of activity time, buy back contact, revenue sharing and capacity to calculate the value of second sub-factor, i.e., price. The digraph for these two sub-factors, i.e., investment and price is given in Figure 5. To know the value of factor SI, again VPM is used for investment and price sub-factors. Similarly the values of all sub-factors and factors can be calculated. Then based on Figure 3 another VPM will be used to calculate the overall service quality.

7 Conclusions

The model presented in this paper can be used as an aid to understand and develop suitable supply chain strategy based on required customer sensitivity and risk alleviation competency dimensions. This would facilitate the supply chain managers to infer about the improvements needed if they want to migrate from one model to another model of managing their supply chains in view of changing market requirements. The proposed systems methodology for developing a information system by considering all attributes responsible for development, and implementation, along with interactions between the constituents and using a digraph and matrix approach, which is a powerful tool for structural modelling information system constituents and their interaction with each other. This approach integrates all possible structural functional and performance parameters in a mathematical model for analysis and optimisation.

7.1 Limitations of proposed work

Though, the data has been collected from expert of same field, i.e., automobile industry and from academia, yet the values may change as different expert opinion will differ and also from industry to industry.

7.2 Scope for future work

This technique can also be used to other manufacturing industries. As this technique is also helpful to know the current position of service quality and the maximum value of service quality, an industry shall be able to know the efforts required to reach at the maximum position.

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