An approach for analysing supply chain complexity drivers through interpretive structural modelling

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An Approach for Analyzing Supply Chain Complexity Drivers through Interpretive Structural Modelling

Abstract

Today's greater product variety, shorter product life cycle, and lower production costs are pushing companies to look beyond their own boundaries, thereby, creating complexity in the management of the supply chain. To manage such complexity, it is imperative that the management understand the associated complexity drivers and their interrelationships. This study identified twenty-three drivers responsible for supply chain complexity and classified them by using various criteria. In addition, the study presents a structural model using interpretive structural modelling (ISM) methodology to understand the inter-relationships between one driver to another. The research findings showed that drivers such as customer need, competitor action, and government regulation are beyond the control of supply chain partners, and have found the highest dominance with respect to supply chain complexity. Conversely, drivers related to tactical issues such as production planning and control, logistics and transportation, forecasting error, and marketing and sales are found to be the dependent drivers. Remaining drivers, such as company culture, number of suppliers, product variety, and organizational structure fall between the former two classifications. These drivers are related to strategic issues and require action from the upper level of the management hierarchy.

Keywords Supply chain complexity, Complexity drivers, Driver classification, Interpretive structural modelling (ISM), ISM digraph.

1. Introduction

Managing the supply chain (SC) is a critical issue in any kind of business domain, as the success or failure of an organization is highly dependent on the capacity and capability to manage its SC network. In the era of technological revolution, global companies are working in a distributed business environment, where they need to keep on eye on every aspect of their supply networks. To be successful in today's competitive business environment, firms always need to monitor their supply networks on real-time basis (Roh et al., 2014; Khadem et al., 2017). Furthermore, the growing trend of market competition and higher customer demands with more preferences are creating a complex scenario within global business environment. Higher product variety, shorter product life cycle and increasing product development cost are pushing manufacturing companies to look beyond their own boundaries. Such changes within the business environment create additional complexity to the manufacturing companies.

The complexity is further exacerbated when there is a lack of strategical coordination among SC stakeholders that needs to be adaptive, flexible and coherent (Surana et al., 2005; Vilko et al., 2014). Therefore, along with the improvement of product design and development procedure, it is necessary to improve the SC management of the companies to reduce complexity (Eckstein et al., 2015). To maintain stability in their everyday operations, firms need to monitor their SC structures that affect the occurrence of disruptions due to complexity (Bode and Wagner, 2015). Such complexity and disruption in the SC network have detrimental impacts on the business environment (Blome et al., 2014).

SC complexity has been considered as an important research effort that attempts to harness the generic factors or drivers causing the complexities in diverse business domains. According to Serdarasan (2013), "A supply chain complexity driver is any property of a supply chain that increases its complexity". These drivers may be associated within plant levels such as organizational structure, information flow, operational processes or outside the plant level that is connected with downstream and upstream partners (Bozarth et al., 2009). The identification of the drivers is critical to manage or mitigate complexity in a SC (Walker et al. 2008). Bode and Wagner (2015) found that the presence of a complexity driver increases the frequency of SC disruptions, as well as, the drivers interact and amplify each other's effects in a synergistic manner. These drivers can be interpreted as a useful technique or tool for measuring and managing SC and associated disruptions (Yang and Yang, 2010) as Kaplan (1990) stated that 'No measures, no improvement'.

Identification of complexity drivers helps the organizational manager to measure the overall performance of their SC. Such measurements scheme can be adopted in both upstream and downstream of the SC network (Olugu et al., 2011). In SC network, complexities arise by drivers generated through interactions between manufacturers, customers, assemblers, distributors and retailers (Pathak et al. 2007). Many researches have been carried out in the past to understand SC complexity (Perona and Miragliotta, 2004; Bode and Wagner 2015). The term has been discussed from various viewpoints in the literature. However, no efforts are found in past research to understand the major drivers that trigger complexity in SC and the relationship of one driver over others in terms of complexity. Understanding of complexity drivers and interaction or dependency of one driver over others allows the organization to develop a clear strategy to manage complexity. Therefore, to improve SC management, companies need to identify, classify and analyze the drivers responsible for complex SC. From the consequences, three research questions (RQ) are identified for this research, which can be stated as follow:

- RQ 1: What is the generic concept of SC complexity that evolves in the industrial domain?

- RQ 2: What are the available drivers, which cause complexity in SC?
- RQ 3: How to analyze and categorize the interactions among the identified drivers, which are responsible for SC complexity?

The remaining portion of the paper is structured as follows. Section 2 illustrates the relevant reviews of existing literature, while, Section 3 is dedicated to the identification of SC complexity drivers and their classifications based on the predefined criteria. In section 4, the drivers are analyzed to know the interactions and contextual relationships among them by using an interpretive structural modelling (ISM) tool. In Section 5, the results obtained from ISM tool is validated statistically. Section 6 discusses the insights drawn from the research for managerial implications. The paper concludes with future research directions in Section 7.

2. Literature review

Complexity is a concept that plays an important role in many academic disciplines. It is considered as an important theme in the SC literature, where there is a general consensus that supply chains have become increasingly complex over the last decades and that this complexity is not a desirable feature (Bode and Wagner, 2015). There is no universal definition of SC complexity. However, most of the research studies have identified SC complexity as a multi-faceted, multi-dimensional phenomenon that is driven by several sources (Manuj and Sahin, 2011). Kavilal et al. (2018) defined complexity as the aspect to measure the stability of connectivity between various suppliers. In manufacturing, a wide mix of components, subgroups and final products, together with the need to deliver them to many different customers in various ways create complexity (Perona and Miragliotta, 2004). In general, any kind of complexity in the SC will have negative impact on operations (Bozarth et al., 2009), trigger disruptions (Chopra and Sodhi, 2014), and complicates decision-making process (Narasimhan and Talluri, 2009). Although, dealing with complexity is not so easy, but various studies have shown that if it can be managed properly leads to better SC performances (Koudal and Engel, 2007; Eckstein et al., 2015). The company that can identify the drivers of complexity and accommodate them with appropriate actions from all concerned SC partners may derive a competitive advantage (Fisher, 1997; Isik, 2010). Such evidence motivates to justify the necessity to consider complexity management as an integral part of SC management. The research so far on SC complexity management is focused mainly on three essential areas as described in the following sub-sections.

2.1 Identification of complexity drivers

Complexities within SC are numerous and are evolving due to globalization, customization, innovation, flexibility, sustainability, and uncertainties. In general, SC complexity depends on several drivers such as number of suppliers (Goffin et al., 2006), degree of differentiation among the suppliers (Choi and Krause, 2006), delivery lead time and reliability of suppliers (Vollmann et al., 2005), extent of global sourcing (Cho and Kang, 2001), level of inter-relationship among the suppliers (Choi and Krause, 2006), etc. The first step towards SC complexity management is to identify the drivers responsible for complexity (Aelker et al., 2013) and then prioritize them (Kavila et al. (2017). Many papers have contributed to the identification of SC complexity drivers. Mohrschladt (2007) identified various drivers of complexity in the chemical industry's supply chain and analyzed the effect of these drivers on the plant's performance. Bozarth et al. (2009) identified eleven drivers of SC complexity. Their analysis demonstrated that complexity arising at any location in supply chain have a negative impact on manufacturing plant's performance. Serdarasan, (2013) identified eighteen drivers after extensive literature surveys that create complexity in SC. De Leeuw et al. (2013) identified eight drivers and illustrated a mechanism to cope with SC complexity in distributive trade. Furthermore, Bode and Wagner (2015) identified three different complexity drivers at upstream level of SC. They found that all these complexity drivers increase the frequency of disruption in SC. It can, therefore, be concluded that identifying and understanding the drivers are critical before devising strategies to manage SC complexity (Manuj and Sahin, 2009).

2.2 Classification of complexity driver

After the necessary identification of SC complexity drivers, it is important to classify them in order to manage them efficiently. Complexity in SC has been categorized using various criteria. Accordingly, the drivers of SC complexity also have been classified. Studies found that SC complexity is mainly classified as static and dynamic (Serdarasan, 2013). According to Hamta et al. (2015), the drivers of static complexity are associated with the structure of the SC, the number and the variety of its components and strengths of interactions between them. On the other hand, the dynamic complexity is related to the uncertainty in SC and involves the aspects of time and randomness. It represents the drivers that create complexity at an operational level in SC. However, this criterion of categorizing complexity drivers is not limited. Flynn and Flynn (1999) and Bode and Wagner (2015) categorized SC complexity drivers based on location, such as upstream, mid-stream or downstream levels of SC. Upstream complexity and associated drivers are basically related to supplier base, whereas, downstream complexity and the associated drivers are related to customer base. Childerhouse and Towill (2004) and Blecker et al. (2005) categorized SC complexity and the associated drivers based on the origin such as internal, external and interfacial. According to them, internal complexity in SC may arise due to the drivers, which are an integral part of organization. The drivers of internal complexity include product, process and information flow, all of which are related to a business unit (BU). On the other hand, external complexity arises due to the drivers that lie outside of the organization but creates complexity to the whole SC. According to Serdarasan (2013), interfacial complexity drivers are generated within the supply and/or demand interface and are mainly associated with both the material and information flow between suppliers, customers and/or service providers. Tachizawa et al. (2015) categorized SC complexity drivers as coercive and non-coercive, which have different implications in terms of green SC management approaches. Their findings suggest that monitoring the SC complexity drivers is not sufficient to improve SC performance but firms need to adopt collaborative practices with their suppliers.

2.3 Quantification of complexity

Quantitative measurement of complexity is important if the organization wants to manage its SC complexity properly (Isik, 2010). In this regard, past papers can be grouped into two different categories. In the first category is the papers (Efstathiou et al., 2002; Chen et al., 2014; Hamta et al., 2018), which have used the entropy-based approach to measure complexity. This approach measures SC complexity based on information theoretic model that is rooted in the seminal work of Shannon (1948). Entropy based model divides complexity into static and dynamic types. In this model, the information needed to specify the current state of a system depends on the complexity level of the system. More complex the system is, more information is needed to quantify its complexity level and vice-versa. Efstathiou et al. (2002) developed web-based information theoretic model to quantify the complexity of manufacturing system. Their model, embedded with the expert system, can estimate the complexity of organization and provide suggestions to minimize complexity. Chen et al. (2014) investigated SC complexity with a directional network structure. The paper utilizes entropy functions to the structural analysis of SC network, considering the difference in structural types of SC members and establishing a method to measure complexity. Furthermore, Hamta et al. (2018) modified Shannon's entropy model to measure the SC complexity in an assembly line. Their model considered the relationships between SC and assembly systems to measure static complexity of assembly SC network and assembly lines inside the network.

On the other hand, several papers have contributed to the exploratory approach to measure SC complexity. The approach uses empirical data to identify a relationship between complexity and measures of performance. Different measures of performance are considered by various researchers to quantify SC complexity. Milgate (2001), and Vachon and Klassen (2002) developed a conceptual model of SC complexity to measure the impact of complexity on SC performance. Their exploratory study confirms that complexity has an impact on the delivery performance of speed and reliability. Perona and Miragliotta (2004) measured the complexity based on the indices of relationship with the supplier, procurement policy, production order, and product variety. Their finding suggests that the ability to control complexity within manufacturing and logistic systems will result in core competence to improve efficiency and effectiveness of SC. Choi and Krause (2006) analyzed effect of supply based complexity on SC performance in terms of transaction costs, supply risk, supplier responsiveness, and supplier innovation. The paper defined supply base complexity in terms of number of suppliers, degree of differentiation among suppliers and their level of inter-relationships. Cagliano et al. (2009) proposed performance measurement as a tool to capture the effects of complexity on the behavior of SC. The paper argues that the complexity of SC can be measured based on the dimension of utilization, productivity, and effectiveness. Jacob and Swink (2011) discussed the effect of cost efficiency, quality, and delivery to measure the performance of complexity related to product portfolio architecture. The paper defined product portfolio complexity on the basis of multiplicity, diversity, and interrelatedness of products within the portfolio. Aitken et al. (2016) developed a conceptual model in pursuit of understanding whether the company should reduce or absorb complexity. The paper discussed strategic and dysfunctional complexities at BU level and argued that these complexities require different organizational responses. Recently, Chand et al., (2018) proposed multi-criteria decision approach to measure SC complexity in the mining industry. The paper uses AHP method to quantify the level of complexity and discusses the strategy the company can use to reduce complexity. Articles by Manuj and Shahani (2011), Serdarasan, (2013) and Piya et al., (2017) emphasizes that the company should consider implementing specific strategy(s) to tackle the complexity created by the particular driver. These papers discussed various drivers of complexity and the strategy the company can implement to minimize the effect of these drivers on complexity.

Based on the above literature reviews, it is clear that even though many researches have been carried out in the domain of SC complexity, no past research has contributed to the clear understanding of the contextual relationship that exists between the drivers of SC complexity. Without knowing the contextual relationship, it is almost impossible to know the interaction effect of one driver over others. Before developing managerial models and strategy, to contain complexity, deeper knowledge about the drivers, their classifications and interaction effects is needed (Cagliano et al., 2009). According to Serdarsan (2013), there is a need to have research on interpretive approach to managing complexity in SC. To fill this research gap, we have identified various drivers of SC complexity, classify them based on the various criteria, and proposed an interpretive structural model considering interpretive logic to analyze the drivers of SC complexity and studied contextual relationships between them.

3. SC Complexity Drivers

Complexity in the supply chain leads to process disruptions, which will have adverse effects on costs, SC performance, and customer satisfaction (Cheng et al., 2014). Organizational managers generally apply various developed approaches to tackle the complexity that arises at various level of SC. Nevertheless, before developing and applying any managerial approaches, deeper knowledge about the drivers responsible for SC complexity and their effects are needed to be determined and understood thoroughly (Cagliano et al., 2009). Through determining such complexity drivers in SC, the partners' organizations can monitor and manage their SC efficiently. Past literature has studied SC complexity either from system level or business unit (BU) point of view (Choi and Krouse., 2006; Bozarth et al., 2009). Accordingly, drivers of complexity may lie within a BU or at system level. To run organization smoothly and to add value to the entire SC network, manager should acquaint themselves with all the drivers, either at BU or at system level, which creates complexity. In this study, the generic drivers of SC complexity at both system level and BU are identified based on extensive literature review.

Literature was reviewed using bibliographic databases, such as Science Direct, Emerald, Springer, Google Scholar, and ISI Web of Science. To search from the literatures, keywords such as "supply chain", "supply chain complexity," "complexity driver," "complexity factors," and "manufacturing/production complexity" were used. De Leeuw et al. (2013) have defined five significant dimensions of SC complexity. These dimensions are numerousness, variability, diversity, visibility, and uncertainty. Numerousness in SC is related to the number of products, processes, and customers (Isik, 2010). Variability in SC results fluctuation and inaccuracy in product demand, logistics need, forecasting, etc. Diversity is related to variety of products, processes, and company cultures. Visibility is associated with the ability to assess and impart accurate information along the chain. The last dimension uncertainty results risks and ambiguity, which are associated with technology, supplier, information etc. In line with the dimensions as defined by De Leeuw et al. (2013), this paper follows these five dimensions in the pursuit of identifying SC complexity drivers. Around 120 papers were investigated out of which around fifty papers listed in the reference are purely related to SC complexity. Papers related to other areas of supply chain such as agility, sustainability, supply chain design and so on are either discarded due to irrelevance to the research domain of SC complexity or are cited in the paper to discuss or highlight some aspect related to SC. From the literature review, 23 drivers were identified. These drivers and their relationship with SC complexity were discussed with experts involved in SC domain to ensure integrity and relationship with respect to SC complexity. The identified drivers and their relationships are presented in Table 1.

Table 1: Identified drivers of SC complexity

#No	Complexity Driver	Reference	Relation to SC complexity
1.	Product variety	Banker et al. (1989), Jacob and Swink (2011), Lampoon et al. (2017)	More product variety results into more supply chain partners, as well as, inventory and other logistics support for multiple products thus making the chain more complex to manage.
2.	Manufacturing process	Perona and Miragliotta (2004), Flynn and Flynn (1999)	Types and nature of manufacturing process adopted by a firm affects the complexity level.
3.	Internal communication and information sharing	Shamsuzzoha and Helo (2011)	Ineffective communication and information sharing leads to chaos and distorted information.
4.	Planning and Scheduling	Isik (2010), Bode and Wagner (2015)	Inefficient planning and work scheduling leads to operational complexity, delivery delays, and increased production costs.
5.	Resource constraint	Suh (2005)	Frequent disruption due to the lack of resources among any SC partner affects the trust and level of collaboration between partners. This will limit the capability of the whole chain.

6.	Organizational structure	Wilding (1998), Serdarasan (2013)	Adopted organizational structure affects the level of complexity within the given organization. Complex structure, if exists, on any one organization will further lead to complexity for the whole chain.
7.	Logistics and transportation	Hesse and Rodrigue (2004), Sivadasan et al. (2010), Stadtler (2015)	The role of logistics and transportation may reveal a substantial support to manage supply chain. Inadequate and inefficient management of logistics and transportation often creates complexity that affects the productivity of the entire SC. A flexible, multimodal, and robust logistics and transportation network is necessary in a dynamic SC.
8.	Marketing and sales	Wilding (1998), Wong et al. (2015)	Lack of coordination between marketing and sales processes influence the supply chain efficiency and triggers to organizational profitability. Improper management of this driver generates complexity within the SC network.
9.	Product development	Loch et al. (2003), Nepal et al. (2012)	In product development cycle, the selection of product architecture greatly affect supply chain configuration and complexity.
10.	Customer need	Krishnan and Gupta (2001), Da Silveira (2005)	Variety of customer needs and frequently changing needs increase heterogeneity and service options. This will add complexity to the SC.
11.	Competitor action	Hashemi et al. (2013)	Company has to keep track on what its competitors are doing. Any action of a competitor will trigger reaction to be competitive in the market. Therefore, the actions of competitors increase complexity in the product design, production, marketing and supply chain integration.

12.	Technological change	Bleaker et al. (2005), Hasemi et al. (2013), Gunasekaran et al. (2014)	Company needs to keep pace with advancements in technology. However, technological change necessitates a company to establish new production line, materials, process and even new supply chain partners.
13.	Product life cycle	Fisher et al. (1999), Ramdas and Sawhney (2001), Aelker et al. (2013)	Shorter product life cycle necessitates supply chain to support increase in the number of process, products and production lines over a given time frame, thereby, often creating complexity.
14.	Government regulations, laws and legal issues	Cho and Kang (2001), Mohrschladt (2007)	Firms are exposed to various laws related to health, safety, environment, import/ export and so on. Having fewer legal hurdles and regulations to follow in different jurisdictions is better for the entire supply chain. Satisfying legal issues of all the jurisdiction where organization works creates complexity.
15.	Organizational standards	Ellram (1991), Isik (2010)	It is critical to meet organizational standards (e.g. ISO, ASME) in order to remain competitive. However it may often create challenge for the whole supply chain as acquiring standards only by the parent organization may be insufficient. Therefore, from the complexity perspective, acquiring less organizational standards for the product or company to remain competitive is better.
16.	Improper process synchronization	Wilding (1998)	Improper synchronization of work process between SC partners will create chaos and confusion.
17.	Forecasting error	Lee et al. (1997), Chen et al. (2000), Govindan et al., (2010)	Improper method of forecasting and distorted information flow at different points in the SC network can lead to wider fluctuations in the production, order delivery process and results into operational complexity.
18.	Incompatible information technology	Serdarasan (2013)	Incompatibility of information technologies being used by SC partners results into complexity due to distorted information sharing. This will negatively affect the entire value chain.

19	Number of suppliers	Vachon and Klassen. 2002, Wu and Choi (2005), Goffin et al. (2006)	Increase in the number of suppliers will increase the level of complexity in terms of SC coordination and follow-up. It also decrease the supplier responsiveness thereby, making it difficult to manage them efficiently.
20	Supplier location	Sivadasan et al. (2010)	Distance between the supplier locations from the parent company creates difficulty to monitor and control the supplier and thus creates complexity.
21	Number of customers	Bozarth et al. (2009), Jacobs et al. (2011)	Company always strives to increase the number of potential customers to maximize revenue. However, increased number of customers increase the tasks levels of customer relationship management, thereby, increases the level of complexity.
22	Company culture	Pathak et al. (2007)	Cultural difference between the partners may affect the level of innovation, raise the issue of transparency and different way of thinking. Therefore, having SC partners with similar working culture is preferred as it reduces complexity and improves SC performance.
23	Incompatible supply chain network	Shah (2005), Serdarasan (2013)	For a successful business, choosing SC partners with right competencies is important. Any mismatch among SC partners results in incompatible SC network design, and inefficient SC operations, which lead to complexity.

Further, the identified drivers were classified based on various criteria. As discussed in Section 2, past literature has classified complexity drivers based on three criteria such as driver's origin, stability, and location. However, SC complexity and the associated drivers can also be classified based on the level of management hierarchy who needs to take action to address complexity created by the drivers. Management hierarchy in the organizational structure can be classified as top level, middle level and lower level management (Rue et al., 1992). Top level management is basically involved in the issues related to strategic decisions. On the other hand, middle and low level management are involved in operational or tactical issues. Some of the complexity drivers are related to operational or tactical issues, while others are related to strategic issues (Piya et al., 2017). Such categorization of complexity drivers helps to focus attention or action from a specific level of management hierarchy to accommodate complexity that may be introduced by the drivers (Piya et al., 2017). Definitely, proper coordination between all levels of management is essential to address any complexity efficiently. For example top-level management should take decision on product variety after consultation and in coordination with the sales and operations management. Table 2 shows the comprehensive classification of SC complexity drivers based on four criteria.

Table 2: Classification of SC complexity drivers

Complexity Origin	***Complexity Driver (D)***	***Management level***		***Location***			***Stability***	
		Strategic	***Operational***	***Upstream***	***Mid-stream***	***Down stream***	***Static***	***Dynamic***
Internal	Product variety (D1)	△			△		△	
	Manufacturing process (D2)	△			△		△	
	Internal communication and information sharing (D3)		△		△			△
	Planning and Scheduling (D4)		△		△			△
	Resource constraint (D5)		△		△			△
	Organizational structure (D6)	△			△		△	
	Logistics and transportation (D7)		△		△			△
	Marketing and sales (D8)		△		△			△
	Product development (D9)	△			△		△	
External	Customer need (D10)		△			△	△	
	Competitor action (D11)	△				△		△
	Technological innovation (D12)	△			△		△	
	Product life cycle (D13)		△		△			△
	Government regulations, laws and legal issues (D14)	△				△	△	

	Organizational standards (D15)	△			△			△
Interfacial	Improper process synchronization (D16)		△	△				△
	Forecasting error D(17)		△	△		△		△
	Incompatible information technology (D18)		△	△				△
	Number of suppliers (D19)	△		△			△	
	Supplier location (D20)	△		△			△	
	Number of customers (D21)		△			△	△	
	Company culture (D22)	△			△		△	
	Incompatible supply chain network (D23)	△		△				△

4. Analysis of complexity drivers

Many of the complexity drivers identified in Table 1 are interrelated and have the capability to influence each other. Understanding such interrelationship and influence could enable an enterprise to be acquainted with the drivers and to ascertain those influential drivers for which managers should feel quintessential to minimize or overcome complexity in their SC network. This section will analyze such inter-relationship among drivers using interpretive structural modelling (ISM). ISM is an interactive learning modelling tool widely used to translate prominent relationships among factors that define a problem for complex system (Sage 1977). Warfield first proposed it in the year 1974 (Warfield, 1974). In ISM, some basic ideas from graph theory are applied systematically such that theoretical and conceptual leverage are exploited to explain the complex pattern of contextual relationships among a set of variables (Govindan et al., 2010). It uses expert's opinion to provide an ordered and directional framework to observe a realistic picture for complex problems for decision-making (Chang et al., 2013; Thirupathi and Vinodh, 2016). Since the inception, it has been used for many purposes in different areas (Gorane and Kant, 2013; Alzebdeh et al., 2015; Vasanthakumar et al., 2016) addressing a wide range of problems, both strategic and tactical with high profit impact and supplier issues (Chidambaranathan et al., 2009).

One major advantage of ISM is that it requires less number of experts than other techniques such as Structural Equation Modelling. According to Yadav and Barve (2015), ISM gives a clear structural view showing directed links between the drivers through ISM diagraph from an unstructured model.

Figure 1 shows the steps followed while using ISM tool in this research. As discussed in section 3, the drivers influencing complexity in SC have been identified (Step 1) based on the literature review. The remaining steps will be discussed next based on the case study conducted.

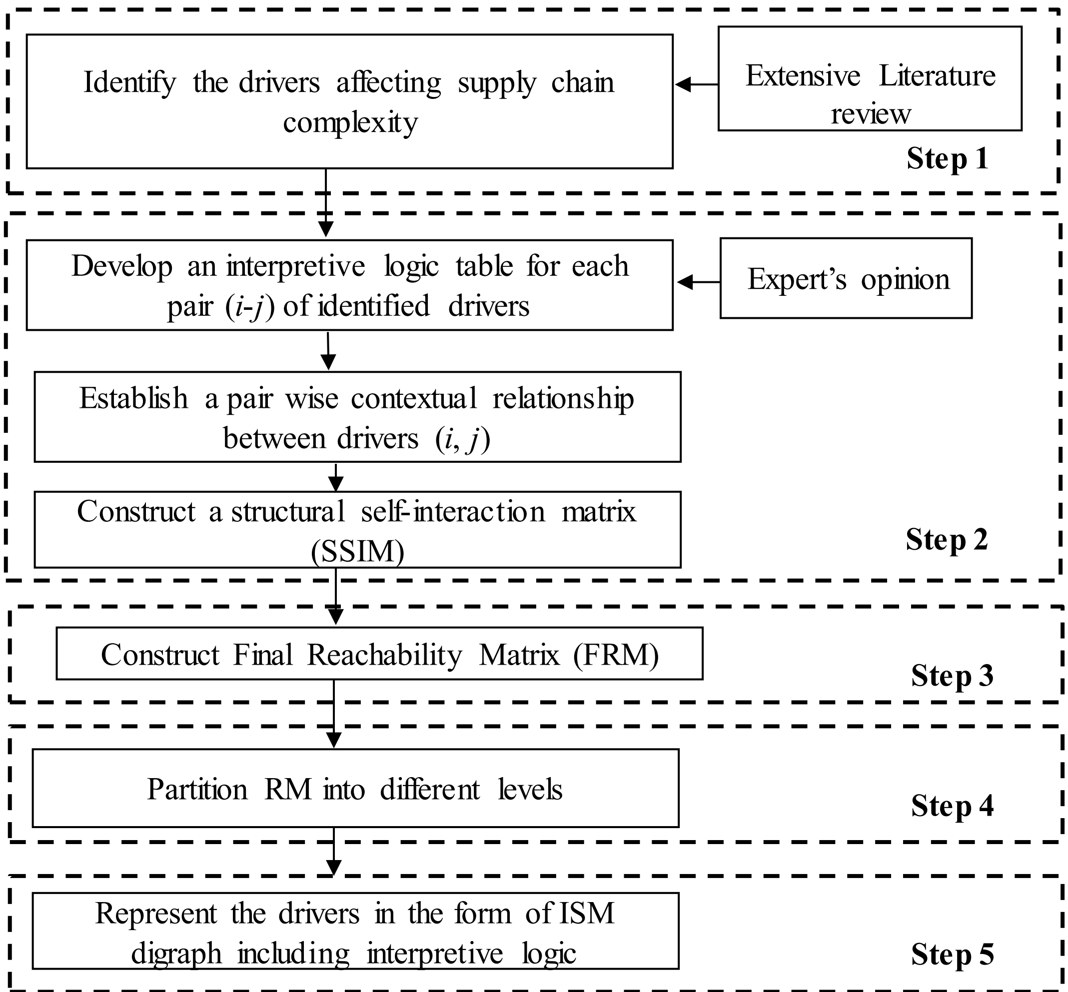

Figure 1: Steps in using ISM methodology

4.1 Case study

To use ISM methodology, it is necessary to understand the contextual relationships between complexity drivers. For the purpose, initially, a survey was conducted via e-mail to experts working at different organizations situated in the industrial estate in Oman. However, due to low turnover responses, 15 experts were met personally, informed about the research objectives and invited for brainstorming sessions to understand their opinion regarding the relationship among the drivers. The number of expert is based on the finding that most of the past literatures have used industry experts varying from 5 to 15 in numbers (Qureshi *et al.*, 2007). Out of 15 experts, only 8 turned up for the brainstorming sessions. The details on the background of experts who attended brainstorming sessions are as shown in Table 3. From the table it is evident that all the experts in the case study are working in companies producing Fast Moving Consumer Goods (FMCG). All these companies have multiple supply chain partners, especially for raw material and semi-finished products, spanning local as well as overseas suppliers. Before starting brainstorming session, as experts were introduced to each driver and confirm its association with complexity as shown in Table 1, we can say that the opinion received, on the validation and with respect to the relationship among drivers, from experts were based on their complete understanding of the drivers. Several brainstorming sessions were organized in pursuit of understanding the complementary effect of one driver on others and to reach consensus among experts. The brainstorming technique was selected due to the fact that it is considered as one of the most effective techniques for creative problem solving, resolve biases among participants and reach consensus (Rawlinson, 1981).

Table 3: Demography of expert for the brainstorming session

Business sector - Confectionary: 3 - Food and Beverage: 3 - Livestock Feed:1 - Detergent:1

<u>Designation of people participated</u> - Supply chain manager: 3 - Production manager: 2 - Human resource manager: 1 - GM and MD: 2
<u>Experience of people in their job (in years)</u> - 8 to 12: 4 - 13 to 18: 3 - 22: 1

4.1.1 Interpretive logic table

In traditional ISM, interpretation of links between the drivers in ISM diagraph is relatively feeble as it does not answer in what way the directed links will achieve the specified contextual relationship. It means that traditional ISM only assists in providing answers to "what" in the development of SC theory. However, it does not mention for the cause of linkages, thereby, cannot answer "why or how," in theory building. Therefore, within the scope of this research study, at first interpretive logic table is developed based on the identified drivers, which is followed by presenting contextual relationships between the drivers. This table helps to understand why or how one driver leads to or affects other drivers of SC complexity. Considering such an approach also helps to improve ISM diagraph, which is an outcome of ISM model. With such diagraph, it will be easier for industrial managers to understand why or how one driver leads to or affects other drivers.

Table 4 shows an interpretive logic table for SC complexity driver "Product variety". The table consists of two-way relationships comparison of "Product variety" with other drivers and the reason why or how the relationship is true. The total relationships to compare for the development of interpretive logic tables is given by equation $2\sum_{i=1}^{n-1}(n-i)$. As the total drivers (n) of SC complexity identified in this research are 23, altogether 522 relationships were compared to develop interpretive logic table for the entire SC complexity drivers. In the Table, 4th and 5th columns are the results obtained from multiple brainstorming sessions with the experts.

Table 4: Interpretive logic table for product variety (D1)

Driver (*i-j*)	Compared relationship	Comparison statement	T/F	If the comparison statement is true, why?	Symbolic Relation
D1-D2	D1→D2	Product variety lead to manufacturing process	T	To increase product variety, company should have flexible manufacturing process.	V
	D2→D1	Manufacturing process lead to product variety.	F	-	
D1-D3	D1→D3	Product variety lead to internal communication and information sharing	T	More product variety means different specifications and requirements. This will affect to internal communications and information sharing within the company.	V
	D3→D1	Internal communication and information sharing lead to product variety	F	-	
D1-D4	D1→D4	Product variety lead to planning and scheduling	T	More product variety results to more supply chain partners, which greatly affect to necessary planning and scheduling of company's production processes.	V
	D4→D1	Planning and scheduling lead to product variety	F	-	
D1-D5	D1→D5	Product variety lead to resource constraint	F	-	O
	D5→D1	Resource constraint lead to product variety	F	-	
D1-D6	D1→D6	Product variety lead to organizational structure	T	More product variety needs to involve more human resources that results to the need to maintain organizational structure efficiently.	V
	D6→D1	Organizational structure lead to Product variety	F	-	
D1-D7	D1→D7	Product variety lead to logistics and transportation	T	More variety of product results into more supply chain partners and associated logistics and transportation needs.	V

	D7→D1	Logistics and transportation lead to product variety	F	-	
D1-D8	D1→D8	Product variety lead to marketing and sales	T	For different products, company may need to use different marketing and sales strategy to attract customers.	V
	D8→D1	Marketing and sales lead to Product variety	F	-	
D1-D9	D1→D9	Product variety lead to product development	T	More product variety means more product development activities, such as more R&D activities before going for mass production.	V
	D9→D1	Product development lead to product variety	F	-	
D1-D10	D1→D10	Product variety lead to customer need	F	-	A
	D10→D1	Customer need lead to product variety	T	To remain competitive, company should satisfy the need of its customers. With changing need of customer, company has to introduce different product variety by improving existing product or introducing completely new product.	
D1-D11	D1→D11	Product variety lead to competitor action	F	-	A
	D11→D1	Competitor action leads to product variety	T	To achieve competitive advantage over competitors, company should closely watch the action of the competitors and act accordingly. Any action of competitor in terms of introduction of new product variety will propel the company to introduce new variety in order to counter the effect of competitor's action in the market.	
D1-D12	D1→D12	Product variety lead to technological change	F	-	O
	D12→D1	Technological change lead to product variety	F	-	
D1-D13	D1→D13	Product variety lead to product life cycle	F	-	O
	D13→D1	Product life cycle lead to product variety	F	-	
D1-D14	D1→D14	Product variety lead to government regulations, law and legal issues	F	-	O
	D14→D1	Government regulations, law and	F	-	

		legal issues lead to product variety			
D1-D15	D1→D15	Product variety lead to organizational standards	T	To be competitive, company strives to achieve standards such as ISO, ASME for their products. More the product variety, results to manage more logistics needs to maintain standard for all product varieties.	V
	D15→D1	Organizational standards lead to product variety	F	-	
D1-D16	D1→D16	Product variety lead to improper process synchronization	T	More product variety results into more supply chain partners. With the increase in supply chain partners will increase difficulty for the company to have proper synchronization of processes with all the partners.	V
	D16→D1	Improper process synchronization lead to product variety.	F	-	
D1-D17	D1→D17	Product variety lead to forecasting error	F	-	O
	D17→D1	Forecasting error lead to product variety	F	-	
D1-D18	D1→D18	Product variety lead to incompatible information technology	T	To produce more product variety often needs to communicate more with the suppliers and their information technology systems, which may result to incompatible information technology.	V
	D18→D1	Incompatible information technology lead to product variety	F	-	
D1-D19	D1→D19	Product variety lead to number of suppliers	T	Increase in the variety of product increases the number of various component parts needed. This will increase the number of suppliers.	V
	D19→D1	Number of suppliers lead to product variety	F	-	
D1-D20	D1→D20	Product variety lead to supplier location	F	-	O
	D20→D1	Supplier location lead to product variety	F	-	
D1-D21	D1→D21	Product variety lead to number of customers	T	More variety of products can satisfy different needs of customers. This helps	

				company to reach to more number of customers.	V
	D21→D1	Number of customers lead to product variety	F	-	
D1-D22	D1→D22	Product variety lead to company culture	F	-	A
	D22→D1	Company culture lead to product variety	T	Culture of innovation and transparency among supply chain partners promote different way of thinking. This leads to coming up with new or different way of satisfying the customer needs.	
D1-D23	D1→D23	Product variety lead to incompatible supply chain network.	T	To produce more product variety often needs to organize more partnerships with potential suppliers, which may result to incompatible supply chain network to manage them efficiently.	X
	D23→D1	Incompatible supply chain network lead to product variety	T	To have variety of product, company should have supply chain partners with right competencies in terms of network design and operational efficiency.	

Table 4 highlights the number of managerial insights. In today's business environment, organizations are faced with increasingly demanding customers due to which there is a growing trend to increase product variety. Offering more product variety helps the organization reach a large number of customers, cater the need for heterogeneous customers and create opportunities to outperform competitors (Perona and Miragliotta, 2004). Brynjolfsson et al. (2003) found that Amazon Company is able to increase customer welfare significantly by increasing customer access to product varieties. Even though product variety helps firm to increase their customer base, it should be supported by the manufacturing system with the construct and features built-into to achieve necessary flexibility. A flexible manufacturing system that can operate reliably for a range of functional requirements is needed to accomplish a growing demand for product variety (ElMaraghy et al., 2012). Empirical research by Um et al., (2017) has demonstrated that the firm that design product variety according to the manufacturing capability of their SC will have better

SC performance. Therefore, product variety should be supported by SC partners with the right competencies in terms of innovation, network design and operational efficiency.

Research by Shou et al. (20017) shows that an increase in product variety leads to increasing number of component parts, SC partners, and extensive interactions with the supplier of these parts. When the firm is characterized by a high degree of product variety, relationships with SC partners may involve exchange hazards, improper process synchronization and coordination difficulties for the planning and scheduling of operational and logistics activities. Malucci (2006) reported losses to the tune of $20,000 per minute in an industry characterized by wider product varieties and multiple SC partners due to improper SC coordination. The firm should enhance their internal and supplier integrations through information sharing and effective collaboration in order to overcome such hazards and difficulties (Shou et al., 2017).

4.*1.2 Structural self-interaction matrix*

In ISM a structural self-interaction matrix (SSIM) is developed to define a contextual relationship that exists between the identified drivers. Depending on the situation, a contextual relationship may be defined using the words "leads to", "complement", "depends on", "affect" or "trigger". In order to express the relationships between the drivers four symbols were used in this research namely '*V*', '*A*', '*X*', and '*O*' the details of which are as follow:

V: driver *i* leads to or affect driver *j*

A: driver *j* leads to or affect driver *i*

X: drivers *i* and *j* lead to or affect drivers *j* and *i* simultaneously

O: no relationship between drivers *i* and *j*

Relationships obtained between the drivers through interpretive logic tables were used to develop SSIM. In Table 4 for example, the compared relationships for drivers (D1, D2) show that the comparison statement between (D1→D2) is true. However, the opposite comparison statement is false. It means that driver D1 leads to/ affect driver D2 but this relationship is not reciprocal. Therefore, the symbolic relationship between D1 and D2 is *V*. Table 5 shows all such symbolic relationships between drivers in the form of SSIM.

Table 5: Structured self-interaction matrix (SSIM)

Driver (*i*/*j*)	D 23	D 22	D 21	D 20	D 19	D 18	D 17	D 16	D 15	D 14	D 13	D 12	D 11	D 10	D 9	D 8	D 7	D 6	D 5	D 4	D 3	D 2	D 1
D1	X	A	V	O	V	V	O	V	V	O	O	O	A	A	V	V	V	V	O	V	V	V	
D2	V	O	O	O	O	O	O	V	X	A	V	O	O	A	A	O	O	O	V	V	O		
D3	O	A	O	O	A	X	V	V	O	O	O	O	O	O	O	V	O	A	O	O			
D4	O	O	A	A	A	O	A	A	O	O	O	A	A	A	A	X	X	O	X				
D5	O	O	O	O	X	O	O	O	X	O	O	O	O	O	O	X	O	O					
D6	O	X	O	O	X	O	O	O	O	O	O	O	A	O	X	V	O						
D7	O	O	O	O	O	O	A	O	O	A	O	O	O	A	O	A							
D8	O	O	O	O	O	O	O	O	O	A	O	A	A	X	A								
D9	O	O	O	O	X	O	O	V	X	O	V	X	A	X									
D10	V	O	O	O	V	O	O	O	O	O	X	X	O										
D11	O	V	V	O	O	O	O	O	V	O	O	V											
D12	O	X	O	O	V	O	O	O	V	O	V												
D13	O	O	O	O	O	O	O	O	A	O													
D14	V	V	O	O	O	O	O	O	X														
D15	O	A	O	O	O	O	O	O															
D16	O	O	O	A	A	A	V																
D17	A	O	O	O	A	A																	
D18	X	O	A	O	A																		
D19	V	O	A	V																			
D20	X	O	O																				
D21	V	O																					
D22	V																						
D23																							

4.1.3 Reachability matrix

The relational indicators in Table 4 were then replaced with binary numbers to generate reachability matrix. To obtain final Reachability matrix (FRM), at first, initial reachability matrix (IRM) as shown in Table 6 is developed by substituting the alphabet with binary values based on the rule that in SSIM if the alphabet is:

- *V* for drivers (*i*, *j*), then the binary value in IRM for (*i*, *j*) becomes 1, and (*j*, *i*) becomes 0.

- *A* for drivers (*i*, *j*), then the binary value in IRM for (*i*, *j*) becomes 0, and (*j*, *i*) becomes 1.
- *X* for drivers (*i*, *j*), then the binary value in IRM for both (*i*, *j*) and (*j*, *i*) becomes 1.
- *O* for drivers (*i*, *j*), then the binary value in IRM for both (*i*, *j*) and (*j*, *i*) becomes 0.

Table 6: Initial reachability matrix (IRM)

Driver (*i*/*j*)	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10	D 11	D 12	D 13	D 14	D 15	D 16	D 17	D 18	D 19	D 20	D 21	D 22	D 23
D1	1	1	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	1	0	1	0	1
D2	0	1	0	1	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	1
D3	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
D4	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D5	0	0	0	1	1	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
D6	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0
D7	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D8	0	0	0	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
D9	0	1	0	1	0	1	0	1	1	1	0	1	1	0	1	1	0	0	1	0	0	0	0
D10	1	1	0	1	0	0	1	1	1	1	0	1	1	0	0	0	0	0	1	0	0	0	1
D11	1	0	0	1	0	1	0	1	1	0	1	1	0	0	1	0	0	0	0	0	1	1	0
D12	0	0	0	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	1	0	0	1	0
D13	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
D14	0	1	0	0	0	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1
D15	0	1	0	0	1	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0
D16	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
D17	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
D18	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0	1
D19	0	0	1	1	1	1	0	0	1	0	0	0	0	0	0	1	1	1	1	1	0	0	1
D20	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0
D21	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1
D22	1	0	1	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	1
D23	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1

One of the important assumptions in using ISM is the internal consistency between the developed relationships. Such internal consistency can be checked by using the concept of transitivity, which says that if A is related to B and B is related to C, then A must be related to C. Therefore, once the IRM is developed, it is necessary to check for internal consistency. Table 7 shows the FRM after using the concept of transitivity. 1* in the table represents the change in the relationship between drivers due to transitivity.

Table 7: Final reachability matrix (FRM)

Driver (*i*/*j*)	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10	D 11	D 12	D 13	D 14	D 15	D 16	D 17	D 18	D 19	D 20	D 21	D 22	D 23	Driving power	Rank
D1	1	1	1	1	0	1	1	1	1	0	0	0	0	0	1	1	0	1	1	0	1	0	1	14	1st
D2	0	1	0	1	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	1	6	6th
D3	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	3	9th
D4	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	8th
D5	0	0	0	1	1	0	1*	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	5	7th
D6	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	6	6th
D7	0	0	0	1	1*	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	8th
D8	0	0	0	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	5	7th
D9	0	1	0	1	0	1	0	1	1	1	0	1	1	0	1	1	0	0	1	0	0	0	0	9	4th
D10	1	1	0	1	0	0	1	1	1	1	0	1	1	0	0	0	0	0	1	0	0	0	1	11	2nd
D11	1	0	0	1	0	1	0	1	1	0	1	1	0	0	1	0	0	0	0	0	1	1	0	10	3rd
D12	0	0	0	1	0	0	0	1	1	1	0	1	1	0	1	0	0	0	1	0	0	1	0	9	4th
D13	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1*	0	0	0	0	0	0	3	9th
D14	0	1	0	0	0	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	7	5th
D15	0	1	0	0	1	0	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	6	6th
D16	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	4	8th
D17	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	10th
D18	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0	1	6	6th
D19	0	0	1	1	1	1	0	0	1	0	0	0	0	0	0	1	1	1	1	1	0	0	1	11	2nd
D20	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	1*	5	7th
D21	1*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	6	6th
D22	1	0	1	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	1	7	5th
D23	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1*	0	0	1	5	7th
Dependance	6	6	6	15	7	6	8	12	8	4	1	5	6	2	9	8	7	7	8	4	3	5	10		
Rank	7th	7th	7th	1st	6th	7th	5th	2nd	5th	9th	12th	8th	7th	11th	4th	5th	6th	6th	5th	9th	10th	8th	3rd		

After a transitivity check in FRM, the driver power and dependence were calculated and the drivers were ranked accordingly. Summation of a row indicates driver power and summation of a column indicates dependence. From Table 7 it is observed that driver 1 (D1) has the highest driving power but less dependence. On the other end, driver 17 (D17) has the least driving power but more dependence. Further, depending on the summation of driving power and dependency, the drivers are clustered into four different quadrants as shown in Figure 2.

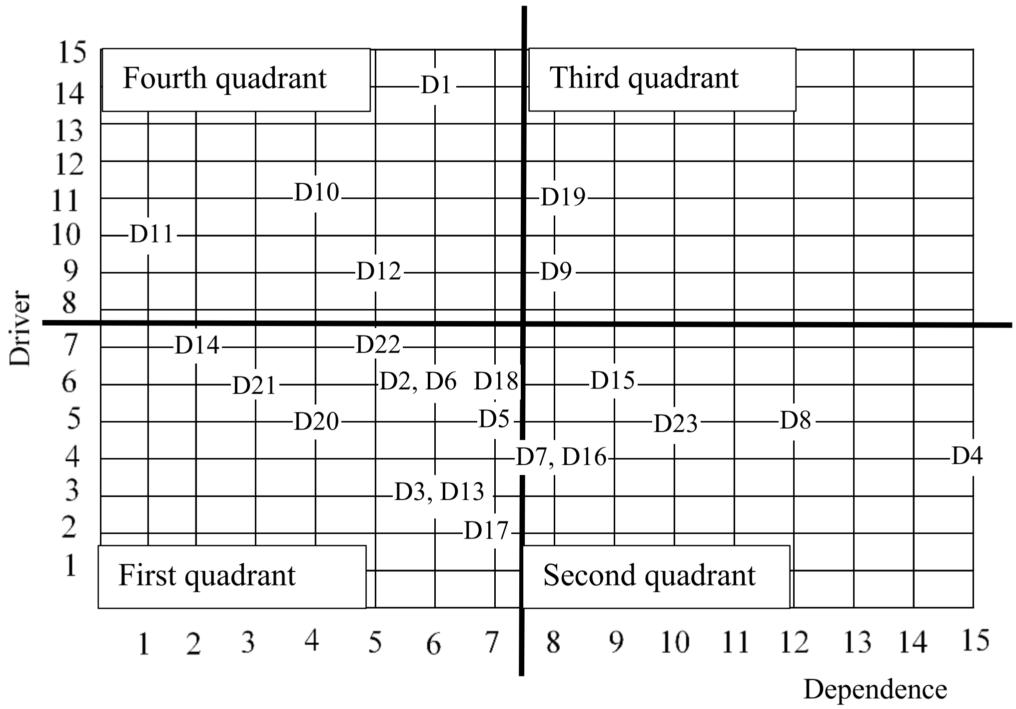

Figure 2: Driver power and dependence diagram

First quadrant: This quadrant is known as an autonomous quadrant because the drivers in this quadrant have less driving power and less dependency. These drivers are usually disconnected from the system i.e., neither can they strongly drive other drivers nor will they be strongly driven by others. Figure 2 shows that many drivers of complexity lie in this quadrant.

Second quadrant: Drivers that fall under this quadrant are known as dependent drivers, which have low driving power but high dependency. From the present study, it is identified that six drivers (D7, D16, D15, D23, D8 and D4) fall under this quadrant. These drivers are strongly affected by the drivers that fall under the fourth quadrant.

Third quadrant: Drivers with high driving power and high dependency falls under this quadrant. This quadrant is known as linkage, meaning that any action on the drivers within this quadrant will have a knock on effects on others. In the current study, only two drivers (D9 and D19) fall under this quadrant. However, both of these drivers lie very close to the boundary of the fourth quadrant.

Fourth quadrant: This quadrant consists of the drivers that have strong driving power but weak dependency. In this study, four drivers (D1, D10, D11, D12) fall under this category. The driver in this quadrant lead to or affect the driver in the other quadrants.

4.1.4 Level partition

From the FRM, the reachability set and antecedent set are derived for each driver. The reachability set consists of driver (*i*) itself and other drivers (*j*), which it may help to accomplish. On the other hand, the antecedent set consists of driver (*i*) itself and the other drivers (*j*), which may help in its accomplishment. Thereafter, the common drivers of these two sets help in obtaining the interaction set. The drivers that have the same reachability and intersection sets in the first iteration will be clustered as level I. The top-level driver in the hierarchy i.e., level I will not leads to any other drivers above its level. Once the top-level driver is identified, it is separated from the whole remaining sets and same procedure is repeated to find the second level drivers in the next iteration and continue doing so until the last driver remains in the sets. The outcomes from seven iterations are shown in Table 8.

Table 8: Levels of drivers of complexity in supply chain

Driver (*i*/*j*)	Reachability set	Antecedent set	Intersection set	Level
D1	1,2,3,4,6,7,8,9,15, 16, 18, 19, 21, 23	1,10,11, 21, 22,23	1,21,23	VI
D2	2,4,5, 13,15,16,23	1,2,9,10,14,15	2, 15	V
D3	3,8,16,17, 18	1,3,6,18,19,22	3,18	IV
D4	4,5,7,8	1,2,4,5,7,8,9,10,11,12,16, 17,19,20,21	4,5,7,8	I
D5	4,5,7,8	2,4,5,7, 8,15,19	4,5,7,8	I
D6	3,6,8,9,19	1,6,9,11,19,22	6,9,19	V
D7	4, 5, 7,8	1,4,5,7,8,10,14,16	4,5,7,8	I

D8	4,5,7,8	1,3,4,5,6,7,8,9,10,11,12,14	4,5,7,8	I
D9	2,4,6, 8,9,13,15,16,19	1,6, 9,10,11,12,15,19	6,9,15, 19	V
D10	1,2,4,7,8,9,10,12,13, 19,23	8,9,10,12,13	8,9,10,12,13	VII
D11	1,4,6,8,9,11,12,15,21,22	11	11	VII
D12	4,8,9,12,13,15,19, 22	9,10,11,12,22	9,12,22	VI
D13	13	2,9,10,12,13,15	13	III
D14	2,7,8,14,15,22,23	14,15	14,15	VI
D15	2,5,9,13, 15	1,2,5,9,11,12,14,15,22	2,5,9,15	V
D16	4,7,16	1,2,3,9,16,18,19,20	16	III
D17	4,17	3,17,18,19,23	17	II
D18	3,16,17,18,20,23	1,3,18,19,20,21,23	3,18,20,23	IV
D19	3,4,5,6,9,16,17,18,19,20,23	1,5,6,9,10,12,19,21	5,6,9,19	V
D20	4,16,18,20,23	18,19,20,23	18,20,23	IV
D21	1,4,18,19,21,23	1,11,21	1,21	VI
D22	1,3,6,12,15,22,23	6,11,12,14,22	6,12,22	VI
D23	17,18,20,23	1,2,10,14,18,19,20,21,22,23	18,20,23	IV

4.1.5 ISM Diagraph

The drivers are then arranged graphically in levels, according to Table 8 and by removing transitivity links, as shown in Figure 3. Such graphical representation is known as a diagraph or directed graph, which illustrates the relationship between the drivers. If there is a link between driver *i* and *j*, this is directed by an arrow which points from *i* to *j*. Why or how the directed link achieves the specified contextual relationship is shown in the diagraph. This helps industrial manager to understand the cause of linkage.

From the diagraph, it is observed that the identified drivers of SC complexity can be classified into seven levels. These seven levels can be further grouped into three categories of drivers. At the highest level (VII), there are three drivers (D10, D11, D14) all of which lie outside of the organizational unit i.e., external complexity drivers. In terms of stability of the driver, drivers D10 and D14 are static in nature, whereas, driver D11 is a dynamic complexity driver. Management will have little or no control over these complexity drivers. As observed from the diagraph, these external complexity drivers are the major drivers of SC complexity. This result agrees with the result of Chand et al., (2018), which has shown that external drivers such as laws & regulations and competition are the main drivers of SC complexity. These drivers lead to other drives above their level and affect SC performance.

Most of the drivers from level IV to level VI are strategic in nature. Drivers at level IV are mainly related to the incompatibility of network, information and communication technologies either at BU level or within the chain. In terms of stability of the driver, drivers at level V and level VI are static complexity drivers. To manage strategic drivers, planning is needed at the strategic or top level of the management hierarchy. At the top levels of diagraph (Level I and Level II) are the drivers that are mostly operational or tactical in nature. To manage these drivers, planning or action is needed at mid or lower levels of the management hierarchy. All the drivers at Level I, Level II and Level III are dynamic complexity drivers.

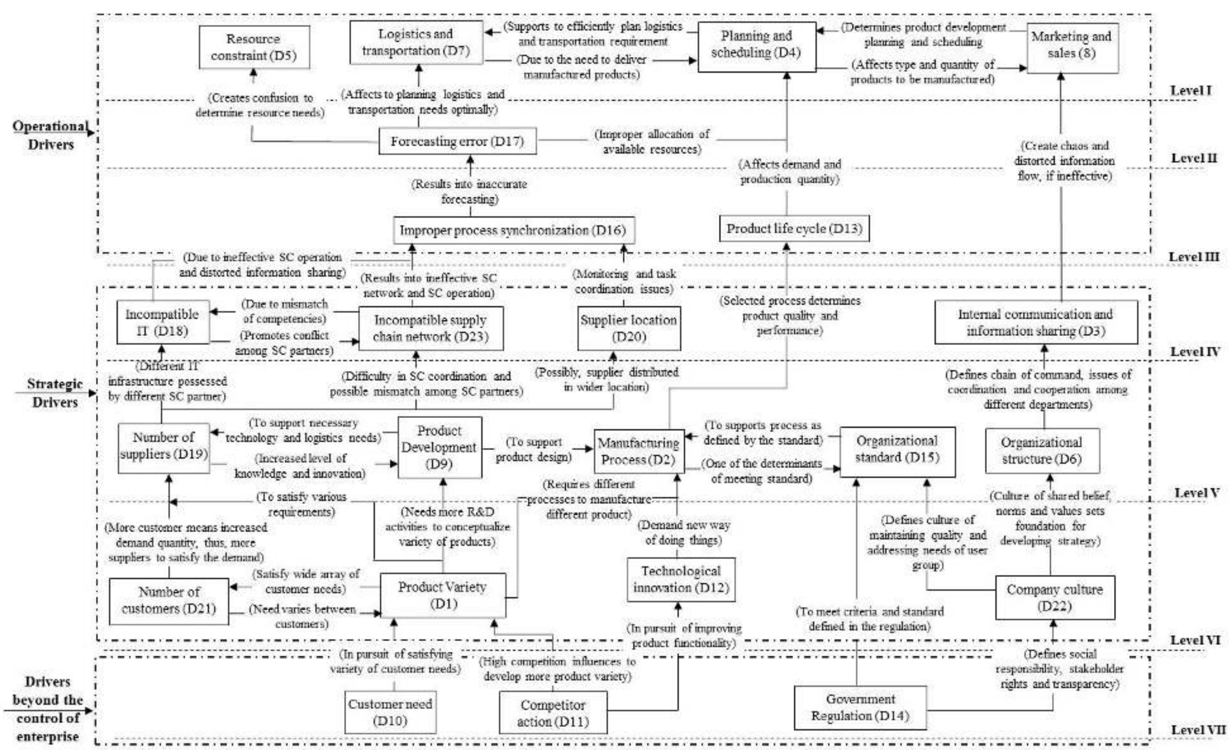

Figure 3: ISM diagraph with interpretive logic

The impact of organizational culture and structure on the organizational performances are usually researched independently from one another. However, ISM diagraph indicates that culture complements the structure of the organization. This is due to the reason that the design and implementation of organizational structure are hugely affected by the culture of the organization (Janićijević, 2013). Moreover, the diagraph also shows that the structure that an organization adapts affects internal communication and information sharing, which is in line with the finding of Kim, (2005). According to the diagraph, complexity drivers such as product development, manufacturing process, which are triggered due to product variety, and internal communication and information sharing, will have an impact on production planning. All these drivers are internal manufacturing complexity drivers and affect attainment of production schedule. Bozarth et al., (2009) have empirically provided such results.

Further, as an example of one link in a chain (from lower to higher level), the following can be interpreted from the ISM diagraph in Figure 3.

- To satisfy customer needs (D10) or if the need of the customer is increased, then the company may have to increase its product variety (D1). Now a day, many companies are moving towards product customization to satisfy customer needs (Piya et al., 2016; Piya, 2019).
- To increase product variety (D1), lots of research and development (D8) activity on the part of entire SC partners is necessary to conceptualize variety of products. Also, product variety affects the manufacturing process (D2), as different products may need different processes of manufacturing. Moreover, an increase in the variety of products increases the number of various component parts. This will increase the number of SC partners (D19).
- An increase in the number of suppliers (D19) will increase the possibility of having incompatible SC networks (D23) due to mismatch of competencies. An increase in the number

of suppliers will also increase the possibility of having incompatible Information technology (D18) as a result of different IT infrastructure possessed by different SC partners. Such incompatibility will have an effect on process synchronization (D16) among SC partners, thereby, causing forecasting error (D17).

- Forecasting error (D17) will affect all the activities at the shop floor level, such as production planning and scheduling (D4), logistics and transportation need (D7), and so on.

5. Statistical Validation

As discussed in section 4.1, all the experts for brainstorming sessions in the case study are working in FMCG company. To understanding the percentage of opinions who are in favor that the complexity drivers and their interrelationships identified in this research apply to the SC of other industries, statistical analysis is conducted based on the questionnaire as presented in Appendix A. The data were collected from the same experts who participated in the brainstorming sessions. The collected data were analyzed by using Mini-tab software. The analysis found no outlier data in the data set and the data follow normal distribution at a 95% confidence interval (Figure 4). Further, a one-sample *t*-test was conducted to validate the result to the SC of other industries. At first, test value was set at 9.5 which means that 95% of the opinion is in favor that their view applies to the SC of all industries. However, the null hypothesis is rejected in this case.

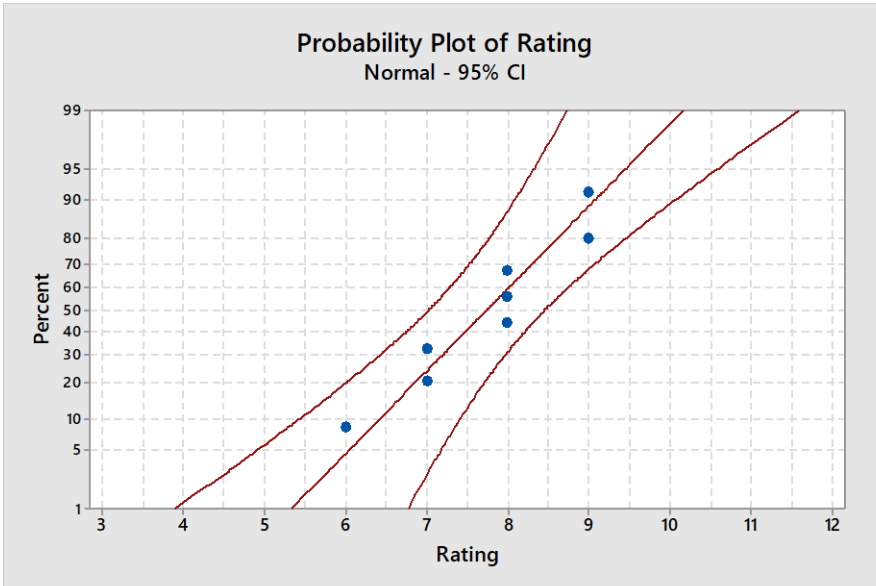

Figure 4: Normal Probability Plot for the rating data

Next, the test was carried out by setting the test value at 9. In this case, the null hypothesis was accepted at a 95% confidence interval (CI: 7.75±0.865). Therefore, it can be interpreted that 90% of the opinions are in favor that the complexity drivers and their interrelationships as identified in this research is applicable to the SC of industries other than industry that produces FMCG. Further discussion with the experts reveals that depending on the nature of industry and environment in which it operates, the level of complexity the identified driver exerts on SC do vary. Therefore, it can be said that even though these are generic drivers of SC complexity, the degree of complexity the driver creates on SC will vary from one company to another.

6. Managerial Implications

Globalization exerts extra pressure on companies to stay in the competition. In this changing business environment, it is critical for companies to monitor and manage their supply networks efficiently. To execute smoother business operations and to be competitive, organizations managers need to identify the associated drivers responsible for SC complexity. This research identifies and explores the way out to get the drivers responsible for the complexity in SC. It should be noted that complexity or complexity driver itself is not harmful to the business success of an organization, instead, it should be considered as a challenge, which if managed will create opportunities to improve overall SC performance. Following managerial insights can be drawn from this study:

- Various drivers create complexity within the SC network. These drivers can be classified based on multiple criteria. Managers should acquaint themselves with drivers that create complexity. Understanding the characteristic of complexity drivers, classifying them and taking necessary actions are essential to reduce uncertainty, process disruption and make a sound decision.
- External complexity drivers are the main triggers for increasing complexity in SC. Such drivers are beyond the control of an organization or SC partner. However, reacting quickly to these drivers will help reducing its knock-on effect on strategic drivers of complexity. Strategic drivers lie within the scope of a higher level of management hierarchy. These drivers will have impact on operational drivers, which are related to the shop floor level or at tactical level. ISM diagraph shows that operational drivers have the highest level of dependency. Any complexity created by these drivers needs to be addressed by middle or lower level in the management hierarchy.
- The ISM diagraph as depicted in Figure 3 visualizes the interdependencies of the SC complexity drivers. For instance, drivers 'Logistics and transportation (D7)', 'Planning and scheduling (D4)' and 'Marketing and sales (D8)' are dependent on each other and any changes of anyone's directly effects on other. In that case, if there need any changes, organizational managers need to closely monitor the effects of the changes on other dependent drivers too. Such strategical

needs within business organizations help managers to investigate the complexity drivers and control them to avoid detrimental effects over business operations.

- All the operational drivers are dynamic complexity drivers and these drivers represent uncertainty in SC with respect to time and randomness. Improving process synchronization and robust collaboration with all SC partners including customers and service providers is essential to deal with operational complexity drivers (Serdarasan, 2013).
- In order to manage the SC complexity, it is essential for the organizational managers to maintain real-time communication and coordination between all levels of management hierarchy and the entire SC partners. Such real-time communication and information exchange among supply chain stakeholders contributes to eliminate or minimize the complexity level within the SC network. This real-time communication and coordination can be orchestrated through implementing advanced ICT such as Internet of Things (IoT), Big-Data, Blockchain, etc., within the supply chain and logistics operations. Such technologies might enable managers to track and trace any drivers, which are responsible to create any forms of complexity within the supply network.

7. Conclusions

Analysis, measurement, and reduction of complexity in SC play vital role to improve the performance of the whole chain. Such measurement technique allows companies to take necessary actions before it becomes complex, which might be difficult to handle cost-efficiently (Heckmann et al., 2015). For that purpose, it is essential that the company's management must be well acquainted with the drivers and their inter-relationships that drive SC towards complexity.

This research study tried to answer three research questions as mentioned in the introduction section. The first research question was attended through detailing the concept of SC complexity, its nature, characteristics and overall impact within the industrial domain. The second research question was answered through identifying available drivers, which are responsible for creating complexity within SC network. The third and final research question was concentrated mainly to analyze the identified drivers and categorize them based on driver power and dependencies. ISM methodology was used for such analysis. The analysis revealed that complexity in SC is mainly triggered by the drivers, which are beyond the control of organization or SC partners. These drivers will drive strategic drivers of complexity, which further will drive operational drivers.

From this research study, several key findings are also analyzed, which are proved as beneficial for the companies to manage complexity in their SC. For instance, this study presents a comprehensive classification of the identified drivers using various criteria, which will make it easier for the company's management personnel to understand the drivers and takes necessary action to manage complexity. Besides, the developed structural model visualizes the relationship between identified drivers and the reason for such relationships, which will help to understand the most dominant drivers that drive other drivers towards complexity.

The drivers in the paper were identified based on the literature review and later validated by the experts working in FMCG companies. Nevertheless, depending on the nature of industry and environment in which it operates, the applicability and level of complexity exerted by identified drivers on SC do vary. Accordingly, management preference on the driver to cushion the effect of complexity on SC may vary too. As a research expansion, authors are working on developing mathematical model that can measure the level of complexity created by one driver as compared to others within supply chain. This proposed model will help to quantify how complex is the supply chain of a given industry and which drivers are creating more complexity to the chain. Moreover, it is possible that addressing one driver of complexity may trigger another new driver or may increase the level of severity of another existing complexity driver. Therefore, understanding the level of severity exerted by each complexity driver on others and its impact on various measures of SC performances is essential.

References

1. Aelker, J., T. Bauernhansl, and H. Ehm. 2013. "Managing complexity in supply chains: A discussion of current approaches on the example of the semiconductor industry". *Procedia CIRP 7*: 79-84.
2. Aitken, J., C. Bozarth, and W. Garn. 2016. "To eliminate or absorb supply chain complexity: a conceptual model and case study". *Supply Chain Management: An International Journal* 21(6): 759-774.
3. Alzebdeh, K., H. A. Bashir, and S. K. Alsiyabi. 2015. "Applying Interpretive Structural Modeling to Cost Overruns in Construction Projects in the Sultanate of Oman". *The Journal of Engineering Research* 12 (1): 53-68.
4. Banker, R. D., S. M. Datar, S. Kekre, and T. Mukhopadhyay. 1989. "Cost of product and process complexity", Carnegie Mellon University, Tepper School of Business.
5. Blecker, T., W. Kersten, and C. M. Meyer. 2005. "Development of an approach for analyzing supply chain complexity. In Mass Customization: Concepts–Tools–Realization". *Proceedings of the International Mass Customization Meeting* (pp. 47-59).

6. Blome, C., T. Schoenherr, and D. Eckstein. 2014. “The impact of knowledge transfer and complexity on supply chain flexibility: a knowledge-based view”. *International Journal of Production Economic*s 147: 307-316.

7. Bode, C., and S. M. Wagner. 2015. “Structural drivers of upstream supply chain complexity and the frequency of supply chain disruptions”. *Journal of Operations Management* 36: 215-228.

8. Bozarth, C.C., D. P. Warsing, B. B. Flynn, E. J. Flynn. 2009. “The impact of supply chain complexity on manufacturing plant performance”. *Journal of Operations Management* 27(1): 78-93.

9. Brynjolfsson, E., Y. Hu, and M. D. Smith. 2003. “Consumer surplus in the digital economy: Estimating the value of increased product variety at online booksellers”. *Management Science 49*(11): 1580-1596.

10. Cagliano, A. C., A. Carlin, and C. Rafele. 2009. “Understanding supply chain complexity with performance measurement”. *IFAC Proceedings Volumes* 42(4): 1126-1131.

11. Chand, P., J. J. Thakkar, and K. K. Ghosh, 2018. “Analysis of supply chain complexity drivers for Indian mining equipment manufacturing companies combining SAP-LAP and AHP”. *Resources Policy*, *59*, 389-410.

12. Chang, A. Y., K. J. Hu, and Y. L. Hong. 2013. “An ISM-ANP approach to identifying key agile factors in launching a new product into mass production”. *International Journal of Production Research* 51(2): 582-597.

13. Chen, F., Z. Drezner, J. K. Ryan, and D. Simchi-Levi. 2000. “Quantifying the bullwhip effect in a simple supply chain: The impact of forecasting, lead times, and information”. *Management science* 46(3): 436-443.

14. Cheng, C. Y., T. L. Chen, and Y. Y. Chen. 2014. "An analysis of the structural complexity of supply chain networks". *Applied Mathematical Modelling* 38(9-10), 2328-2344.

15. Chidambaranathan, S., C. Muralidharan, and S. G. Deshmukh. 2009. "Analyzing the interaction of critical factors of supplier development using Interpretive Structural Modeling—an empirical study". *The International Journal of Advanced Manufacturing Technology* 43(11): 1081-1093.

16. Childerhouse, P., and D. R. Towill. 2004. "Reducing uncertainty in European supply chains". *Journal of Manufacturing Technology Management*, *15*(7), 585-598.

17. Cho, J., and J. Kang. 2001. "Benefits and challenges of global sourcing: perceptions of US apparel retail firms". *International marketing review* 18(5): 542-561.

18. Choi, T.Y., and D.R. Krause, D.R. 2006. "The supply base and its complexity: implications for transaction costs, risks, responsiveness, and innovation". *Journal of Operations Management* 24 (5):637-652.

19. Chopra, S. and M. S. Sodhi. 2014. "Reducing the risk of supply chain disruptions". *Sloan Management Review* 55 (3): 73–80.

20. Da Silveira, G. J. 2005. "Market priorities, manufacturing configuration, and business performance: an empirical analysis of the order-winners framework". *Journal of Operations Management* 23(6): 662-675.

21. De leeuw, S., Grotenhuis, R. and van Goor, A.R. (2013). "Assessing complexity of supply chains: evidence from wholesalers". *International Journal of Operations & Production Management* 33(8): 960-980.

22. Eckstein, D., M. Goellner, C. Blome and M. Henke. 2015. "The performance impact of supply chain agility and supply chain adaptability: the moderating effect of product complexity". *International Journal of Production Research* 53(10): 3028-3046.

23. Efstathiou, J., A. Calinescu, and G. Blackburn. 2002. "A web-based expert system to assess the complexity of manufacturing organizations". *Robotics and Computer-Integrated Manufacturing 18*(3-4): 305-311.

24. ElMaraghy, W., H. ElMaraghy, T. Tomiyama, and L. Monostori. 2012. "Complexity in engineering design and manufacturing". *CIRP Annals* 61(2): 793-814.

25. Fisher, M., K. Ramdas, and K. Ulrich. 1999. "Component sharing in the management of product variety: A study of automotive braking systems". *Management Science* 45(3): 297-315.

26. Flynn, B. B., E. J. Flynn. 1999. "Information-processing alternatives for coping with manufacturing environment complexity". *Decision Sciences* 30 (4): 1021–1052.

27. Goffin, K., F. Lemke, and M. Szwejczewski. 2006. "An exploratory study of close supplier–manufacturer relationships". *Journal of operations management*, 24(2): 189-209.

28. Gorane, S. J., and R. Kant. 2013. "Modeling the SCM enablers: an integrated ISM-fuzzy MICMAC approach". *Asia Pacific Journal of Marketing and Logistics* 25(2): 263-286.

29. Govindan, K., D. Kannan, and A. Noorul Haq. 2010. "Analyzing supplier development criteria for an automobile industry". *Industrial Management & Data Systems* 110(1): 43-62.

30. Gunasekaran, A., P. Hong, and T. Fujimoto. 2014. "Building supply chain system capabilities in the age of global complexity: Emerging theories and practices". *International Journal of Production Economics* 147(2 Part B): 189-197.

31. Hamta, N., M. A. Shirazi, S. Behdad, and S. F. Ghomi. 2018. “Modeling and measuring the structural complexity in assembly supply chain networks”. *Journal of Intelligent Manufacturing*, 29 (2): 259-275.

32. Hashemi, A., T. Butcher, and P. Chhetri. 2013. “A modeling framework for the analysis of supply chain complexity using product design and demand characteristics”. *International Journal of Engineering, Science and Technology* 5(2): 150-164.

33. Heckmann, I., T. Comes, and S. Nickel. 2015. “A critical review on supply chain risk – Definition, measure and modeling”. *Omega* 52: 119-132.

34. Hesse, M., and J. P. Rodrigue. 2004. “The transport geography of logistics and freight distribution”. *Journal of transport geography* 12(3): 171-184.

35. Isik, F. 2010. “An entropy-based approach for measuring complexity in supply chains”. *International Journal of Production Research* 48(12): 3681-3696.

36. Jacobs, F. R., W. Berry, D. C. Whybark, and T. Vollmann. 2011. *Manufacturing planning and control for supply chain management*. McGraw Hill Professional.

37. Jacobs, M. A., M. Swink. 2011. “Product portfolio architectural complexity and operational performance: Incorporating the roles of learning and fixed assets”. *Journal of Operations Management* 29(7-8): 677-691.

38. Janićijević, N. (2013). “The mutual impact of organizational culture and structure”. *Economic Annals 58*(198): 35-60.

39. Kaplan, R. S. 1990. *Measures for Manufacturing Excellence*, Boston, MA: Harvard Business School Press.

40. Kavilal, E.G., P. V. Shanmugam and S. Joshi. 2018. “An integrated interpretive structural modeling and a graph-theoretic approach for measuring the supply chain complexity in the

Indian automotive industry". *Journal of Manufacturing Technology Management,* 29(3): 478-514.

41. Khadem, M., A. Shamsuzzoha, and S. Piya. 2017. "Optimization Modeling of a Poultry Industry Supply Chain Network". *International Journal of Supply Chain Management*, *6*(2): 27-32.

42. Kim, H. S. 2005. "Organizational structure and internal communication as antecedents of employee organization relationships in the context of organizational justice: A multilevel analysis". *Doctoral dissertation*, University of Maryland, College Park.

43. Koudal, P., and D. A. Engel. 2007. "Globalization and emerging markets". In *Building Supply Chain Excellence in Emerging Economies*, edited by Hau L. Lee and Chung Y. Lee, 37-66. Springer US.

44. Krishnan, V., S. Gupta. 2001. "Appropriateness and impact of platform-based product development". *Management Science* 47(1): 52-68.

45. Lampon, J. F., P. Cabanelas, and J. Gonzalez-Benito. 2017. "The impact of modular platforms on automobile manufacturing networks". *Production Planning & Control* 28(4): 335-348.

46. Lee, H. L., V. Padmanabhan, and S. Whang. 1997. "The bullwhip effect in supply chains". *Sloan management review* 38(3): 93.

47. Loch, C. H., J. Mihm, and A. Huchzermeier. 2003. "Concurrent engineering and design oscillations in complex engineering projects". *Concurrent Engineering: Research and Application* 11(3): 187–199.

48. Manuj, I., and F. Sahin. 2011. "A model of supply chain and supply chain decision-making complexity". *International Journal of Physical Distribution & Logistics Management* 41(5): 511-549.

49. Malucci, L. J. 2006. “Beneath the surface”, *APICS Magazine* 16 (8): 12.

50. Milgate, M. 2001. "Supply chain complexity and delivery performance: an international exploratory study." *Supply Chain Management: An International Journal* 6(3): 106-118.

51. Mohrschladt, R. 2007. “Managing the unexpected in complex chemical supply chains”. *SAP White Paper: SAP*.

52. Narasimhan, R., and S. Talluri. 2009. “Perspectives on risk management in supply chains”. *Journal of Operations Management* 27(2): 114-118.

53. Nepal, B., L. Monplaisir, and O. Famuyiwa. 2012. “Matching product architecture with supply chain design”. *European Journal of Operational Research* 216(2): 312-325.

54. Olugu, E.U., K. Y. Wong, and A. M. Shaharoun. 2011. "Development of key performance measures for the automobile green supply chain”. *Resources, Conservation and Recycling* 55(6): 567-579.

55. Pathak, S. D., J. M. Day, A. Nair, W. J. Sawaya, and M. M. Kristal. 2007. “Complexity and additivity in supply networks: building supply network theory using a complex adaptive systems perspective”. *Decision Sciences* 38(4): 547-580.

56. Perona, M., and G. Miragliotta. 2004. “Complexity management and supply chain performance assessment. A field study and a conceptual framework”. *International journal of production economics* 90(1): 103-115.

57. Piya, S. 2019. “Mediator assisted simultaneous negotiations with multiple customers for order acceptance decision”. *Benchmarking: An International Journal* 26(5):1581-1604.

58. Piya, S., M. Khadem and A. Shamsuzzoha. 2016. “Negotiation based decision support system for order acceptance”. *Journal of Manufacturing Technology Management*, *27*(3): 443-468.

59. Piya, S., A. Shamsuzzoha, M. Khadem, and M. Al-kindi. 2017. "Supply Chain Complexity Drivers and Solution Methods". *International Journal of Supply Chain Management 6*(4): 43-50.

60. Qureshi, M. N., D. Kumar, and P. Kumar. 2007. "Modeling the logistics outsourcing relationship variables to enhance shippers' productivity and competitiveness in logistical supply chain". *International Journal of Productivity and Performance Management* 56(8): 689-714.

61. Ramdas, K., and M. S. Sawhney. 2001. "A cross-functional approach to evaluating multiple line extensions for assembled products". *Management Science* 47(1): 22-36.

62. Rawlinson, J. G. (1981). *Creative thinking and brainstorming*. Farnborough, Hants: Gower.

63. Roh, J., P. Hong, and H. Min. 2014. "Implementation of a responsive supply chain strategy in global complexity: The case of manufacturing firms". *International Journal of Production Economics* 147: 198-210.

64. Rue, L. W., L. L. Byars, and J. R. Brooks. 1992. "*Management: Skills and application*". Homewood, IL: Irwin.

65. Sage, A. P.1977. *Interpretive structural modeling: Methodology for largescale systems*. New York, NY: McGraw-Hill.

66. Serdarasan, S. 2013. "A review of supply chain complexity drivers". *Computers & Industrial Engineering* 66(3): 533-540.

67. Shah, N. 2005. "Process industry supply chains: Advances and challenges". *Computers & Chemical Engineering* 29(6): 1225-1235.

68. Shamsuzzoha, A. and P. T. Helo. 2011. “Information dependencies within product architecture: prospects of complexity reduction”. *Journal of Manufacturing Technology Management* 22(3): 314 – 329.

69. Shannon, C. E. 1948. “A mathematical theory of communication”. *Bell system technical journal 27*(3): 379-423.

70. Sivadasan, S., J. Smart, L. H. Huatuco, and A. Calinescu. 2010. “Operational complexity and supplier–customer integration: case study insights and complexity rebound”. *Journal of the Operational Research Society* 61(12): 1709-1718.

71. Stadtler, H. 2015. “Supply chain management: An overview”. In *Supply chain management and advanced planning*, edited by Stadtler Hartmut., Kilger Christoph and Meyr Herbert, 3-28. Springer Berlin Heidelberg.

72. Suh, N. P. 2005. “Complexity in engineering”. *CIRP Annals-Manufacturing Technology* 54(2): 46-63.

73. Surana, A., S. Kumara, M. Greaves, and U. N. Raghavan. 2005. “Supply-chain networks: a complex adaptive systems perspective”. *International Journal of Production Research* 43(20): 4235-4265.

74. Tachizawa, E. M., C. Gimenez, and V. Sierra. 2015. “Green supply chain management approaches: drivers and performance implications”. *International Journal of Operations & Production Management* 35(11): 1546-1566.

75. Thirupathi, R. M., and S. Vinodh. 2016. “Application of interpretive structural modelling and structural equation modelling for analysis of sustainable manufacturing factors in Indian automotive component sector”. *International Journal of Production Research* 54(22): 6661-6682.

76. Turner, N., A. James, and C. Bozarth. 2018. "A framework for understanding managerial responses to supply chain complexity". *International Journal of Operations & Production Management* 38(6):1433-1466.

77. Um, J., A. Lyons, H. K. S. Lam, T. C. E. Cheng, and C. Dominguez-Pery. 2017. "Product variety management and supply chain performance: A capability perspective on their relationships and competitiveness implications", *International Journal of Production Economics* 187: 15-26.

78. Vachon, S., and R. D. Klassen. 2002. "An exploratory investigation of the effects of supply chain complexity on delivery performance". *IEEE Transactions on engineering management* 49(3): 218-230.

79. Vasanthakumar, C., S. Vinodh, and K. Ramesh. 2016. "Application of interpretive structural modelling for analysis of factors influencing lean remanufacturing practices". *International Journal of Production Research* 54(24): 7439-7452.

80. Vilko, J., P. Ritala, and J. Edelmann. 2014. "On uncertainty in supply chain risk management". *The International Journal of Logistics Management* 25(1): 3-19.

81. Walker, H., L. D. Sisto, and D. McBain. 2008. "Drivers and barriers to environmental supply chain management practices: lessons from the public and private sectors". *Journal of Purchasing and Supply Management* 14(1): 69-85.

82. Warfield, J. N. 1974. "Toward interpretation of complex structural models". *IEEE Transactions on Systems, Man, and Cybernetics* 5: 405-417.

83. Wilding, R. 1998. "The supply chain complexity triangle: uncertainty generation in the supply chain". *International Journal of Physical Distribution and Logistics Management* 28(8): 599–616.

84. Wong, C. W., K. H. Lai, and E. W. Bernroider. 2015. “The performance of contingencies of supply chain information integration: The roles of product and market complexity”. *International Journal of Production Economics* 165: 1-11.

85. Wu, Z., and T. Y. Choi. 2005. “Supplier–supplier relationships in the buyer–supplier triad: Building theories from eight case studies”. *Journal of Operations management* 24(1): 27-52.

86. Yadav, D. K., and A. Barve. 2015. “Analysis of critical success factors of humanitarian supply chain: An application of Interpretive Structural Modeling”. *International Journal of Disaster Risk Reduction* 12: 213-225.

87. Yang, B., and Y. Yang. 2010. “Postponement in supply chain risk management: a complexity perspective”. *International Journal of Production Research* 48(7): 1901-1912.