Supply Chain Complexity Drivers and Solution Methods

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Abstract— Increased globalization, shorter product life cycle and rapid technological advancement in the manufacturing as well as service industry necessitates the company to have multiple supply chain partners. The partnership may be physical or virtual, thus making the chain more challenging and complex to manage. Therefore, the present supply chain network is characterized by its complexity, which requires proper management and strategy for its mitigation. In addition, the dynamic world in this complex supply chain system demands the manager to make faster and efficient decision. To manage the overall supply chain complexity and to make an efficient decision it is important that the manager understand the associated complex interactions within a supply chain, as well as, proper solution method to mitigate them. In this paper, generic supply chain complexity drivers are identified through literature survey and expert opinion. These drivers are then classified according to their origin. Finally, solutions methods are proposed to manage complexity in supply chain.

Keywords— Supply chain, Supply chain complexity, Complexity drivers, Solution method

1. Introduction

Management consultants coined the term supply chain (SC) in 1980s [14], [15]. Thereafter, supply chain management (SCM) has generated greater enthusiasm among researchers as well as industrial practitioners with rapid increase in the number of articles published in this discipline. SCM is a system of individuals, organizations and the flow of resources, services, activities and information between them [17]. The members of the SC network are the companies, which collaborate with each other to contribute towards the development of the final products or services. Effective integration and closer relationships between SC members are important to have effective SC [8], [25].

The network of SC is an essential part to many successful industries around the globe. All products start from planning stage at the parent company until it reaches the customer. The product goes into various stages at the point of various SC partners, adding value at each stages, before it reaches the customer. Not only manufacture based company, even in service industry, service provider has to deal with many SC partners to add value to their product offering. Due to the globalization of business domain, the importance of SC is getting profound more than ever. It is therefore critical for organization to manage their SC network as smoothly as possible. However, often, it is not an easy task to manage SC network according to the needs [18]. Efficient and effective management of the network poses many hurdles and challenges [7]. Today's SC exhibit a large and complex interaction with their suppliers, customers and other firms thereby making the chain complex to manage. Ref. [24] and [29] describes SC as complex adaptive systems. SC complexity can be defined as the complexity demonstrated by the products, processes and relationships that make up a chain. Complexity makes it difficult to manage SC efficiently as planned. This is a growing concern in global business domain due to its importance in day-to-day business environment. Various factors inherent within and outside of the chain contribute to SC complexity. These factors are known as

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complexity drivers. The identification of the drivers are critical to manage or mitigate complexity [27].

The rest of the paper is structured as follows. Section 2 reviews the research that has been carried out in this area in the past. Section 3 describes the methodology followed in this research. Section 4 identifies and classify various drivers of complexity. Section 5 discusses the strategic action or method that may be implemented to mitigate specific driver of complexity. The paper concludes with future research directions in Section 6.

2. Literature Review

According to ref. [26] "complexity has been the topic of several manufacturing, organizational, and information technology studies creating a variety of definitions and applications depending on the perspective and/or theories". Ref. [4] defined complexity in SC as the risks or the difficulties that arises within various entities of SC during conceptualization, production and distribution of product. On the other hand, ref. [28] defined it as the deterministic chaos, parallel interactions and amplifications. Ref. [26] proposed complexity as a 3D construct, comprising numerousness, interconnectivity and system unpredictability. They also expressed SC complexity as a measure of complexity exhibited by the components and delivery performance of its associated factors. Ref. [19] relates SC complexity with the product architecture. Ref. [21] conducted an empirical research to investigate the effect of complexity on SC. Their research findings show that the way company handles their system complexity has a deep impact on their performance. Moreover, ref. [3] found that the presence of complexity driver increases the frequency of SC disruptions, as well as, the drivers interact and amplify each other's effects in a synergistic manner. Complexity in a SC may lead to increase in costs, poor overall SC performance and lower customer satisfaction thereby tarnishing the reputation of company. Therefore, it is important to deal with complexity arising within SC efficiently.

Various factors affects SC and makes it complex. These factors are commonly known as drivers, which are directly associated with its complexity. This complexity can arise within plant level (e.g. process layout, information flow, operational processes, etc) or outside of the plant connected with downstream and upstream partners [4]. Studies found that SC complexity drivers are mainly categorize as static and dynamic [23]. In static complexity, the drivers are associated with the SC structure, while dynamic drivers are related to uncertainty or randomness in the SC. The drivers of specific SC complexity can be defined through multiple sources such as observations, questionnaire interview, historical database, archives, etc. Through determining the complexity drivers in SC, the partners' organizations can be able to monitor and manage their SC efficiently. It supports to achieving better SC performances [12], [13]. In industrial supply network, complexities arise through interactions between manufacturers, assemblers, distributors and retailers [20]. Understanding such interactions may allow developing a clear strategy to analyze and manage complexity.

The aim of this research is to understand complexity issues within the SC, identify the drivers of complexity and suggest method to overcome it through predefined specific complexity classification.

3. Research Methodology

Identification of drivers that lead to complex SC is the first and foremost important task to overcome the complex situation that arises within SC network. To identify these drivers, this research followed theoretical approach by conducting literature review. From such literature review, 18 drivers responsible for SC complexity were identified. Based on these complexity drivers a list is prepared together with the consequence of these drivers on SC network. The list is forwarded by e-mail to 30 experts working in various companies for confirmation and further addition of complexity drivers based on their experience. However, the response rate was very poor, around 16%, which is not enough to come to rigid conclusion. Therefore, next, list was presented physically to the managers of 16 different companies the demographic information of which is as shown in Table 1. Note that the percentage in the table is presented in round figure.

Table 1: Demography of selected company and respondent

Business sector of company - Oil and gas: 25% - Logistics and transportation:13% - Engineering service and consultancy: 13% - Real estate and construction: 6% - Machinery and equipment Supplier: 18% - Manufacturing and process:25%
Designation of people communicated - Supply chain manager: 32% - Production manager: 18% - Sales and purchasing manager: 23% - Human resource manager: 9% - Project manager: 18%
Experience of people in their job (in years) - 3 to 5: 28% - 6 to 10: 45% - 11 to 15: 18% - 16 to 20: 9%
Company establishment (in years) - 5 to 10: 23% - 11 to15: 28% - 16 to 20: 31% - 21 and above: 18%

During physical meeting, the purpose of the list and the identified drivers were explained to the managers. In addition, the managers were requested to identify any factors, which is not in the list but they believe that it creates complexity within their SC network. From the physical interaction, ten new drivers were identified. Therefore, the list was revised by including these new drivers with its possible impact and five experts were invited for the brainstorming session to get consensus on these drivers, especially for the newly identified drivers. Brainstorming technique was selected due to the reason that it is one of the most effective techniques available of creative problem solving [22]. Finally, literature review and brainstorming session of experts result into the identification of 26 drivers of complexity. These identified drivers are then clustered based on the point where it originates such as internal driver, external driver and interfacial driver. The internal drivers are characterized based on the SC complexity within the organizational boundary and associated mainly with internal processes. Whereas, external drivers lie outside of the organizational boundary and deals with external SC environments such as geographical locations, political rules etc. On the other hand, interfacial driver are the drivers that originates between supply and demand. In addition, several solution methods to manage different SC complexities are highlighted within the scope of this research.

4. Supply Chain Complexity Drivers

Managing SC complexity involves the coordination and control of the upstream, mid-stream and downstream flows of products and services through the company in order to achieve several goals such as reducing costs, increasing performance, achieving a higher customer satisfaction, improving profitability and enhancing the reliability of communication [23]. SC becomes more complex when a company has to deal with large number of suppliers/ partners. Consequently, managing complexity becomes a crucial task in such companies. Management of complexity first requires identification and then controlling of drivers that drives SC towards complexity [1]. However, before identification, it is imperative to understand what a complexity driver is [11]. Many drivers influence SC complexity and could be classified based on the origin of drivers.

4.1 Internal complexity:

Internal complexity is related to the difficulties that is generated within various entities of organization. It can extend to include products, process, as well as, related to the aspect of organization itself. Figure 1 shows all the drivers that is related to internal complexity. These drivers can be further categorized into either strategic or tactical issue. Strategic issues are the one that needs to be addressed at the higher level in the management hierarchy. On the other hand, tactical issues should be dealt at the lower level.

One of the main driver of internal complexities within a SC is the heterogeneous demands that stands for diversity. As an example, customization of products has become a norm in many segment of companies due to the unique product demanded by the customer. However, customization requires a lot of diversity in products and the availability of product plans and programs. Product diversity as well as product customization requires different skill set, various types of resources and the company has to strive for continuous product development. Therefore, the issue of customization needs to be addressed at strategic level taking into account available resources, skill set and employee

motivation. In addition, the organizational structure, including departments and its organization are a major example of organizational aspects that affect the complexity if not organized to best fit the company situation.

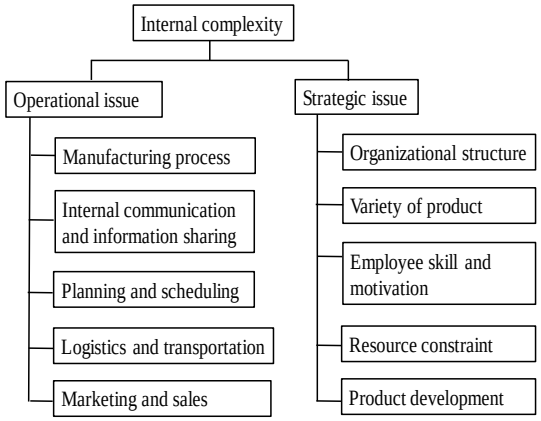

Figure 1: Internal SC complexity driver

The other key driver of internal complexity is concerned with the operational issue [2]. This is a dominant source of complexity not only as an internal driver but also at the interface between the SC partners. The operational issue may be related to manufacturing process, information and communication system used or marketing and sales. The manufacturing processes can significantly affect the internal complexity of SC, especially, in coordinating planning and scheduling of production process and managing logistics and transportation needs. The variety in manufacturing process and its complexity are directly proportional to SC complexity. As this type of complexity lie within the company, comparatively, it can be managed with little effort.

4.2 External Complexity:

External complexity lies outside of the organization boundary. This type of complexity is directly affected by environmental factors, such as technology change and the action of competitor upon which company do not have control over it. The competitor can have a dominant effect on the external complexity, since they can develop the product or service faster and more efficiently by implementing advanced technologies at which the company is not aware off. The external complexity driver can lead to increased operational costs, delay and difficulty in the management of cooperation between partners.

Figure 2 shows all the drivers that is related to external complexity. The drivers of external complexity can be further categorized in terms of issue they are related to. The drivers are related either to market issue or societal issue. Drivers related to market issue includes complexity due to changing customer need, action of competitor, technological innovation, and product life cycle. On the other hand, societal issue include laws related to regional, domestic and international jurisdiction. It also encompasses standard and regulations imposed by various organization, as well as, legal and political issues. As all the drivers of external complexity lie beyond the control of SC partners, managing the complexity due to such driver will be difficult.

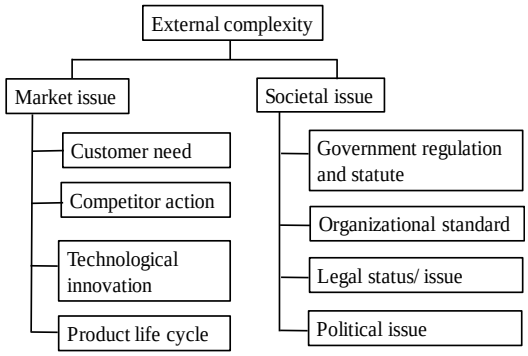

Figure 2: External SC complexity driver

4.3 Interfacial complexity:

In between internal and external complexity, some drivers within the interface of supplier and customer which create complexity. These drivers are basically related to supply and demand issues and involves flow of information and material. Figure 3 shows all the drivers that is related to interfacial complexity. Drivers related to interfacial complexity can further be divided from the point of view of operational and strategic issues. Operational issues such as improper synchronization of process and information between partners, as well as, incompatible partners and use of incompatible information system between partners create chaos and confusion. In addition, amplification of demand due to improper forecasting from a downstream to an upstream SC has been identified in an industry from long time

[16]. Amplification results into increasing swing in the inventory while moving further upward the chain. Such bullwhip effect increases the complexity in the chain for managing raw material and process planning.

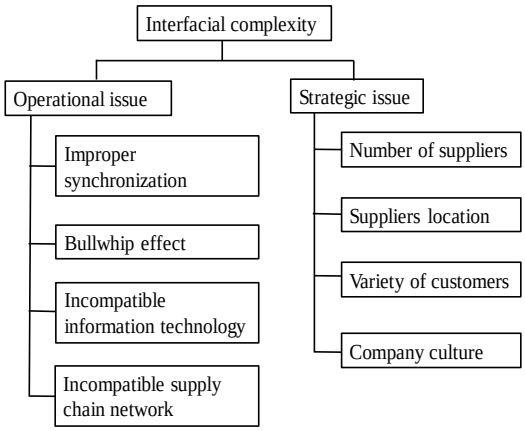

Figure 3: Interfacial SC complexity driver

Apart from operational issues, strategic issues such as number of suppliers, their locations, variety of customers and the culture of company will also affect the level of complexity. Having multiple suppliers is considered as a solution to reduce the supply risks in terms of cost and reliability. However, this is not always true as increase in the number of suppliers for same component may cause difficulty in assembly affecting the property of getting homogeneous product [26]. Degree of flexibility, decision making process and level of innovation etc is greately affacted by the culture embraced by the company. Having SC partners embracing different culture may results into conflicting point of view with different level of transparancy, thereby resulting into complexity. As interfecial complexity arises between the partners, it is managable to some extent and depends heavily on their level of cooperation.

5. Solution Methods

Ref. [10] discussed four major steps to manage complexity in the SC. Those four steps are identification of drivers, measuring the level of complexity, analyzing the complexity measure and then finally using strategy to control complexity. This flow cycle helps to adopt good practices as necessary to manage the complexity. As discussed in section 4, many driver creates complexity in SC. These drivers affect productivity, cost, lead time and conflict among SC partners, which may have significant impact on the satisfaction level of entire stakeholder within the chain. In addition, complexity may act as an obstacle in the realization of agile SC [5]. Therefore, it is imperative to take some actions or company should develop some solution method to overcome this complexity. Table 2 displays proposed solution methods to manage overall SC complexity.

Table 2: Proposed solution method to manage SC complexity driver

Complexity	Solution method
Internal complexity	
Variety of product	- Use concept of modularization or product postponement strategy. - Minimize number of component parts in the product.
Manufacturing process	- Redesign product without affecting its core characteristic. - Automate production system.
Internal communication and information sharing	- Improve coordination among departments. - Create culture of transparency.
Planning and Scheduling	- Use specialized software for planning and scheduling. - Adopt robust planning method and synchronize processes.
Employee skill and motivation	- Develop scientific metrics to measure employee performance. - Identify training needs and train them on necessary skill. - Identify employee needs and satisfy rational needs to create intrinsic motivation.
Resource constraint	- Identify and overcome bottleneck in the production process. - Promote collaboration to share resources. - Update existing knowledge capital and technology

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Organizational structure	- Create virtual structure whenever deemed essential. - Fix the span of control based on scientific merit. - Minimize the level of hierarchy wherever possible.
Logistics and transportation	- Redesign or reformulate the transportation network. - Outsource distribution process to experience and trust worthy partner.
Marketing and sales	- Adopt digital marketing and social media. - Promote online advertisement and sales configurator. - Implement customer centric production processes. - Offer training to marketing and sales personnel.
Product development	- Involve supply chain partner during conceptualization and designing phase of product. - Use the concept of cloud computing to collect information's from various sources within the chain.
External Complexity	
Customer need	- Implement the concept of adoptive supply chain. - Create knowledge network for the faster identification of customer need.
Competitor action	- Form a collaborative business network with competitors to create win-win situation between partners. - Share knowledge and expertise among each other for mutual benefits.
Technological innovation	- Create a culture of innovation. - Develop state-of-art R&D facility.
Product life cycle	- Adopt concept of design for manufacturing and assembly. - Reduce time to market. - Manage seasonal fluctuation of demand.
Government regulations and statutes	- Create public information departments to assist in providing information and obtaining compliance. - Develop knowledge network and institutional mechanism to support cross-boundary thinking and problem-solving related to new policy, regulation and restriction.
Organizational standards	- Obtain compliance with industrial standard such as ISO, ASME, ILO, etc. - Conduct survey by internationally recognized organization (e.g. ISO) to get accreditation. - Use survey results to make improvements to operations. - Implement a culture to continuous improvement
Political factors	- Identify the main political risks by geography. - Integrate political risk into existing organizational risk management system. - Diversify political risk wherever possible.
Legal issues	- Get IP right for the product that come out of company through innovative action. - Manage legal risks by avoiding practicing illegal issue. - Make business plan following the rules and regulations.
Interfacial complexity	
Improper process synchronization	- Adopt cloud manufacturing strategy. - Improve supply chain collaboration. - Use state-of-art information technology for real time communication.

Bullwhip effect	- Improve demand forecasting at all level of supply chain. - Use state-of-art information technology for real time information.
Incompatible information technology (IT)	- Encourage all supply chain partners to use IT system compatible to each other.
Large number of suppliers	- Check trade-off between complexity level and suppliers reliability to identify optimal number of suppliers.
Supplier location	- Use supplier location as one of the criteria in the selection of supplier. - Encourage supplier to establish their unit near your location.
Variety of customers	- Use concept of modularization or product postponement strategy to satisfy need of various customers. - Identify strategic positioning of the order penetration point.
Company culture	- Encourage team work within company. - Improve cross-cultural cohesion within employees and between partners. - Promote transparency and simplify company's rules and regulations.
Incompatible supply chain network	- Redesign the network by looking at the objective and capabilities of different partners. - Improve network capability through cross-functional collaboration.

6. Conclusions

In this paper, at first, we have identified generic complexity drivers through literature review and expert opinion. The drivers are categorized based on their origin. Three different categories of complexity drivers considered are internal complexity, interfacial complexity and external complexity. Company will have complete control over complexity drivers related to internal complexity as the drivers lie inside the company. However, as the external complexity drivers lie outside of the company or SC network, company will not have control over such drivers. Since, interfacial complexity arises due to the issue between supplier and customer, company still will have control over the drivers to some extent. Apart from identifying drivers of complexity, the paper also propose solution method that can be adopted to overcome complexity created by the drivers.

According to ref. [9], to manage complexity properly it is necessary to measure complexity drivers using a proper methodology so that the company can understand how big it is. Ref. [6] discusses the use of entropy method to monitor and measure the complexity of manufacturing system. In addition, it is possible that addressing one driver of complexity may trigger another new driver or may increase the level of severity of an existing complexity driver. Therefore, understanding the level of severity of each complexity driver and their interaction effect is essential. In line with this research work, the current research will be extended to develop a quantitative model that can measure the level of complexity exerted by the drivers. This will help company to categorize complexity drivers based on their impact as compared to others. In addition, the next avenue of research may be to develop a method that helps to understand the interaction effect of one driver over others.

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