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Abstract

Purpose – The purpose of this paper is to investigate the interactions among the key factors of supply chain (SC) in the Indian automotive industry. These key factors are helpful to measure supply chain performance (SCP) and to improve the firm's effectiveness.

Design/methodology/approach – In this paper, an interpretive structural modeling with a fuzzy cross-impact matrix multiplication applied to classification-based approach is used to examine the interactions among the key factors of SCP measurement.

Findings – The authors have identified the most dominant key factors used for measuring the performance in automotive SC. The results exhibit that the order lead-time and order entry method are the most significant key factors. These key factors have high driving power to measure SCP whereas the post-transaction measure of customer service and customer query time are highly dependent on other factors. Such relationships among the key factors can help a firm's top management to make essential judgments in order to solve the overall SC problems and provide a better approach to proactively deal with problems.

Originality/value – In this paper, the authors have explored the interactions among the key factors of the SCP in the Indian automotive industry.

Keywords Supply chain, Supply chain management

Paper type Research paper

1. Introduction

Supply chain performance measurement (SCPM) has been receiving incessant attention from the practitioners as well as from researchers since last two decades. In current business environment, supply chain management (SCM) plays a vital role in business activities, manufacturing industries, and the service industries for increasing their effectiveness, efficiency, customer service, and profit. Gunasekaran *et al.* (2001) mentioned that SCM is an important and specialized management tool for increasing a firm's efficiency and reaching their goals. Therefore, it is mandatory for industries to focus on the key factors of supply chain (SC). According to Ren *et al.* (2004), planning and operations have significant influence on supply chain performance (SCP). The authors also stated, "you cannot manage what you cannot measure." SC logistic performance was perhaps an initial attempt to define SCP (Chia *et al.*, 2009). A unique attribute of a SCPM is that the measurement system covers the entire SC including the measurement of interdependencies cross the borders of firms (Beamon, 1999; Gunasekaran *et al.*, 2001, 2004; Shepherd and Gunter, 2006). Performance measurement is an essential tool for companies to improve efficiency and effectiveness of SC (Beamon, 1999; Neely *et al.*, 2002; Shepherd and Gunter, 2006).

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In recent years, several theories of managing the performance of the SC are discussed in literature (Brewer and Speh, 2000; Park *et al.*, 2005; Yeh *et al.*, 2007). Gunasekaran *et al.* (2001, 2004) proposed a framework-related generic processes for measuring the operational, tactical, and strategic levels of performance in a SC. Choy *et al.* (2007) developed a system of performance management for measuring associated suppliers using a benchmarking structure. Charan *et al.* (2008) shown that a better SCMP system promotes a strong relationship between the SC members. In today's business surroundings, a long-term relationship among the different parties of a SC is essential. Although most of the industries have realized the importance of an extended SC and new technologies, nevertheless, many of them still do not have effective strategies for a completely integrated SC. Saad and Patel (2006) analyzed the structure of SCP measure and the difficulty of implementing such measures in the Indian automotive industry. The authors found that the Indian automotive industries are not implementing the important concepts of SCM properly. In past few years, several attempts are made from the Indian perspectives to measure SCP at industry level. However, only a few of them have actually implemented. Since recently, the Indian market has opened for foreign companies to invest and work, the Indian automotive sector is flooded with automotive manufacturers like Honda, Ford, and Toyota, etc. This has generated a tough competition among automotive companies in terms of product cost, quality, delivery, and flexibility. To compete companies are trying to improve the overall performance of their SC. The primary focus of this paper is to investigate the different key factors of SCP in Indian automotive industries. The reason behind focussing on automotive industry is that it has been fastest growing sector in India and has more than 10 percent contribution in Indian GDP (Joshi *et al.*, 2013). It is mandatory for all industries to focus on better strategy, technology, and other customer requirements to develop an effective measurement system for SCP. This will result in a deeper understanding of the SC and improve its overall performance (Sharma and Bhagwat, 2007; Chen and Paulraj, 2004). Gunasekaran and Kobu (2007) mentioned that it is essential, but at the same time a major challenge, for the firm's top leaders to develop appropriate key factors to measure SCP. However, there is a lack of awareness about identification of the factors that affect business performance. Very few studies are present in literature on identification of key factors for measuring SCP from the Indian context (Charan *et al.*, 2008; Ganga and Carpinetti, 2011).

The primary objective of this paper is first to identify different key factors of SCPM from a literature review and discussion with experts of Indian automotive industry. The secondary objective is to investigate the inter-relationships among the identified key factors of SCPM. The interpretive structural modeling (ISM) approach (Warfield, 1974; Sage, 1977) was utilized to investigate the inter-relationships among the different key factors. Further, in order to categorize the key factors according to their dependence and driving power, we integrated the ISM approach with a fuzzy cross-impact matrix multiplication applied to classification (Fuzzy MICMAC) (Duperrin and Godet, 1973; Saxena *et al.*, 1992). Fuzzy MICMAC is derived from the fuzzy direct relationship matrix (FDRM), the significance of a criterion is considered less by its direct inter-relationships and more by its various indirect inter-relationships (Qureshi *et al.*, 2008). Fuzzy logic is an appropriate method to deal with vagueness and subjectivity, which becomes an exciting supporting approach to manage SCP (Ganga and Carpinetti, 2011). Therefore, we used integrated ISM and Fuzzy MICMAC together to categorize the key factors according to their dependence and driving powers.

The reminder of the paper is organized as follows. Section 2 discusses relevant literature to identify different key factors of SCP. Section 3 describes the methodology. The ISM approach for modelling the key factors is discussed in Section 4. Section 5 illustrates the integration of ISM and Fuzzy MICMAC approaches to understand the driving power and dependence of the key factors. Section 6 discusses the findings and conclusions of the study. Finally, limitations and scope for future work are presented in Section 7.

2. Literature review

In section, the different factors of SCP are identified from the literature review. After identification of factors for SCP, a brainstorming session was held with 16 experts who have minimum ten years' experience in the area of automotive SCM. The factors identified from the literature were distributed among the experts panel to discover the relevance of these factors in the automotive SCM. Based on the experts' opinion, 20 key factors were finalized that affect SCP. Finally, the experts were asked to establish the inter-relationships among the finalized key factors. Table I shows the list of the 20 key factors related to SCPM. These key factors are discussed below in more detail.

2.1 Quality

Quality is the most important factors of the production performance that is used to maintain product quality. Attributes like cost, quality, delivery, innovation, and flexibility are considered a competitive priority factor or end goal of a firms' performance in terms of customer expectations (Hill, 1987; De Toni and Tonchia, 1998; Sharma *et al.*, 2013). Dangayach and Deshmukh (2001) also highlighted that high quality and the performance values of any manufactured product are crucial. Indian companies are based on their quality that is reported in a survey of manufacturing companies (Chandra and Sastry, 1998).

2.2 Capacity utilization

Capacity utilization is another aspect of performance measurement and plays an important role in determining the performance level in a SC. Capacity utilization is a factor that indicates how well capacities are used in the delivery of services (Fitzgerald *et al.*, 1991). Wild (1995) stated that each manufacturing schedule takes a position inside the structure set by capacity assessments. It clears the significance of determining and managing the capacity utilization (Bhagwat and Sharma, 2007).

2.3 Buyer-supplier relationship

A strong relationship between buyer and supplier emphasizes the long-lasting relationship and future planning for any business. Many studies (Ellram, 1991; De Toni *et al.*, 1994; Towill, 1997; Meena and Sarmah, 2012) have emphasized the importance of strong relationship/partnerships for good SC operations. Selection of appropriate suppliers and an effective supplier relationship management are the key factors for increasing the competitiveness of firms (Ghodsypour and O'Brien, 2001; Aksoy and Ozturk, 2011; Choy *et al.*, 2003a).

2.4 On-time delivery of goods

The most important measure of delivery performance is the delivery of the final product to the customer. On-time delivery is one of the most important key factors of

Table I.
Key factors and their source

Sl. no.	Key factors of SCP	Author(s)
1	Quality	Hill (1987), De Toni and Tonchia (1998), Dangayach and Deshmukh (2001), Chandra and Sastry (1998)
2	Capacity utilization	Wild (1995), Bhagwat and Sharma (2007), Slack *et al.* (1995), Gunasekaran *et al.* (2004), Cho *et al.* (2012), Fitzgerald *et al.* (1991)
3	Buyer-supplier relationship	Ghodsypour and O'Brien (2001), Ellram (1991), De Toni *et al.* (1994), Towill (1997), Aksoy and Ozturk (2011), Johnston and Glark (2008), Meena and Sarmah (2012)
4	On-time delivery of goods	Chao *et al.* (1993), Aksoy and Ozturk (2011), Stewart (1995), Gunasekaran *et al.* (2004), Christopher (1992)
5	Flexibility to meet particular customer needs	Bhagwat and Sharma (2007), Bower and Hout (1988), Stewart (1995), Gunasekaran *et al.* (2001, 2004)
6	Customer query time	Gunasekaran *et al.* (2001, 2004), Bhagwat and Sharma (2007), Beamon (1999)
7	Flexibility of delivery systems to meet particular customer needs	Novich (1990), Bhagwat and Sharma (2007), Hill (1985), Cho *et al.* (2012)
8	Supplier selection	Aksoy and Ozturk (2011), Braglia and Petroni (2000), Karpak *et al.* (1999), Hong *et al.* (2005), Ghodsypour and O'Brien (1998), Meena *et al.* (2011), Meena and Sarmah (2013)
9	Delivery lead-time	Stewart (1995), Gelders *et al.* (1994), Gunasekaran *et al.* (2001), Shepherd and Gunter (2006)
10	Product cost	Kekre *et al.* (1995), Beamon (1999), Rosenthal and Tatikonda (1993), Brierley *et al.* (2006)
11	Range of product and services	Mapes *et al.* (1997), Gunasekaran *et al.* (2001, 2004), Fisher (1997), Bhagwat and Sharma (2007)
12	Customer order path	Gunasekaran *et al.* (2001, 2004), Bhagwat and Sharma (2007), Cho *et al.* (2012)
13	Mutual assistance in solving problems	Ellram (1991), Maloni and Benton (1997), MacBeth and Ferguson (1994), Landeros *et al.* (1995), New (1996), Maloni and Benton (1997), Cho *et al.* (2012), Thakkar *et al.* (2007), Doran *et al.* (2005)
14	Effectiveness of master production schedule	Gunasekaran *et al.* (2001), Cho *et al.* (2012), Robinson *et al.* (2008), Bhagwat and Sharma (2007)
15	Order lead-time	Gunasekaran *et al.* (2001, 2004), Bhagwat and Sharma (2007), Christopher (1992), Bower and Hout (1988), Towill (1997), Cho *et al.* (2012)
16	Flexibility	Robinson *et al.* (2008), Beamon (1999), Das (1996), Slack (1991)
17	Post-transaction measures of customer service	Bruhn and Georgi (2006), Gunasekaran *et al.* (2001, 2004), Bhagwat and Sharma (2007), Cho *et al.* (2012)
18	Purchase order cycle time	Boer *et al.* (2001), Aksoy and Ozturk (2011)
19	Order entry method	Gunasekaran *et al.* (2001, 2004), Bhagwat and Sharma (2007), Cho *et al.* (2012)
20	Effectiveness of delivery invoice methods	Gunasekaran *et al.* (2001, 2004), Bhagwat and Sharma (2007)

SCP (Chao *et al.*, 1993; Aksoy and Ozturk, 2011). Stewart (1995) revealed that any delivery performance can probably be increased through a reduction in lead-time attributes. On-time delivery determines whether perfect delivery has taken place or not and measures the level of customer service (Gunasekaran *et al.*, 2004).

2.5 Flexibility to meet particular customer needs

This is an essential factor for measuring the customer service performance in terms of customer demand. It includes product design, quality, delivery, reliability, and flexibility to fulfill the customer needs (Bhagwat and Sharma, 2007; Roh *et al.*, 2014). In another way, this refers to accessibility and the capability to supply products and services that meet a particular customer's needs. According to Bower and Hout (1988), the flexibility of any system has a high impact on engaging consumers and provides a high level of awareness to the customers (Gunasekaran *et al.*, 2001).

2.6 Customer query time

This refers to the time it takes for an organization to reply to a customer's query with the necessary information or a corresponding delivery (Gunasekaran *et al.*, 2001; Bhagwat and Sharma, 2007; Beamon, 1999; Tewari and Misra, 2013). It is not unethical for customers to ask about the status of their order. This kind of information really helps both service providers and customers to plan their further activities, and helps the industry to retain them as customers (Bhagwat and Sharma, 2007; Gunasekaran *et al.*, 2001). Fast service and the right response to customers' query are crucial for keeping customers happy.

2.7 Flexibility of delivery systems to meet particular customer needs

Nowadays, delivery system processes are becoming more flexible to consumer needs and expectations. Good flexibility always benefits the decision of the end users thus it can be considered an important attribute for satisfying and holding on to customers. Novich (1990) notified that the delivery of customers' order can be grouped into diverse sections, and the kind of flexibility processes that persuades consumers to place orders is significant for attracting customers (Bhagwat and Sharma, 2007). According to Cho *et al.* (2012), flexibility of the delivery system means flexibility of the service processes to meet various customer needs in terms of customer processing.

2.8 Supplier selection

Supplier selection plays a noteworthy role for both parties (buyer and supplier) in terms of cost and time reduction, which can improve the value and quality of the commodities (Aksoy and Ozturk, 2011). Selecting a good supplier can minimize the manufacturing costs and lead-time (Meena *et al.*, 2011; Meena and Sarmah, 2013). Braglia and Petroni (2000) revealed that firms benefit from a better supplier selection and a high level of reliability, since it reduces inventory costs and improves product quality. Thus, efficient supplier selection is an important key factor of SCP and potential research area.

2.9 Delivery lead-time

Delivery lead-time helps to increase the delivery performance of the SC (Stewart, 1995; Gelders *et al.*, 1994). Delivery lead-time reflects whether correct or faultless delivery has delivered on-time or not (Hammamia and Freinb, 2013). Other attributes influence delivery performance such as transportation, frequency of delivery, delivery reliability, etc.

2.10 Product cost

Product cost comes under the output measures of production performance and it includes the quality and quantity of the final product and customer responsiveness.

Manufacturers and researchers have argued that dealing with a limited number of suppliers leads to better quality and a lowering of the product cost (Kekre *et al.*, 1995; Meena *et al.*, 2011; Meena and Sarmah, 2013). According to Brierley *et al.* (2006), product costs are very important for decision making within the production process. The final resources affect the production of a SC, and the output of the SC system is important in determining the flexibility of the system. In this case, the output performance measures should be utilized properly (Beamon, 1999; Neely *et al.*, 2002).

2.11 Range of product and services

Companies that produce a wide range of products are expected to launch the latest technologies/products more gradually than companies with a narrower assortment of goods (Mapes *et al.*, 1997). Gunasekaran *et al.* (2004) reveals that a broad range of goods probably tend to perform less well in the areas of added values, such as the number of workers, speed, and delivery reliability. This clearly implies that the range of products affects the SCP. Fisher (1997) emphasized that the right selection of the SC approach depends upon the nature of the commodities, range, and product originality. The range of products and services also acts as an important strategic metric, and hence, it must be considered as a key factor for SCP (Gunasekaran *et al.*, 2001; Bhagwat and Sharma, 2007).

2.12 Customer order path

The customer order path determines the amount of time spent on different parts of the SC or a series of activities that need to deliver a service (Cho *et al.*, 2012). Inefficiencies can be identified and corrected by analysis of customer order path (Gunasekaran *et al.*, 2004). According to Gunasekaran *et al.* (2001) and Bhagwat and Sharma (2007), the whole process of the customer order path includes various activities such as the customer ordering status, order lead-time, delays in documentation, time spent in the storehouse, time used in product inspection, and rechecking. Therefore, it is one of the key factors of SCP. These different problems can be removed by deploying the JIT, IT, and advanced engineering methods.

2.13 Mutual assistance in solving problems

A strong partnership emphasizes a long-term relationship, mutual planning, and problem-solving efforts (Maloni and Benton, 1997). If a buyer-supplier relationship is strong, then their mutual understanding can be very helpful to solve different problems. Presently, trader partnerships has been given a lot of attention from businesses and researchers, resulting in a stable stream of supporting literature (e.g. Ellram, 1991; MacBeth and Ferguson, 1994; Landeros *et al.*, 1995; New, 1996; Maloni and Benton, 1997; Bhagwat and Sharma, 2007). Meena and Sarmah (2012) mentioned that to have a long-term relationship, both parties must be satisfied with each other's performance. Furthermore, mutual assistance supports the development of the buyer-supplier partnership.

2.14 Effectiveness of a master production schedule

Master scheduling in SC planning is used for scheduling the production throughout the SC, validating and managing the production plan. Scheduling deals with the distribution of resources and tasks over time to perform a set of activities (Cho *et al.*, 2012). Gunasekaran *et al.* (2001) stressed that suitable measures need to be taken to improve the master production schedule in SCM, since it provides the foundation for order promising and links the total production plan to the manufacturing of specific items, quantities, and dates. Scheduling also has a major impact supplier performance, capacity utilization, and customer satisfaction (Cho *et al.*, 2012). According to Robinson *et al.* (2008), scheduling depends on customer needs and supplier performance in the SC.

2.15 Order lead-time

The total order cycle time refers to the time between receiving a consumer's order and product delivery and it is also referred as order lead-time (Gunasekaran *et al.*, 2004). Order lead-time is another significant key factor and a base of economic advantage (Bower and Hout, 1988; Christopher, 1992; Gunasekaran *et al.*, 2001) as it directly affects the level of buyer satisfaction (Towill, 1997). A decrease in the order lead-time helps to reduce the response time of a firm's SC (Christopher, 1992; Gunasekaran *et al.*, 2004; Bhagwat and Sharma, 2007).

2.16 Flexibility

Flexibility is an important measure of production performance. According to Robinson *et al.* (2008), flexibility is particularly important when controlling the master production schedule, in which an effort to maintain "schedule flexibility" the firm tends to release procure orders one at a time to the retailer. Flexibility means offering a wide range of products and services and being able to adjust to the uncertainty of demand for the product offered. Flexibility has different meanings for different managers and several perfectly legitimate alternative paths exist toward flexible manufacturing (Beamon, 1999). Beamon (1999) highlighted various measures for flexibility in production systems. Slack (1991) defines system flexibility as the flexibility of the whole process.

2.17 Post-transaction measures of customer service

Customer service performance, while it is not the last stage of a SC, provides services to the end user. This type of service is applied after the delivery of final product (Bruhn and Georgi, 2006; Xuea *et al.*, 2013). Customer service plays a significant role for both the customer's needs and satisfaction, and for feedback to advance the development of the SC (Gunasekaran *et al.*, 2004; Bhagwat and Sharma, 2007). The timely availability of spares help industries to improve consumer facilities/services, and buyers are also able to trace problems occurring from warranty claims.

2.18 Purchase order cycle time

Purchase order cycle time treated with greater significance for fast and efficient delivery. It begins when materials are needed by a supplier, and is followed by many steps. Each step of the process is significant. Boer *et al.* (2001) suggested that the implications of the purchasing function and purchasing judgments have become more significant. As firms become more dependent on suppliers, the direct and indirect costs of poor decision making become more severe (Aksoy and Ozturk, 2011). The purchase order lead-time can have a significant impact on a company's base line. It is a key element of the delivery cycle time, along with the time it takes to make and deliver the product.

2.19 Order entry method

The order entry method helps to determine the requirement of the consumers, which converted into information and exchanged across the different parties of SC

(Gunasekaran *et al.*, 2001, 2004). SC may face huge loss, if the customers' requirements are not exchanged correctly at different stages of SC. It is important factor of the order planning measures and it can be improved through various efforts and associations among the different partners of SC (Gunasekaran *et al.*, 2004; Bhagwat and Sharma, 2007). Cho *et al.* (2012) mentioned that order entry method is one of the important key factors of SCPM.

2.20 Effectiveness of delivery invoice methods

Invoice methods help in receiving goods or materials with the delivery date, time, and the conditions. If the delivery invoice method is effective, then a product can be distributed effectively. This method determines if a product is delivered or not (Gunasekaran *et al.*, 2004). According to Gunasekaran *et al.* (2001) and Bhagwat and Sharma (2007), areas of discrepancy can be identified to ensure zero faults in the delivery performance.

3. Research methodology

In this paper, we have used ISM for modelling and investigating the inter-relationships among the key factors of SCP because it uses experts' opinions from brainstorming sessions to develop contextual relationships. Moreover, it is widely known method, which is applicable in diverse fields and helps to classify and highlight relationships among the different factors (Warfield, 1974; Sage, 1977). There are two basic concepts to know regarding the ISM approach, i.e., transitivity and reachability (Mudgal *et al.*, 2010). If variable x communicates to y and y communicates to z, then transitivity implies that variable x will necessarily communicate to z as shown in Figure 1. Transitivity is the basic theory in ISM and is always used in this modeling approach (Sharma *et al.*, 1995; Farris and Sage, 1975). The inter-relationships among the different key factors of SCP are achieved through the steps discussed by Mudgal *et al.* (2010). The flow diagram for the structure of an ISM methodology is shown in Figure 2 (Mudgal *et al.*, 2010).

4. ISM approach for modelling the key factors of SCP

For developing the ISM-based model, various steps are followed and we have used 20 key factors to develop the model. The identification of key factors and their relative relationships guide the development of the different matrices. After developing a model, the key factors were classified into four clusters based on their driving and dependence power by using a Fuzzy MICMAC analysis.

4.1 Structural self-interaction matrix (SSIM)

After identification of 20 key factors through a literature review and experts' opinions, the next step was to analyze these key factors. The contextual relationships between

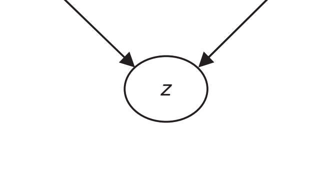

Figure 1.
Concept of transitivity

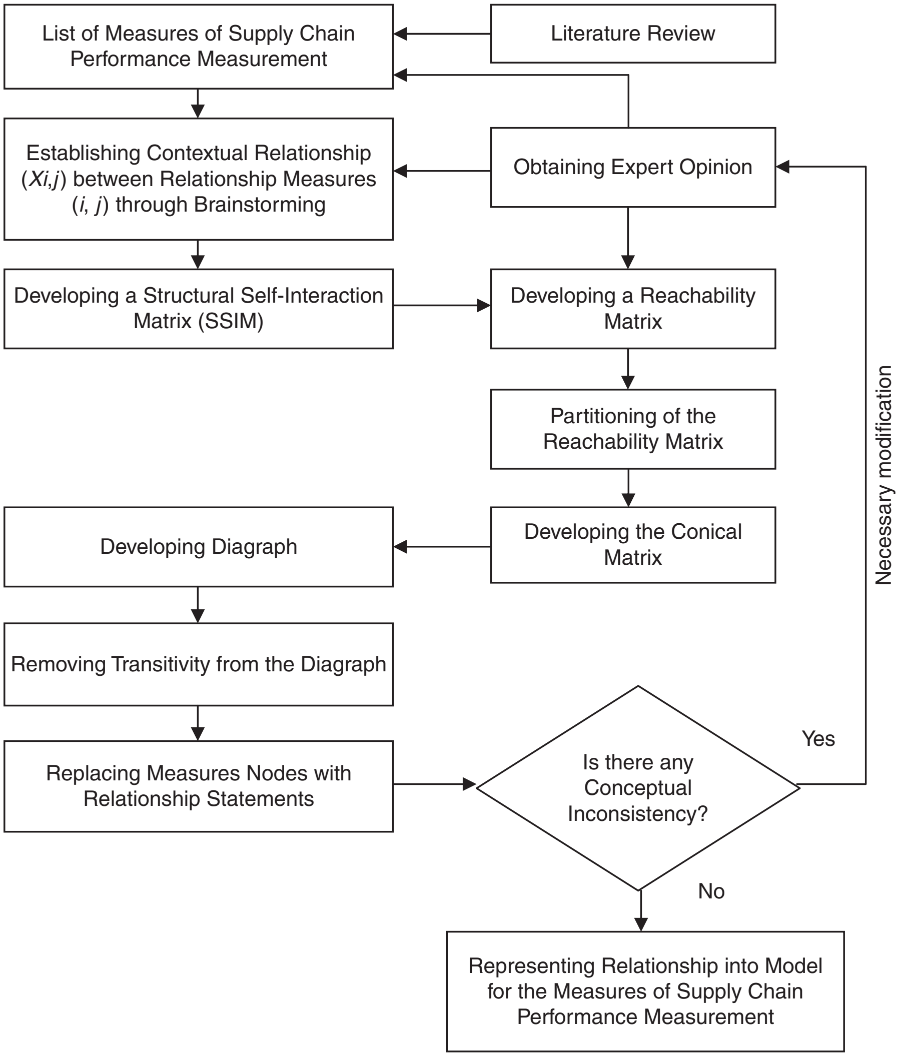

Figure 2.
Flow chart for ISM methodology

the key factors of the SC are made by expert opinions in a brainstorming session. A group of experts was consulted from academia and industry. These experts had over ten to 15 years of experience and were well familiar with the Indian automotive SC and their relationships. For analyzing the inter-relationships among these key factors, an appropriate relationship of "leads to" type was chosen. Four symbols (V, A, X, O) are used for establishing the contextual relationship among the key factors and a SSIM was developed which is presented in Appendix 1:

> V = if variable x influences variable y, A = if variable x is influenced by variable y; and X = if variables x and y influence each other, O = if variables x and y do not influence each other.

4.2 Development of reachability matrix

According to the theory of this model, the initial and final reachability matrices (FRMs) from the SSIM are to be developed. Thus, SSIM needs to be transformed into binary numbers (i.e. 1's or 0's), which is called the initial reachability matrix (see Appendix 2). The given rules are used to substitute V, A, X, O of the SSIM matrix to get reachability matrix:

- If (x, y) entry in the SSIM is V then (x, y) entry in the reachability matrix will be 1 and (y, x) entry will be 0.
- If (x, y) entry in the SSIM is A then (x, y) entry in the reachability matrix will be 0 and (y, x) entry will be 1.
- If (x, y) entry in the SSIM is X then (x, y) entry in the reachability matrix will be 1 and (y, x) entry will also be 1.
- If (x, y) entry in the SSIM is O then (x, y) entry in the reachability matrix will be 0 and (y, x) entry will also be 0.

In the next sub-step, the FRM is achieved by incorporating the transitivity. The transitivity concept is introduced for this purpose, and some of the cells of the IRM are filled in by inference. Transitivity holds the relation between three elements, for example, if the relationship holds between the first and second, and the relationship holds between the second and third, then the relationship must necessarily hold between the first and third (i.e. $x > y$, $y > z$ then $x > z$). Thus, after incorporating the transitivity concept in Appendix 2, the FRM is developed and is shown in Appendix 3. Moreover, the dependence and driving power of each factor are calculated by summing up the number of 1's in the columns and rows, respectively.

4.3 Partition of reachability matrix

After getting the FRM, partitions are made in order to find the hierarchy of each key factor. The level partitions of the different key factors are achieved by analyzing Appendices 4-5. The reachability set and antecedent set (Warfield, 1974) for each key factor is achieved from the FRM. The reachability set includes the key factor itself and another key factor that it might help to attain, whereas the antecedent set contains itself and other key factor that assist in getting it. After this, the intersection set is derived for all key factors based on the reachability set and the antecedent set. If the membership in the intersection set and reachability set are the same, then the highest priority is assigned in the hierarchy of the ISM model and that key factor is excluded from the following iteration. This process is repeated until the final iteration leads to the lowest level. Further, Appendix 4 explains the first iteration in which customer query time (key factor 6) is found at level I. Similarly, these processes are repeated until the level of each key factor is obtained. Results for iterations ii-xv are presented in Appendix 5.

4.4 Developing conical matrix

The development of the conical matrix is attained from the partitioned reachability matrix by clubbing together key factors according to their level, across the columns and rows of the FRM, which is used for developing the final diagraph and later the structural model. For example, key factor 17 is found at level II and key factor 13 at level X. Correspondingly, all the key factors were clubbed according to their level partition (see Appendix 6). Furthermore, the dependence power of a key factor is calculated by summing up the number of 1's in the columns and the driving power is calculated by summing up the number of 1's in the rows. Subsequently, ranks are calculated by giving the highest rank to the key factor that have the highest number of 1's in the rows and columns, which indicate the driving power and dependence power, respectively.

4.5 Development of diagraph

Based on the conical form of the reachability matrix, an initial diagraph including the transitivity links is obtained and generated by the nodes and lines of the edges. Relationship between two key factors is shown by an arrow from one key factor to another key factor. After confirming the hierarchy, an arrow is required to show the direction of the action. Similarly, a graph called a diagraph, is achieved after all the relationships (direct and indirect) are completed. Thus, a final diagraph is developed by removing the indirect links as shown in Figure 3. Based on the development process, top-level key factors are placed at the top of the diagraph and second-level key factors are placed at second position and so on, until the bottom level is placed at the lowest position in the diagraph.

4.6 Building the ISM-based model

Next, the diagraph is transformed into an ISM-based model by replacing the nodes of the key factors with statements as depicted in Figure 4. Figure 4 explains that order entry method (key factor 19) and order lead-time (key factor 15) are very important key factors in the Indian automotive SC as a hierarchy of ISM showing their position at the bottom level. Customer query time (key factor 6) secured the top position in the hierarchy, which means this key factor may influence the efficiency of SCP and the entire process of Indian automotive SC. Key factors 19 and 15 lead to the customer order path (key factor 12) and it will guide the supplier selection (key factor 8) toward the SCPM. Similarly, supplier selection leads to the purchase order cycle time (key factor 18) and it leads to the buyer-supplier relationship (key factor 3). Supplier selection plays a crucial role in reducing costs and improving the quality of the products. A strong buyer-supplier relationship always benefits from mutual assistance for solving problems (key factor 13). A strong buyer-supplier relationship should be in position before assigning the effectiveness of a master production schedule (key factor 14) and capacity utilization (key factor 2) which would be counter to SCPM in the Indian automotive SC. Key factors 2 and 14 are interrelated and lead to product cost (key factor 10), quality (key factor 1), flexibility (key factor 16), and a range of products and services (key factor 11). These key factors will further help with the flexibility of delivery systems to meet particular customers' needs (key factor 7). Key factor 7 guides to other key factors that are at the top of the hierarchy such as the effectiveness of the delivery invoice methods (key factor 20), on-time delivery of goods (key factor 4), delivery lead-time (key factor 9) and these key factors will further proceed to flexibility to meet the particular customer needs (key factor 5), and the post-transaction measure of customer service (key factor 17). Without the support of all bottom side of key factors, it would be very difficult to fill all gaps of customers' query and their needs in a SC.

5. Integration of ISM and Fuzzy MICMAC

The direct and indirect relationships among the key factors for implementing SCPM across the Indian automotive SC were carried out by an ISM and Fuzzy MICMAC. A direct relationship matrix (DRM) is obtained by examining the direct relationships among the criterion in the ISM as given in Appendix 1. Further, transitivity is ignored and

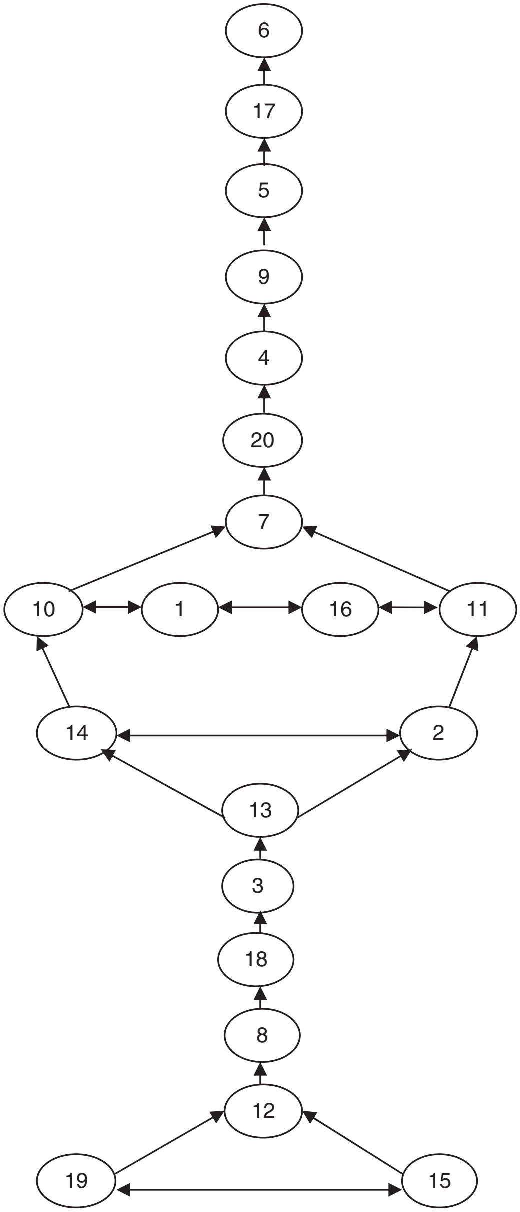

Figure 3.
Diagraph shows the levels of automotive SC measures

the diagonal entries are converted to zero. Then a DRM is derived which is shown in Appendix 7.

5.1 Fuzzy direct relationship matrix (FDRM)

Further analysis may be improved by considering the possibility of reachability instead of the mere consideration of reachability used so far. Usually, MICMAC

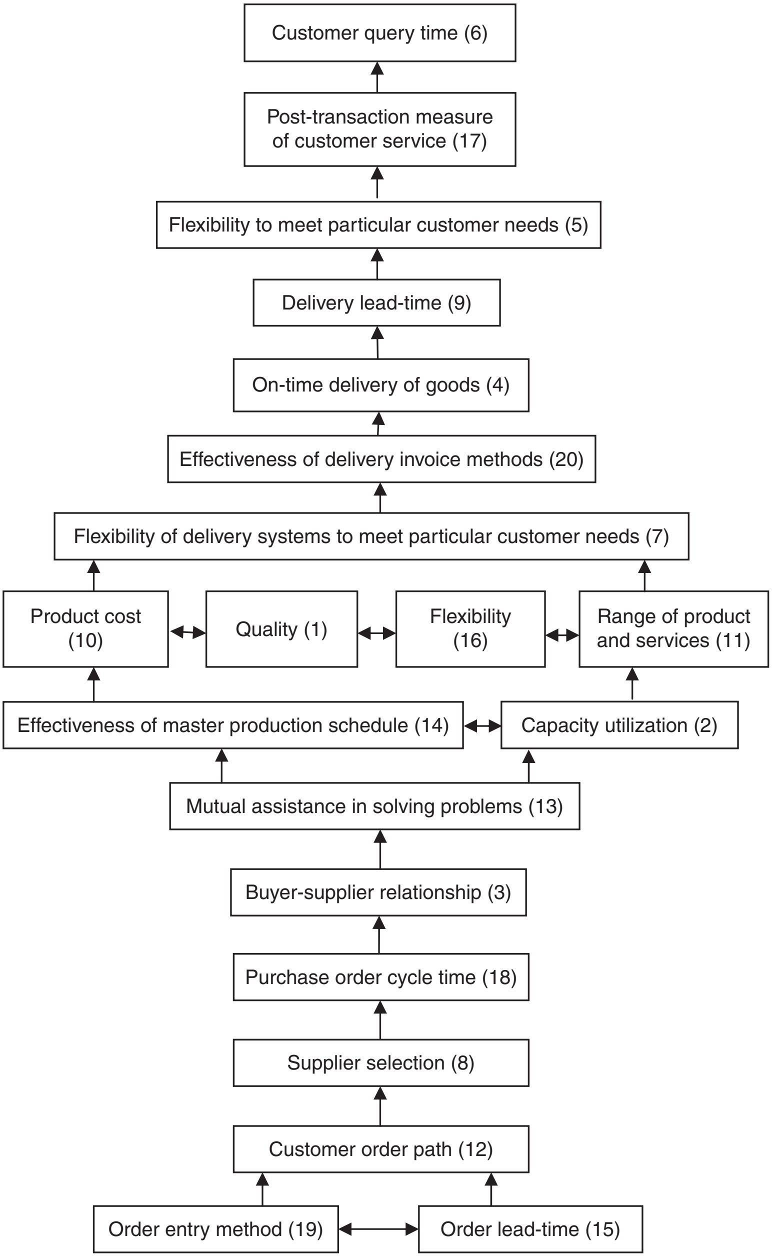

Figure 4. ISM-based model for automotive supply chain measures

considers only the binary type of relationships, so at this stage we have used a fuzzy set theory to increase the earlier sensitivity. By using the Fuzzy MICMAC, an additional input of possibility of relations among the key factors is established. The possibility of relations can be defined by a qualitative consideration on 0-1 scale, which is given in Table II (Qureshi *et al.*, 2008).

The possibility of the numerical value of reachability is covered up on the DRM to obtain a FDRM. Further, the DRM is achieved by examining the direct relationship among the key factors in the diagraph, disregarding the transitivity and making diagonal entries 0. The DRM and FDRM are shown in Appendices 7 and 8, respectively.

5.2 Convergence of FDRM

The FDRM is taken as a support to begin the procedure of finding the fuzzy indirect relationships between key factors. The matrix is multiplied or reproduced repeatedly up to a power until the hierarchies of the driving and dependence power are stabilized. This multiplication process follows the principle of fuzzy matrix multiplication (Zadeh, 1965), which is essentially a generalization of the Boolean matrix multiplication. According to the fuzzy set theory, when two fuzzy matrices are multiplied, the product matrix will also be a fuzzy matrix. Multiplication follows the rule given below: the product of fuzzy set A and fuzzy set B is fuzzy set C:

$$C = A.B = \max k\left[\min\left(a_{ik}, b_{kj}\right)\right]$$

where $A = (a_{ik})$ and $B = (b_{kj})$ are two fuzzy matrices.

5.3 Stabilization of fuzzy matrix

As discussed in the previous part, the FDRM process and matrix multiplication stabilizes the matrix. The fuzzy stabilized matrix is given in Appendix 9. Further, the ranks are calculated by giving the highest ranks to the key factors with the highest number of 1's in the rows and columns, which indicate the driving power and dependence power, respectively. The purpose of this classification of the key factors is to analyze the driving and dependence powers of the key factors that influence the performance of the SC in the Indian automotive sectors.

5.4 Fuzzy MICMAC analysis

The MICMAC method was developed by Duperrin and Godet (1973) to study the diffusion of impacts through reaction paths and loops for developing a hierarchy of key factors that can be used to identify and analyze different elements in a complicated system (Warfield, 1990). In addition, the MICMAC theory is based on the multiplication properties of matrices (Sharma *et al.*, 1995; Raj *et al.*, 2008). The purpose of the MICMAC analysis is to analyze the driving power and dependence of the variables (Mandal and Deshmukh, 1994; Faisal *et al.*, 2006). This study has integrated fuzzy with MICMAC, as Saxena *et al.* (1992) and Qureshi *et al.* (2008) stated in their study, that Fuzzy MICMAC derived from the FDRM can be a big help since the significance of a criterion is measured less by its direct inter-relationships and more by many indirect inter-relationships. Indirect relationships between the key factors have an impact on the selection method through the influence of interactions in the form of chains and reaction loops. This is known as feedback. The Fuzzy set theory has been applied to each criterion in the traditional MICMAC for a possible reachability matrix based on dependence as well as driving power. In addition, the Fuzzy MICMAC facilitates the

Table II.
Fuzzy scale

Possibility of reachability	No.	Negligible	Low	Medium	High	Very high	Full
Value	0	0.1	0.3	0.5	0.7	0.9	1.0

critical investigation of each criterion. In a Fuzzy MICMAC analysis, all the key factors are clustered into four categories, similar to a MICMAC analysis, of autonomous, dependent, linkage, and independent (driver) key factors according to their categories (see Figure 5). The first cluster is comprised of the key factors that have a weak driving power and weak dependence, which are called autonomous factors/variables. These key factors are relatively disconnected from the system with only a few links, which may be strong. The second cluster portrays dependent key factors that have strong dependence but weak driving power, which are called dependent key factors. The third cluster includes the key factors that have a strong driving power as well as a strong dependence. These are called linkage key factors because they are unstable, in the sense that any action on these key factors will have an effect on others and a feedback on themselves. The fourth cluster contains the key factors that have a strong driving power, however, a weak dependence that are called independent or driver key factors.

6. Conclusions and managerial implications

The SCPM key factors used in this paper are essential for the policy makers and managers to improve SCPM in the Indian automotive industry. There may be a few hidden key factors in any SC, thus this paper describes 20 key factors and explores the relationships among them. These key factors are identified based on literature review and a brainstorming session. The purpose of the brainstorming session was to identify the key factors of SCPM and developing a relationship matrix as a first step toward building the ISM-based model. The relationships among the key factors were explored using the ISM approach. The key factors identified in this paper are helpful in measuring the SCP of the Indian automotive firms. The driving and dependency power are calculated (see Figure 5) using Fuzzy MICMAC analysis. Figure 4 provides valuable suggestions for the top management of automotive firms about the significance of the key factors.

The results provided in Figure 4 show that the order entry method (key factor 19) and order lead-time (key factor 15) are the significant key factors, showing a higher driving power at the bottom of the hierarchy. Therefore, top management should focus on these key factors to make an effective and efficient SC. These results may be useful for the firm's management in order to rethink their business strategy. It is evident from Figure 5 that there is no autonomous key factor, which suggests that all the considered key factors influence SCPM in the Indian automotive industry.

It is also observed that the customer query time (key factor 6), post-transaction measure of customer service (key factor 17), flexibility to meet particular customer needs (key factor 5), delivery lead-time (key factor 9), on-time delivery of goods (key factor 4), effectiveness of delivery invoice methods (key factor 20), and flexibility of the delivery systems to meet particular customer needs (key factor 7) are the weak key factors. However, they have a strong dependence on other key factors such as the order entry method (key factor 19), order lead-time (key factor 15), customer order path (key factor 12), supplier selection (key factor 8), purchase order cycle time (key factor 18), buyer-supplier relationship (key factor 3), and mutual assistance in solving problems (key factor 13). These key factors represent the awareness related to SCPM with a high support of buyer's strategy or planning performance as well as supplier's involvement, as shown in Figure 4. Figure 5 also indicates that there are four linkage key factors, i.e., product cost (key factor 10), quality (key factor 1), flexibility (key factor 16), and range of product and services (key factor 11). These connect the driving key factors

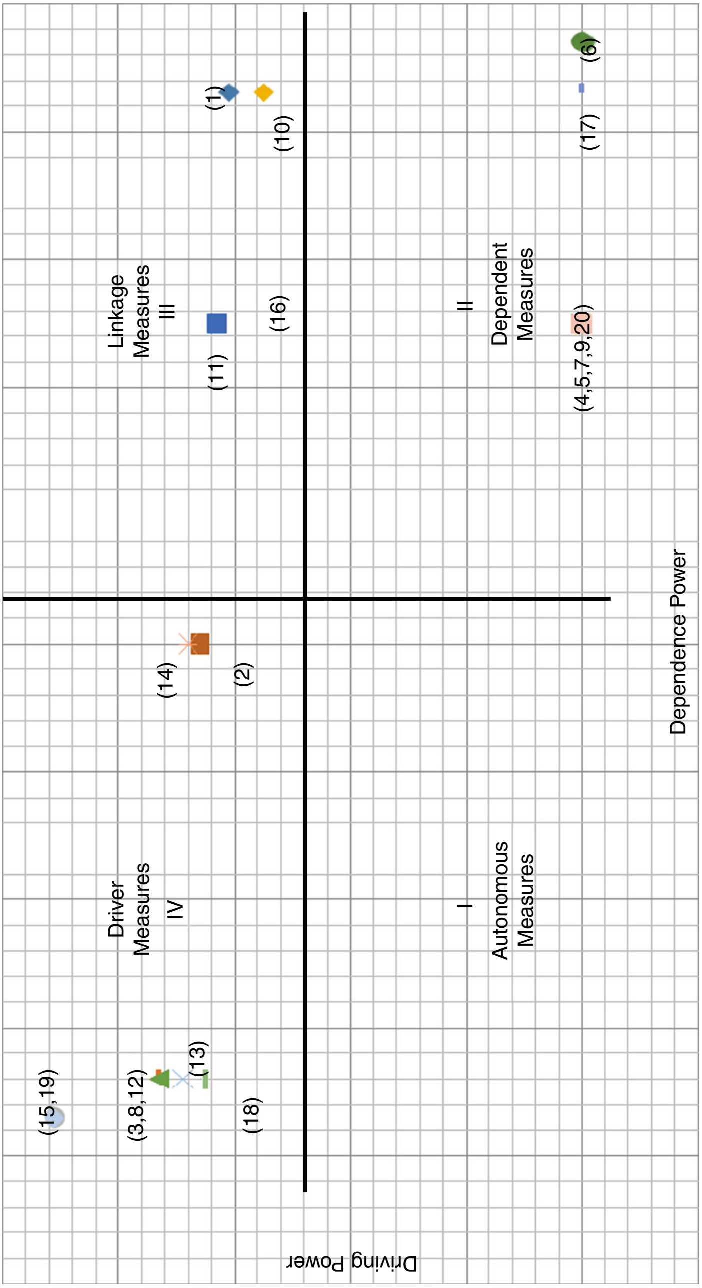

Figure 5.
Driving power and dependence power diagram

with the dependent key factors. The linkage key factors are derived from the absolute driving key factors and are the result of absolute dependent key factors. Only seven key factors have a strong driving power and are less dependent on others. Therefore, these are the root key factors and firms' top managers must pay more attention on these key factors. Nine key factors have the least amount of dependence but a strong driving power. Thus, these are root key factors and management should focus on these key factors as an initiative to improve their SCP. Some important key factors were uncovered in this study and put into an ISM model to explore the relationships among them. In this paper, a model is developed to identify the key factors for SCPM in the Indian automotive industry. However, it is more generalized in nature, so it can also be utilized in other industry.

7. Limitations and scope for future work

The model developed here is limited to identification of the key factors of the SCPM in the Indian automotive industry based on literature review and the experts' opinion. Similar study can be conducted in different sectors as well from different perspectives. The ISM-based model may be tested in other industries and real world setting by adding or removing some key factors based on the type of industry and test any correlations among the key factors. The key factors considered here may be partial or their relationships may be different according to the types and sizes of the firm. Furthermore, apart from the ISM approach, other techniques may be utilized with a larger sample size.

The model proposed in this paper has not been statistically validated yet. The developed hypothetical model may be tested using structural equation modeling (Jharkharia and Shankar, 2005). Future research for researchers or academicians is to test and validate this model, which can be done as discussed above. This study can also be applied to automotive clusters analysis and comparison can be made by using the analytic hierarchy process (AHP) or fuzzy AHP.

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Appendix 1

Sl. no.	Measures	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	Quality	V	A	A	V	X	A	A	A	A	X	X	O	A	V	V	V	V	A	A	
2	Capacity utilization	V	A	A	V	V	A	X	A	A	V	V	V	A	V	V	V	V	A		
3	Buyer-supplier relationship	V	A	A	V	V	A	V	V	A	V	V	V	A	V	V	V	V			
4	On-time delivery of goods	A	A	A	V	A	A	A	A	A	A	O	V	A	A	V	V				
5	Flexibility to meet particular customer needs	A	A	A	V	A	A	A	A	A	A	A	A	A	A	V					
6	Customer query time	A	O	A	A	A	A	A	A	A	A	A	A	A	A						
7	Flexibility of delivery systems to meet particular customer needs	V	A	A	V	A	A	A	A	A	A	A	V	A							
8	Supplier selection	V	A	V	O	V	A	V	V	A	V	V	V								
9	Delivery lead-time	A	A	A	V	A	A	A	A	A	A	A									
10	Product cost	O	A	A	V	X	O	A	A	A	X										
11	Range of product and services	V	A	A	V	X	A	A	A	A											
12	Customer order path	O	A	V	O	V	A	V	V												
13	Mutual assistance in solving problems	V	A	A	V	V	A	V													
14	Effectiveness of master production schedule	V	A	A	V	V	A														
15	Order lead-time	V	X	V	O	V															
16	Flexibility	V	A	A	V																
17	Post-transaction measures of customer service	A	O	O																	
18	Purchase order cycle time	O	A																		
19	Order entry method	O																			
20	Effectiveness of delivery invoice methods																				

Table AI. Structural self-interaction matrix (SSIM)

Appendix 2

Table AII.
Initial reachability matrix (IRM)

Sl. no.	Measures	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Quality	1	0	0	1	1	1	1	0	0	1	1	0	0	0	0	1	1	0	0	1
2	Capacity utilization	1	1	0	1	1	1	1	0	1	1	1	0	0	1	0	1	1	0	0	1
3	Buyer-supplier relationship	1	1	1	1	1	1	1	0	1	1	1	0	1	1	0	1	1	0	0	1
4	On-time delivery of goods	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0
5	Flexibility to meet particular customer needs	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
6	Customer query time	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Flexibility of delivery systems to meet particular customer needs	0	0	0	1	1	1	1	0	1	0	0	0	0	0	0	0	1	0	0	1
8	Supplier selection	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	0	1	0	1
9	Delivery lead-time	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0
10	Product cost	1	0	0	0	1	1	1	0	1	1	1	0	0	0	0	1	1	0	0	0
11	Range of product and services	1	0	0	1	1	1	1	0	1	1	1	0	0	0	0	1	1	0	0	1
12	Customer order path	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	0	0
13	Mutual assistance in solving problems	1	1	0	1	1	1	1	0	1	1	1	0	1	1	0	1	1	0	0	1
14	Effectiveness of master production schedule	1	1	0	1	1	1	1	0	1	1	1	0	0	1	0	1	1	0	0	1
15	Order lead-time	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1
16	Flexibility	1	0	0	1	1	1	1	0	1	1	1	0	0	0	0	1	1	0	0	1
17	Post-transaction measures of customer service	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
18	Purchase order cycle time	1	1	1	1	1	1	1	0	1	1	1	0	1	1	0	1	0	1	0	0
19	Order entry method	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	0
20	Effectiveness of delivery invoice methods	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	1

Appendix 3

Measures sl. no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Driving power
1	1	0	0	1	1	1	1	0	1[a]	1	1	0	0	0	0	1	1	0	0	1	11
2	1	1	0	1	1	1	1	0	1	1	1	0	0	1	0	1	1	0	0	1	13
3	1	1	1	1	1	1	1	0	1	1	1	0	1	1	0	1	1	0	0	1	15
4	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	5
5	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3
6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
7	0	0	0	1	1	1	1	0	1	0	0	0	0	0	0	0	1	0	0	1	7
8	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1[a]	1	0	1	17
9	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	4
10	1	0	0	1[a]	1	1	1	0	1	1	1	0	0	0	0	1	1	0	0	1[a]	11
11	1	0	0	1	1	1	1	0	1	1	1	0	0	0	0	1	1	0	0	1	11
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1[a]	1	0	1[a]	18
13	1	1	0	1	1	1	1	0	1	1	1	0	1	1	0	1	1	0	0	1	14
14	1	1	0	1	1	1	1	0	1	1	1	0	0	1	0	1	1	0	0	1	13
15	1	1	1	1	1	1	1	1	1	1[a]	1	1	1	1	1	1	1[a]	1	1	1	20
16	1	0	0	1	1	1	1	0	1	1	1	0	0	0	0	1	1	0	0	1	11
17	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2
18	1	1	1	1	1	1	1	0	1	1	1	0	1	1	0	1	1[a]	1	0	1[a]	16
19	1	1	1	1	1	1[a]	1	1	1	1	1	1	1	1	1	1	1[a]	1	1	1[a]	20
20	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	1	6
Dependence	13	9	6	16	18	20	14	4	17	13	13	3	7	9	2	13	19	5	2	15	

Note: [a]Shows the transitivity

Table AIII. Final reachability matrix (FRM)

Appendix 4

Measures	Reachability set	Antecedents set	Intersection set	Level
1	1,4,5,6,7,9,10,11,16,17,20	1,2,3,8,10,11,12,13,14,15,16,18,19	1,10,11,16	
2	1,2,4,5,6,7,9,10,11,14,16,17,20	2,3,8,12,13,14,15,18,19	2,14	
3	1,2,3,4,5,6,7,9,10,11,13,14,16,17,20	3,8,12,15,18,19	3	
4	4,5,6,9,17	1,2,3,4,7,8,10,11,12,13,14,15,16,18,19,20	4	
5	5,6,17	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16,18,19,20	5	
6	6	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	6	I
7	4,5,6,7,9,17,20	1,2,3,7,8,10,11,12,13,14,15,16,18,19	7	
8	1,2,3,4,5,6,7,8,9,10,11,13,14,16,17,18,20	8,12,15,19	8	
9	5,6,9,17	1,2,3,4,7,8,9,10,11,12,13,14,15,16,18,19,20	9	
10	1,4,5,6,7,9,10,11,16,17,20	1,2,3,8,10,11,12,13,14,15,16,18,19	1,10,11,16	
11	1,4,5,6,7,9,10,11,16,17,20	1,2,3,8,10,11,12,13,14,15,16,18,19	1,10,11,16	
12	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17,18,20	12,15,19	12	
13	1,2,4,5,6,7,9,10,11,13,14,16,17,20	3,8,12,13,15,18,19	13	
14	1,2,4,5,6,7,9,10,11,14,16,17,20	2,3,8,12,13,14,15,18,19	2,14	
15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	15,19	15,19	
16	1,4,5,6,7,9,10,11,16,17,20	1,2,3,8,10,11,12,13,14,15,16,18,19	1,10,11,16	
17	6,17	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16,17,18,19,20	17	
18	1,2,3,4,5,6,7,9,10,11,13,14,16,17,18,20	8,12,15,18,19	18	
19	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	15,19	15,19	
20	4,5,6,9,17,20	1,2,3,7,8,10,11,12,13,14,15,16,18,19,20	20	

Table AIV. Measures-level iteration *i*

Appendix 5

Iteration	Measures	Reachability set	Antecedents set	Intersection set	Level
ii	17	17	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16,17,18,19,20	17	II
iii	5	5	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16,18,19,20	5	III
iv	9	9	1,2,3,4,7,8,9,10,11,12,13,14,15,16,18,19,20	9	IV
v	4	4	1,2,3,4,7,8,10,11,12,13,14,15,16,18,19,20	4	V
vi	20	20	1,2,3,7,8,10,11,12,13,14,15,16,18,19,20	20	VI
vii	7	7	1,2,3,7,8,10,11,12,13,14,15,16,18,19	7	VII
viii	1	1,10,11,16	1,2,3,8,10,11,12,13,14,15,16,18,19	1,10,11,16	VIII
viii	10	1,10,11,16	1,2,3,8,10,11,12,13,14,15,16,18,19	1,10,11,16	VIII
viii	11	1,10,11,16	1,2,3,8,10,11,12,13,14,15,16,18,19	1,10,11,16	VIII
viii	16	1,10,11,16	1,2,3,8,10,11,12,13,14,15,16,18,19	1,10,11,16	VIII
ix	2	2,14	2,3,8,12,13,14,15,18,19	2,14	IX
ix	14	2,14	2,3,8,12,13,14,15,18,19	2,14	IX
x	13	13	3,8,12,13,15,18,19	13	X
xi	3	3	3,8,12,15,18,19	3	XI
xii	18	18	8,12,15,18,19	18	XII
xiii	8	8	8,12,15,19	8	XIII
xiv	12	12	12,15,19	12	XIV
xv	15	15,19	15,19	15,19	XV
xv	19	15,19	15,19	15,19	XV

Table AV.
Measures-level iteration *ii-xv*

Appendix 6

Table AVI.
Conical matrix

Measures sl. no.	6	17	5	9	4	20	7	1	10	11	16	2	14	13	3	18	8	12	15	19	Driving power
6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
17	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
5	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
9	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
4	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
20	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
7	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	7
1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	11
10	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	11
11	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	11
16	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	11
2	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	13
14	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	13
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	14
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	15
18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	16
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	17
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	18
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20
19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	20
Dependence	20	19	18	17	16	15	14	13	13	13	13	9	9	7	6	5	4	3	2	2	

Appendix 7

Sl. no.	Measures	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Quality	0	0	0	1	1	1	1	0	0	1	1	0	0	0	0	1	1	0	0	1
2	Capacity utilization	1	0	0	1	1	1	1	0	1	1	1	0	0	1	0	1	1	0	0	1
3	Buyer-supplier relationship	1	1	0	1	1	1	1	0	1	1	1	0	1	1	0	1	1	0	0	1
4	On-time delivery of goods	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0
5	Flexibility to meet particular customer needs	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
6	Customer query time	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Flexibility of delivery systems to meet particular customer needs	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	1
8	Supplier selection	1	1	1	1	1	1	1	0	1	1	1	0	1	1	0	1	0	1	0	1
9	Delivery lead-time	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
10	Product cost	1	0	0	0	1	1	1	0	1	0	1	0	0	0	0	1	1	0	0	0
11	Range of product and services	1	0	0	1	1	1	1	0	1	1	0	0	0	0	0	1	1	0	0	1
12	Customer order path	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	0	1	0	0
13	Mutual assistance in solving problems	1	1	0	1	1	1	1	0	1	1	1	0	0	1	0	1	1	0	0	1
14	Effectiveness of master production schedule	1	1	0	1	1	1	1	0	1	1	1	0	0	0	0	1	1	0	0	1
15	Order lead-time	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	0	1	1	1
16	Flexibility	1	0	0	1	1	1	1	0	1	1	1	0	0	0	0	0	1	0	0	1
17	Post-transaction measures of customer service	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	Purchase order cycle time	1	1	1	1	1	1	1	0	1	1	1	0	1	1	0	1	0	0	0	0
19	Order entry method	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	0	0
20	Effectiveness of delivery invoice methods	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0

Table AVII. Direct relationship matrix

Appendix 8

Measures sl. no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Sum
1	0	0	0	0.3	0.3	0.7	0.3	0	0	0.9	0.5	0	0	0	0	0.3	0.7	0	0	0.3	4.3
2	0.5	0	0	0.5	0.5	0.5	0.7	0	0.5	0.3	0.5	0	0	0.5	0	0.7	0.1	0	0	0.1	5.4
3	0.7	0.5	0	0.7	0.5	0.3	0.7	0	0.5	0.3	0.5	0	0.7	0.5	0	0.7	0.3	0	0	0.3	7.2
4	0	0	0	0	0.5	0.7	0	0	0.7	0	0	0	0	0	0	0	0.5	0	0	0	2.4
5	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0.7	0	0	0	1.6
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0.7	0.7	0.7	0	0	0.5	0	0	0	0	0	0	0	0.3	0	0	0.5	3.4
8	0.9	0.5	0.7	0.5	0.5	0.3	0.5	0	0.3	0.5	0.5	0	0.7	0.5	0	0.5	0	0.5	0	0.5	7.9
9	0	0	0	0	0.7	0.5	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	1.7
10	0.7	0	0	0	0.3	0.3	0.3	0	0.3	0	0.5	0	0	0	0	0.5	0.3	0	0	0	3.2
11	0.7	0	0	0.5	0.5	0.5	0.7	0	0.5	0.7	0	0	0	0	0	0.5	0.3	0	0	0.5	5.4
12	0.5	0.7	0.3	0.5	0.5	0.3	0.5	0.9	0.3	0.5	0.5	0	0.5	0.5	0	0.7	0	0.5	0	0	7.7
13	0.7	0.5	0	0.5	0.3	0.3	0.5	0	0.3	0.5	0.5	0	0	0.5	0	0.5	0.5	0	0	0.5	6.1
14	0.7	0.5	0	0.7	0.3	0.5	0.7	0	0.5	0.5	0.7	0	0	0	0	0.5	0.5	0	0	0.3	6.4
15	0.3	0.5	0.5	0.5	0.5	0.3	0.7	0.5	0.5	0	0.3	0.7	0.5	0.7	0	0.5	0	0.5	0.3	0.5	8.3
16	0.7	0	0	0.7	0.7	0.5	0.9	0	0.7	0.5	0.5	0	0	0	0	0	0.3	0	0	0.5	6
17	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9
18	0.5	0.5	0.5	0.5	0.3	0.3	0.5	0	0.3	0.3	0.5	0	0.3	0.5	0	0.5	0	0	0	0	5.5
19	0.3	0.5	0.5	0.5	0.3	0	0.5	0.7	0.5	0.3	0.3	0.7	0.3	0.5	0.3	0.5	0	0.5	0	0	7.2
20	0	0	0	0.7	0.5	0.3	0	0	0.7	0	0	0	0	0	0	0	0.5	0	0	0	2.7
Sum	7.2	4.2	2.5	7.8	7.9	8.8	7.5	2.1	7.1	5.3	5.8	1.4	3	4.2	0.3	6.4	5.5	2	0.3	4	

Table AVIII. Fuzzy direct relationship matrix

Appendix 9

Measures sl. no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Sum	Rank
1	0.5	0	0	0.5	0.5	0.7	0.5	0	0.5	0.7	0.5	0	0	0	0	0.5	0.7	0	0	0.5	6.1	11
2	0.5	0	0	0.5	0.5	0.7	0.5	0	0.5	0.7	0.5	0	0	0.5	0	0.5	0.7	0	0	0.5	6.6	8
3	0.7	0.5	0	0.5	0.5	0.7	0.5	0	0.5	0.7	0.5	0	0	0.5	0	0.5	0.7	0	0	0.5	7.3	3
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
8	0.7	0.5	0	0.5	0.5	0.7	0.5	0	0.5	0.7	0.5	0	0	0.5	0	0.5	0.7	0	0	0.5	7.3	3
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
10	0.5	0	0	0.5	0.5	0.5	0.5	0	0.5	0.5	0.5	0	0	0	0	0.5	0.5	0	0	0.5	5.5	13
11	0.7	0	0	0.5	0.5	0.7	0.5	0	0.5	0.7	0.5	0	0	0	0	0.5	0.7	0	0	0.5	6.3	10
12	0.7	0.5	0	0.5	0.5	0.7	0.5	0	0.5	0.7	0.5	0	0	0.5	0	0.5	0.7	0	0	0.5	7.3	3
13	0.7	0.5	0	0.5	0.5	0.7	0.5	0	0.5	0.5	0.5	0	0	0.5	0	0.5	0.5	0	0	0.5	6.9	6
14	0.7	0.5	0	0.5	0.5	0.7	0.5	0	0.5	0.7	0.5	0	0	0	0	0.5	0.7	0	0	0.5	6.8	7
15	0.7	0.5	0.3	0.5	0.5	0.7	0.5	0.3	0.5	0.7	0.5	0.3	0.3	0.5	0	0.5	0.7	0.3	0.3	0.5	9.1	1
16	0.7	0	0	0.5	0.5	0.7	0.5	0	0.5	0.5	0.5	0	0	0	0	0.5	0.5	0	0	0.5	5.9	12
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
18	0.5	0.5	0	0.5	0.5	0.5	0.5	0	0.5	0.5	0.5	0	0	0.5	0	0.5	0.5	0	0	0.5	6.5	9
19	0.7	0.5	0.3	0.5	0.5	0.7	0.5	0.3	0.5	0.7	0.5	0.3	0.3	0.5	0.3	0.5	0.7	0.3	0	0.5	9.1	1
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
Sum	8.3	4	0.6	6.5	6.5	8.7	6.5	0.6	6.5	8.3	6.5	0.6	0.6	4	0.3	6.5	8.3	0.6	0.3	6.5		
Rank	2	12	14	5	5	1	5	14	5	2	5	14	14	12	19	5	2	14	19	5		

Table AIX. Fuzzy stabilized matrix

About the authors

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