Managing Supply Chain: of Complexity, Risk and

** Dr. Uday Tate*
*** Prof. Deepak Subedi,*
**** Prof. Basanna Patagundi*

** Professor Marshall University, Huntington, West Virginia 25755, USA*
*** Professor Marshall University, Huntington, West Virginia 25755, USA*
**** Professor and Director, Cambridge Institute of Technology, K. R. Puram, Bengaluru, Karnataka, India*

Issues and Challenges Flexibility

ABSTRACT

Supply chain is a network of organizations. It is a complex system. According to Simon (1962), complexity makes any system, including supply chain, unpredictable, thus resulting in its task of day-to-day management that much difficult. In a complex system, a minor incident in one area has a potential to bring disaster in another. This article elaborates on several types of unpredictability in supply chain systems and also discusses their relationships with various levels of complexities involved in it. Minimizing the negative effects of complexity is very important. This article also discusses the role of modularity and flexibility, and the risk in managing supply chain complexity.

In addition, Bozarth et al. (2009) measured organizations' performances using factors like low-cost delivery, schedule attainment, customer satisfaction, and competitive performance. The authors concluded that an increase in complexity negatively affects organizations' ability to achieve their goals. Also, according to Quinn and Rohrbaugh (1983), an organization must balance between many of its contradictory values to function effectively. For example, an organization must find a balance between the needs for stability and flexibility and between the needs for variety and control. An organization's management of supply chain adds to the complexity it faces. Hence, organizations find balancing between such competing values (e.g., stability and flexibility) very challenging, especially in the face of the COVID-19 pandemic.

Key Terms: *Supply Chain, Complexity, Risk, Modularity, Flexibility, System Balancing*

INTRODUCTION

Supply chain is a complex system. Complexity, according to Simon (1962), is the outcome of multiple nodes and arcs of a supply chain interacting in nonlinear ways (Simon, 1962; Bozarth et al., 2009; Choi and Wu 2009; Touboulic et al., 2018, 2020) with other components and functions of an organization. Add to this, today's global economy has entered the fourth industrial revolution, widely known as Industry 4.0 (Schwab 2016). According to Koh et al. (2019), Industry 4.0 includes technological advancement in emerging technologies in such fields as robotics, artificial intelligence, nanotechnology, quantum computing, biotechnology, the Internet, fifth-generation wireless technologies (5G), 3D printing, big data, and fully autonomous vehicles, to name a few. This revolution has made a supply chain system as the integral part of an organization whether business and non-business-with multiple suppliers, intermediaries, governmental agencies, and customers, increasing its complexity exponentially. In addition, intense competition and changing demands of customers have led to additional challenges and the shortening of organizational life cycle, thus ultimately expanding complexity in organizations (Bala 2014; Bozarth et al., 2009; Gunasekaran et al. 2015; Rajah et al. 2018; Sheffi 2005; Sheffi and Rice, 2005; Touboulic et al. 2018, 2020; Yang and Yang, 2010).

A simple system means the distance between cause and effect, both in physical and temporal sense, is narrow. A complex system puts an extensive demand on information gathering, processing, and on managers' assessment and handling of complex decision processes and systems in their organizations (Cheng et al. 2014; Garud et al., 2003; Galbraith 1974; Manuj and Sahin 2011; Sheel 2016; Simon, 1962; Snowden and Boone, 2007; Pich et al. 2002; Trentin et al., 2012). Bozarth et al. (2009) empirically verified the negative impact of system-based complexities on the performances of manufacturers. According to these authors, higher complexity leads to higher cost in production and more incidents of breakdowns and delays in production processes. They also found that the system complexity negatively affected the customer satisfaction and their competitive positions.

Several studies have proven that a complexity in a system breeds risk (Sheffi, 2005; Simchi-Levi et al., 2008; Chopra and Sodhi, 2004; Gunasekaran et al., 2015; and Yang and Yang 2010). Complex organizations are disproportionately affected by small failures in some remote corners of their supply chain. For example, American electronics and computer manufactures were unduly affected by Taiwan's earthquake of 1999 (Yang and Yang, 2010; Sheffi 2005; Simchi-Levi, 2008). Similarly, electronic giant Ericsson's eventual decision to get out of cell phone manufacturing has been attributed to an insignificant fire in a supplier's plant in New Mexico (Sheffi, 2005; Simchi-Levi et al., 2008; Chopra and Sodhi, 2004; Gunasekaran et al., 2015; Yang and Yang 2010; and Sheffi and Rice, 2005).

A related issue here is that of Modularity. Simon (1962), while discussing Complexity, used a thought experiment to show that a modular product design not only reduces the product complexity but also adds to the flexibility and reduces the associated risks of delay. He gave an example of two (fictitious) watchmakers, each making similar watches with ten thousand parts. One watchmaker used modularity and made ten different modules of one thousand parts each, and the other watchmaker did not use modularity to organize ten thousand parts. The experiment showed that the modularity minimized the effect of breakdowns from any interruption for the first watchmaker, but the similar breakdowns proved to be disastrous for the second watchmaker who did not use modularity. Many studies have shown that a modular product structure, and a disintegrated organizational structure go hand in hand (Baldwin and Clark, 1997; Langlois and Robertson, 1992; Fujimoto, 1999; Fine and Whitney, 1996). Modularization and standardization helps to reduce transaction costs (Williamson, 1996; Garud and Kumaraswamy, 1995; Sanchez and Mahoney, 1995). There are many examples in Auto-Industry in the United States (Langlois and Robertson, 1992; Raff, 1999) and Japan (Fujimoto, 1999), and in the Computer Industry (Baldwin and Clark, 1997; Fine and Whitney, 1996) to support this assertion.

Understanding and balancing the contradicting propositions like complexity, flexibility, and variety in a system are required for effective management of organizations; and it is more relevant when it is a part of a complex system like supply chain (Quinn and Rohrbaugh, 1983; Bozarth et al.,2009). What is complex in one context may not be the same in another situation. Still, flexibility, which can mitigate the effect of complexity and improve the customer satisfaction in one situation, can also exacerbate it without increasing customer satisfaction in many other cases (Bozarth et al., 2009; Fujimoto, 1999 and 1999b; Holweg and Pil, 2004; Ward et al., 2010).

Regarding complexity, one should also recognize that many of today's supply chains have replaced the vertically integrated corporate structures. The vertical structures have been proved complex, costly and inflexible facing increasingly demanding customers and intense market competition (Fine and Whitney, 1996; Langlois and Robertson, 1992). Also, for many products, increasing choices and varieties for customers entails adding complexities (Frohlich, 1998; Fujimoto, 1999; Fujimoto, 1999b; Bozarth et al.,2009).

UNPREDICTABILITY AND COMPLEXITY

Although commonly referred to as risk or uncertainty, there are various kinds of unpredictability. We can describe unpredictability in an ordered system as 'risk', whereas the same in an unordered structure can be regarded as 'uncertainty' or 'ambiguity' (Bazerman and Moore, 2012; Pich et al. 2002; Snowden and Boone, 2007).

Classifying Unpredictability

Knight is world-renowned author of the book, Risk, Uncertainty and Profit (1921), based on his doctoral dissertation at Cornell University. In this monumental book, he carefully distinguished between economic risk and uncertainty. Langlois and Cosgel (1993) explained Knight's definition of risk and uncertainty. According to these authors, playing with a deck of cards entails risk, whose outcomes can be unpredictable, but all the requisite information is available;

therefore, risk can be measured perfectly. Uncertainty arises when information is incomplete (Langlois and Cosgel, 1993). We need more data before calculating risk (Daft and Lengel, 1986). We call this situation 'known-unknown' in the sense that you do not have enough information, but you know what to look for (Snowden and Boone, 2007; Courtney et al., 1997; Pich et al. 2002; Simchi-Levi et al. 2008).

And there is ambiguity. Ambiguity arises when available data provide incomplete and equivocal or conflicting information. Under this condition, more data availability is not necessarily helpful. This situation is called as 'unknown-unknown.' A situation is unknown and what information to look for is unknown. When faced with an "unknown-unknown" circumstance, managers should first create a framework to interpret the information and then the framework can make sense out of the unknown-unknown situation (Weber and Glynn, 2006; Weick, 1989; Snowden and Boone, 2007; Courtney et al.,1997; Pich et al. 2002; Simchi-Levi et al. 2008, pp 316; Subedi, 2017). In such conditions, qualitative data collection methods, such as face-to-face meetings (which provide verbal and nonverbal cues not captured by data), can be useful (Daft and Lengel, 1986; Bazerman and Moore, 2012, pp 76; Pich et al. 2002).

Level of Complexity

In Snowden and Boone's (2007) framework of complexity, the first category is called ordered complexity. It falls in the realm of risk. The ordered complexity is further divided into two levels. The first level is simple and is referred to as a stable environment. At this level, processes and outcomes can be measured and predicted. Prediction do not mean perfection, but it means processes are controlled enough to ensure that any diversions from the predetermined outcome are minimal. There are rules and policies in place to tackle any irregularities (Saffo, 2007; Courtney et al., 1997). Various tools of operations research and operations management, such as optimization, six-sigma, lean manufacturing and just-in-time, are successfully deployed in a simple and stable environment (Pich et al. 2002; Subedi, 2017).

The next level of complexity is called complicated. Any supply chain process can be complicated because it has multiple connections of nodes and arches. Demand forecasting is one among such example. Demands can be predicted but within a range of error. Similarly, while lead-time for production and delivery can be estimated, there will always be some error. This situation can be handled with extra inventory. Or, they can purchase option contracts with the suppliers, allowing the flexibility of ordering more than the initial base order once the demand becomes more clearer (Cachon and Terwiesch, 2013; Gunasekaran et al. 2015; Bozarth et al., 2009).

Another category in Snowden and Boone's (2007) framework is unordered. This category falls within the realm of 'uncertainty' and 'ambiguity.' It is also divided into two levels (Saffo, 2007; Bozarth et al., 2009). The first one is complexity. As defined above, the supply chain is complex. A 'bullwhip' effect is a well-known outcome of this complexity. It is called 'bullwhip', because a slight change in demand from the customers often leads to huge fluctuations in orders received by manufacturers. We should note that the orders manufacturers receives do not represent the demand for the product. The first reason for this is the demand forecasts by intermediaries (e.g., retailers). These numbers reflect the intermediaries' understanding of their customer needs, padded with their own biases and judgements on the requirements of safety stocks, etc. Levels of safety stocks, in turn, are determined by their trust in suppliers' ability to fulfil the order in a timely manner. A slight uptick in demand may lead to bigger padding in forecast and their perceived need for the safety stocks. And when the demand falls just a little, the order for the manufacturer crashes down (Bozarth et al., 2009; Lee, Padmanabhan and Whang, 1997; Cachon and Terwiesch, 2013, pages; Simchi-Levi et al., 2008; Sheffi, 2005).

This is a case of uncertainty, a 'known-unknown' situation. Manufacturers in this case do not know actual data but know where to look for. They can collect undistorted data directly from the end customers. Once done, it will turn into regular risk (Snowden and Boone, 2007; Pich et al., 2002; Lee et al., 1997, Daft and Lengel, 1986; Courtney et al., 1997).

The last case is known as 'chaos.' A chaos is regarded as a highly turbulent situation, often described as crisis, wherein scientific methods of predictions and analysis do not help (Sanial, 2014). Here, the available information is ambiguous. There is no pre-established framework by experts or contingency plan to guide actions under chaos. This leads to an 'unknown-unknown' situation, meaning that you do not know where to look for the information. Management leadership should be able to take a cue from a weak signal and establish a framework to define the problem (Weber and Glynn, 2006; Weick, 1989). The solutions to a defined problem depends on what questions are being actually asked. Ambiguity requires 'rich information' based on verbal and nonverbal cues rather than just quantitative data (Snowden and Boone, 2007; Daft and Lengel, 1986; Courtney et al., 1997; Bazerman and Moore, 2012).

To illustrate, the situation created by a small-scale fire in a plant owned by Royal Philips Electronics plant in Albuquerque, New Mexico, in March of the year 2000, is one such example, as described above (Sheffi, 2005; Simchi-Levi et al., 2008, page 319; Chopra and Sodhi, 2004; Gunasekaran et al., 2015; Yang and Yang 2010; Sheffi and Rice, 2005). The well-reported fire is said to have lasted for less than 10 minutes. The plant's production of fabricated microchips was affected. However, the plant management's initial assessment, as suggested in their statement, was that it would be back to normal quickly. Two main customers of the chips manufactured by Royal Philips Electronics were Ericson and Nokia. Both of them were producers, competing in the growing cell phone market but the way they framed the problem led them to react in a different manner.

Nokia took the fire as an early indicator of looming disaster-well beyond what the situation of small-scale fire suggested. The company sent people to the plant for a face-to-face discussion to assess the situation. It also sent other people to different Philips and Non-Philips microchip producers to arrange for the suitable substitutes. Ericson took the statement from Philips in its face value. This proved to be disastrous. Philips lost around $40 million in that fire. Nokia proved more resilient. It could take away market share from the rival, Ericsson. Overall, loss for Ericson was in the order of $2.3 billion (Sheffi, 2005; Simchi-Levi et al., 2008; Chopra and Sodhi, 2004; Gunasekaran et al., 2015; Yang and Yang 2010; Sheffi and Rice, 2005).

FLEXIBILITY AND RESILIENCE

An important rule in managing complexity is to reduce the level of complexity itself. Any reduction in complexity goes hand in hand with the reduced need for information processing and lower risk (Baldwin and Clark, 1997; Sanchez and Mahoney, 1996; Sanchez, 2003; Garud et al., 2003; Garud and Kumaraswamy, 1995; Ulrich, 1995; Simon, 1962; Galbraith, 1974). Thus, when the complexity in the supply chain is minimized, the residual unpredictability is managed by increasing flexibility (Trentin et al. 2012; Galbraith, 1974). Flexibility, in general, enables the system to cope up with the unpredictability in the market demand by allowing it to change the product mix and volume without incurring undue cost (Gerwin, 1993; Ulrich, 1995, Belis-Bergouignan and Lung, 1999). This is achieved by changing the structure of the product as well as the process of production (Garud et al., 2003; Ulrich, 1995; Baldwin and Clark, 1997).

Modular Product Design

A modular product structure is simpler as compared to the integral one. Under this structure, designing, production, and upgrading of each module can be done independently. Such modules communicate with each other using standard interactions and interfaces. Managers can understand and control the simpler system with the modular parts (Baldwin and Clark, 1997; Sanchez and Mahoney, 1996; Sanchez, 2003; Garud et al., 2003; Garud and Kumaraswamy, 1995; Ulrich, 1995; Simon, 1962).

General Motors provides a historic example of flexibility afforded by the simpler modular product design. When General Motors, for the first time in the 1920s, offered an automobile for “every purse and purpose” and started the trend of changing models every year, it was essentially a conglomerate comprising multiple brands of cars. Alfred P. Sloan streamlined the production process by developing platforms and parts common for multiple brands and multiple years. This simplified the production process of automobiles. In addition, it enabled GM to combine fewer types of parts and platforms to produce a wide number of different models (Chanaron and Lung, 1999; Raff, 1999).

Companies that use common parts and platforms enjoy the advantage of the economies of scope, lowering the cost of production (Baldwin and Clark, 1997; Ulrich, 1995; Jetin, 1999; Mishina 1999; Belis-Bergouignan and Lung, 1999; Chanaron and Lung, 1999; Raff, 1999). In addition, it can maintain the same level of services with fewer parts on hand, thus reducing the complexity and the cost of the inventory management (Simchi-Levi et al., 2008). Toyota had also increased its flexibility by utilizing general-purpose machines, tools, by training workers to multiple skills, and having u-shaped manufacturing cells (Cachon and Terwiesch, 2013; Fujimoto, 1999; Mishina, 1999; Ulrich, 1995; Trentin et al. 2012; Galbraith, 1974).

Modularity in Other Industries

Adoption of modular structure in the computer industry have been discussed extensively by Baldwin and Clark (1997), Simchi-Levi et al. (2008), Sheffi (2005), Yang and Burns (2003), and Yang and Yang (2010). Modularization of IBM's popular computer system/ 360 is an important historic example. It was their adoption of a modular system that made it easier for the corporation to update and develop alternative models. It allowed customers to streamline their system with software and peripheral hardware of their choices. In addition, it became a lot easier for IBM's customers to upgrade with new software and hardware (Baldwin and Clark, 1997).

One of the often-cited supply chain is that of Hewlett-Packard (HP) for printers. For years, HP printers served multiple markets in Europe, each of which has a unique language. HP developed a plain vanilla printer based on aggregate demands. The minor adjustments on fonts, manual, and packaging were postponed till the demands were precisely known (Olavson et al., 2010; Simchi-Levi et al., 2008; Sheffi, 2005; Yang and Burns, 2003; Yang and Yang, 2010). Similarly, with modular components, Dell could produce 'customized' products with lower costs of mass manufacturing (Simchi-Levi et al., 2008; Magretta, 1998).

Resilience with Modularity and Flexibility

When supply chain situations are 'unknown-unknown' types, they are called 'crisis.' Some note that under 'crisis' situations, modular product structures have proven to be helpful (Sheffi 2005; Sheffi and Rice, 2005; Sheffi, 2015). With fire disaster involving Nokia and Ericsson, Nokia benefitted from the modular product design. This allowed Nokia to change the microchips in its cell phones. Ericsson's design was integral. This is another important reason of success of Nokia over Ericsson (Sheffi, 2005; Simchi-Levi et al., 2008; Chopra and Sodhi, 2004; Gunasekaran et al., 2015; Yang and Yang 2010).

As noted earlier in the article, earthquake in Taiwan in September 1999 has been mentioned several times in the supply chain literature because of its impact in the computer industry in the United States. Both Apple and Dell had announced new products based on the supplies of parts from Taiwan. However, Dell, with its modular product design, could replace the chips coming from Taiwan with the ones that were available; but Apple could not adjust due to the shortage of chips from Taiwan and hence it lost its market share from the competitors (Yang and Yang, 2010; Sheffi 2005).

EFFECTIVE SUPPLY CHAIN

Organizations must perform effectively and efficiently to maintain its competitive advantage from a long-term perspective. Bozarth et al. (2009) used low cost, schedule attainment, customer satisfaction, and competitive performance as the measure of organizational performances. Meeting each of these goals depends on the organization's ability to manage the supply chain effectively (Bozarth et al., 2009). According to Quinn and Rohrbaugh (1983), an effective management requires a balancing of contradicting propositions in its supply chain. The most important of such values discussed below are Stability vs. Flexibility and Varieties in product vs. Complexity.

Stability versus Flexibility

Stability demands a simple system, where items are produced according to a production plan (Pich et al. 2002). Flexibility requires a system's ability to respond to variations in demand without undue difficulties or hurdles (Belis-Bergouignan and Lung, 1999; Chan, et al. 2009; Gerwin, 1993;.Sreedevi and Saranga (2017; Ulrich, 1995; Yu and Luo 2015) suggest that flexibility in a supply chain system can serve as an effective solution to the uncertainty generated by the highly increasing competitive global challenges. Many empirical studies have shown that flexibility in supply chain systems has led to an improved business performance in the face of uncertain and dynamic global environment (e.g., Merschmann and Thonemann 2011; Sanchez and Perez 2005; Sreedevi and Saranga 2017). The Toyota production system is considered as an example of the most efficient, flexible process, which is also known for its Total Quality Management (TQM). It also offers wide varieties compared to any other producers in the automobile industry. Toyota has achieved a higher level of profitability, and has gained market share, along with a higher level of customer satisfaction. It has achieved all of this with standardized working process, multi-skills training, and stable production volume, along with its modularization of products and outsourcing as discussed above (Fujimoto, 1999 page 46; Fujimoto, 1999b, Mishina, 1999; Holweg and Pil, 2004; Liker, 2004).

The level of inventory is another critical issue related to efficiency and flexibility of a supply chain system. The role of inventory is to decouple the individual activities, so that the supply chain process is less susceptible to breakdowns and disruptions. A proper inventory management allows the system to adjust to the change in market demand and makes it more flexible (Yin and Yang, 2010; Mishina, 1999). However, if taken too far, it can add to unnecessary complexity. Counting, stocking, managing, and retrieving stocks or inventories are complex processes. It becomes especially difficult when you have old inventories (Bozarth et al., 2009; Gunasekaran et al., 2015). Hendricks and Singhal (2009) found stakeholders take that excessive inventory as the sign of mismatch of demand and supply. Announcements of such mismatches can lead to the reduction of the stock values of the firms by as much as 7 percent or more.

Another related issue is the number of suppliers. Breaking up of a vertical supply chain structure is to order from outside suppliers at cheaper cost (Fine and Whitney, 1996). However, many suppliers can also add to complexity. With the increased number of suppliers comes the possibility of delay, breakdown and inferior quality seem to increase (Bozarth et al., 2009; Gunasekaran et al., 2105). So, success of many Japanese corporations (e.g., Toyota) is often attributed to the system of having fewer selected suppliers and developing close relationships with them. Now, many European and American companies seemed to have followed the Japanese corporate style when managing their supply chains (Sako and Helper, 1999; Fujimoto, 1999; Liker, 2004).

However, dealing with few suppliers may cause its own problem. It may mean higher cost or breakdown of one supplier in some corner may lead to disaster for the buyer. For example, because of failure of airplane wings in stress testing, Boeing lost billions of dollars in cancelled orders, loss of market share and lowering of the company's share price (Mecham 2009; Wallace, 2007; Gunasekaran et al. 2015). Several empirical studies have shown that the announcements of disruptions in supplies or delays in introduction of new product due to supplier failure have resulted in substantial and sustained losses to the announcers (Hendricks and Singhal, 1997; Hendricks and Singhal, 2005). Toyota (and other Japanese companies) mitigated the possibility of unreliable suppliers by maintaining internal capability and having alternative suppliers to be ready as substitutes (Liker, 2004; Webb, 2016; Kubota, 2016; Fine and Whitney, 1996).

Maintaining a balance between efficiency and flexibility is a challenge for many corporations. Even Toyota, with the exemplar Toyota Production System, seemed to have struggled in achieving a balance between efficiency and flexibility in its supply chain system. After the massive loss in the earthquake of March 2011, Toyota came to realize the vulnerability of its lean supply chain. It put in place a system of redundancy, placing alternate suppliers ready in case of emergency. Even then, the disruption of Toyota's supply chain in the recent earthquake (of April 2016), was deemed to be excessive compared to those of other similarly affected companies (Webb, 2016; Kubota, 2016).

Varieties vs. Complexity:

Research have showed that a supply chain needs a balance between internal stability and external market demand to be effective (Quinn and Rohrbaugh, 1983). Internally, an organization is a socio-technical system. It demands routine, stability and harmony. Establishing such routine involves coordination amongst different (and sometimes incompatible) technologies, and groups of people with different priorities. Such effective routines are developed over time through trial and error (Quinn and Rohrbaugh, 1983; Frohlich, 1998; Chanaron and Lung, 1999).

Externally, ever-increasing competition and demanding customers lead to the demands of newer models, and wider varieties of choices even within a model (Fujimoto, 1999 page 46; Fujimoto 1999b; Mishina, 1999). A large variety of models in a system makes it difficult to achieve an economy of scale. The frequent changes in a system's setup can increase mistakes, cost, and lower quality for all those involved in the supply chain. This can also lead to unwanted increases in inventory and can cause mismatches between demands and supplies resulting in customer dissatisfaction. With experience and technology (modularity and flexible process as described above), the complexity and cost can become manageable, but they are still higher than it would otherwise be (Gunasekaran et al., 2015).

It is a common understanding that the added costs of complexity can be more than offset by increased market share, improved customer satisfaction and increased profit for the company (Bozarth et al., 2009; Fujimoto, 1999; Fujimoto 1999b; Mishina, 1999). However, just because companies are offering wide varieties of models and trims, etc., it will not automatically lead to the higher customer demands or satisfaction. Also, proliferation of choices makes comparison and analysis more difficult for the customers, causing customers to ignore those choices (Langlois and Robertson, 1992). A study found that one plant of Toyota had the capability of producing one million varieties of cars and most of which are never produced. Among the choices that were produced, most of them were for one piece only. In fact, only 20% of the varieties covered 80% of the demand. Experts dubbed this 'fat design'. Thus, the cost and complexity of these extra varieties far exceeded any benefit Toyota might have received from extra market share or higher customer satisfaction (Fujimoto, 1999; Mishina, 1999, Fujimoto, 1999b). In fact, few of them suggested that the automobile industry can reduce the number of varieties offered. This would not only reduce complexity, cost, and the risk of mismatch between demand and supply, but it could also increase customer satisfaction. This reduced complexity can also make the production process flexible enough to offer mass-customized car, just like the advantage gained by Dell Computers in the computer market (Holweg and Pil, 2004).

According to Holweg and Pil (2004), the automobile industry never got its act together to make its production process flexible. Hewlett-Packard, after analyzing its products and demands, did just that. It purged unnecessary varieties and streamlined the process, improving not just efficiency and productivity, but also the customer satisfaction (Ward et al., 2010). Not that Toyota did not realize the cost and complexity imposed by 'fat design' besides the cost of engineering and quality (Fujimoto, 1999b), but the crisis of Toyota's braking system showed that their cost-cutting and simplifying efforts they undertook did not produce the desired effects (Cusumano, 2011). This is another example of a crisis induced by complexity.

IMPACT OF THE COVID-19 PANDEMIC ON COMPLEXITY, RISK, AND FLEXIBILITY IN SUPPLY CHAINS:

The impact of the COVID-19 pandemic has been far reaching and overwhelming for individuals and their families, profit- and non-profit organizations, and nations across the globe (Volkin 2020). Specifically, this global curse has impacted the various sectors of any nation's economy, including but not limited to, manufacturers, wholesalers, retailers, exporters and importers of goods and services The negative effects of the pandemic have been particularly severe and profound for supply chains for health-related products (e.g., personal protective equipment) and hospital services (capacity and medical treatments for COVID-19), across the nations--industrialized, developing and underdeveloped nations (Dai, et al. (2020; Rajasekharan 2020; Ranney et al. 2020). According to Sharma et al. (2020), the economic, social, and political impact of the pandemic has created disruptions for many firms and many nations, thus leading to inefficiencies and ineffectiveness in supply chain systems across the globe.

In order to successfully cope and overcome the challenges and disruptions posed by the COVID-19 pandemic, it is imperative that academicians, researchers, and practitioners of supply chain management (SCM) must analyze and evaluate the current practices in an attempt to redesign and innovate SCM systems (Ranney et al. 2020). Such efforts can provide much needed strategic directions, adjustments, and improvements in global supply chain systems, necessary to defeat the pandemic. In light of such efforts, future research on supply chain networks should focus on assessment and evaluation of the current strategic and tactical adjustments made by various firms across the globe in their attempt to cope with the challenges posed by the pandemic. The outcome of research efforts can lead to insights and innovation in such areas of SCM as complexity, uncertainties (risk), and flexibility (Sengupta 2020; Sharma et al. 2020; . It will also initiate a much-needed culture of collaboration in SCM across firms, industries, and nations (Cao and Zhang 2011; Ranney et al. 2020).

In addition to conducting specific research studies on SCM, future research efforts can use a meta-analytic approach to assess the past and current practices in terms of complexity, risk, and flexibility (e.g., Golici and Smith 2013; Leuschner et al. 2013; Manhart et al. 2020; Serdarasan 2013). The proposed meta-analytic research direction should focus not only on the main effects of primary factors that support and influence SCM, but also review their moderating and mediating effects on complexity, risk, and flexibility, in local and global contexts, under the conditions of the COVID-19 pandemic.

CONCLUSION AND DISCUSSION:

The conclusion of this paper is presented in the casual loop diagram of Figure 1. While Figure 1 may not encompass all the details discussed in the articles, it displays the concepts, and their interrelations and interdependencies in a comprehensive and useful manner. For example, while not addressed in this article, the risks of fluctuations in rates of foreign exchanges, and in oil prices, can add to the complexity of the supply chains; and such future research should focus on investigating their role and impact on supply chain systems (Simchi-Levi et al., 2008; Gunasekaran et al., 2015). Another critical issue is that of long-term risk. Even with perfect supply chains, there are examples of companies who started at the top position, but only to lose their power and position to their suppliers (Simchi-Levi et al., 2008; Subedi, 2013). This issue should be examined in future research studies on supply chain.

The complexity, when properly managed by using modularity and outsourcing, can increase customer satisfaction and reduce cost(Figure 1). With modularity and outsourcing, companies can develop more varieties and add choices for their customers. Outsourcing and modularity can also lead to lower inventories, leading to lower cost and complexity. These are conclusions Bozarth et al. (2009) have drawn in their research.

In addition, Figure 1 shows that the relationships between complexity and performances in supply chain are themselves complex. The arrow shows the nonlinear relationships; plus, there are many feedback loops which can exacerbate complexity. Therefore, while adding variety can add to customer satisfaction, additional varieties can lead to extra inventory and increased complexity. Similarly outsourcing, which is a step taken to add efficiency, can also be the source of delays and breakdowns. While reducing inventory can be a hallmark of the efficiency, but it is required not just to add flexibility, but also to mitigate the negative impact of delay and breakdowns. Other relationships in the figure can be interpreted accordingly.

Covid-19 pandemic has created a far-reaching impact on supply chain systems across the globe. Hence it is imperative that the relationships among complexity, risk, and flexibility must be examined withing the context of the challenges posed by the pandemic.

Finally, this leads to the assertion that while the goals of having control in a supply chain system and having flexibility, managing complexity, and providing varieties, may sound conceptually opposite and mutually exclusive; however, an effective management of supply chain's complexity, flexibility, and variety can be mutually beneficial to each other (Quinn and Rohrbaugh, 1983). Figure 1 shows that the relationships in the complex networks are dynamic. We can find example of all in Toyota production system. While the lean or Toyota production system is widely admired, it has been struggling at various instances to attain these balances (Bozarth et al., 2009). So, balancing should be an ongoing endeavor in any supply chain system.

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Annexure:

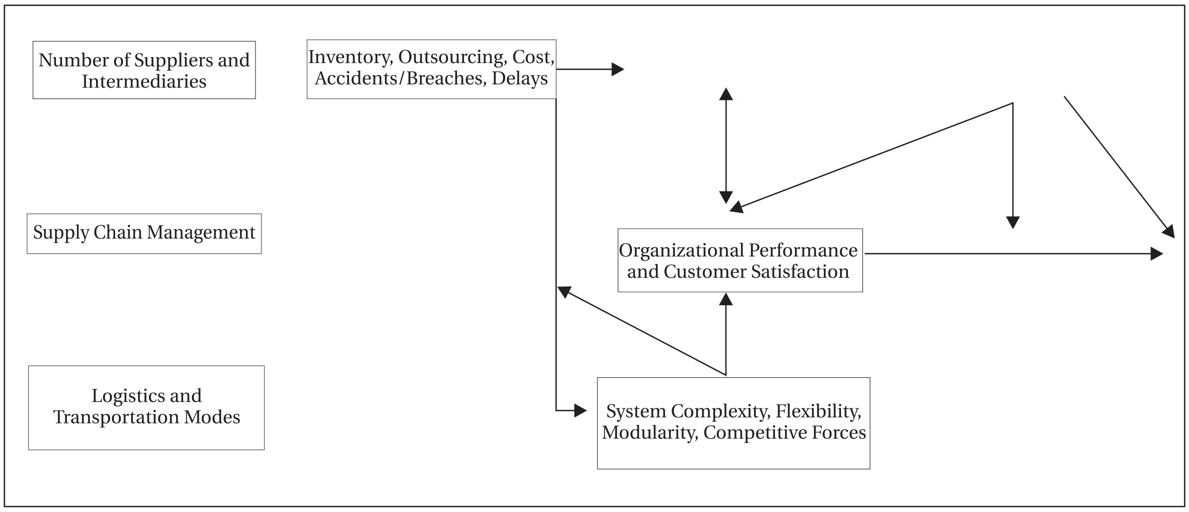

Figure 1: Supply Chain Management Paradigm