Analyzing Supply Chain Complexity Drivers using Interpretive Structural Modelling

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Abstract
Managing supply chain is a critical issue in any business domains. To manage the overall supply chain it is important that the management understands the drivers that is associated with the complex interactions within a chain. In this paper, generic supply chain complexity drivers are identified through literature survey and expert opinion. These drivers are then analyzed using interpretive structure modelling tool to understand the contextual relationships that exists between the identified drivers. Finally, ISM diagraph is developed based on the analyzed contextual relationship.

Keywords—Supply chain, Complexity drivers, Interpretive structural modelling

Introduction

Supply chain management (SCM) has generated greater enthusiasm among researchers as well as industrial practitioners with the beginning of twentieth century. SCM is a system of individuals, organizations and the flow of resources, services, activities and information between them (Lu, 2011). The network of SC is an essential part to many successful industries around the globe. 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 (Manuj and Sahin, 2011). Today's SC exhibit a large and complex interaction with their suppliers, customers and other firms thereby making the chain complex to manage. Although dealing with complexity in supply chain is not easy, various studies have shown that managing complexity leads to better supply chain performances (Vachon & Klassen, 2002.; Koudal & Engel, 2007).

SC complexity has been considered as an important research effort attempting to harness the generic factors or drivers, which are arising in diverse business domains. SC complexity is 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 complexity drivers. The identification of the drivers or factors are critical to manage or mitigate SC complexity (Walker et al. 2008). Due to several reasons, such as distributed business environment, modes of transportation, competitive business environment, etc., the complexity in supply chain is increasing, which needs to be addressed critically in order to minimize its detrimental impacts on business environment (Blome et al., 2014). It has been argued that SC complexity decreases the overall performance of operations, trigger disruptions and contribute decision making process complicated (Chopra and Sodhi, 2014).

The rest of the paper is structured as follows. Section 2 identifies the drivers of supply chain complexity. In section 3, ISM tool is used to understand the contextual relationships between the identified drivers.

Also, based on the contextual relationships ISM diagraph is developed. The paper concludes with future research directions in Section 4.

Supply Chain Complexity Drivers

Management of complexity first requires identification and then controlling of drivers that drives SC towards complexity. Many drivers influence SC complexity (Piya et al., 2017). In this paper, the complexity drivers of SC are identified based on the literature review and expert opinion, which are as follows:

1. *Product variety*: More product variety results into more supply chain partners, thus making the chain more complex to manage.
2. *Manufacturing process*: Types and nature of manufacturing process adopted by a firm affects level of complexity.
3. *Internal communication and information sharing*: Ineffective communication and information sharing leads to chaos and distorted information.
4. *Planning and Scheduling*: Unstable work plan and production schedule creates complexity.
5. *Resource constraint*: Constraint of resources among any of the partners within the chain will limit the capability of the whole chain.
6. *Organizational structure*: Adopted organizational structure affects the level of complexity within the given organization.
7. *Logistics and transportation*: Various distribution and logistics model and different modes of distribution and transportation directly effect on supply chain complexity.
8. *Marketing and sales*: Misplaced coordination between marketing and sales processes influence supply chain and triggers to organizational profitability.
9. *Product development*: The selected architecture will greatly affect all aspect of production including supply chain configuration.
10. *Customer need*: Variety of customer needs and frequently changing needs increase heterogeneity and service options.
11. *Competitor action*: The actions of competitors increase complexity in the product design, production, marketing and supply chain integration.
12. *Technological innovation*: Technological innovation necessitates company to establish new production line, use materials, process and even new supply chain partners.
13. *Product life cycle*: Shorter product life cycle necessitates supply chain to support increase in the number of process, products and production lines over a given period.
14. *Government regulations and legal issues*: Firms are exposed to various types of laws related to health, safety, environment, import/ export and so on. Satisfying legal issues of all the jurisdiction where the entire supply chain works creates complexity.
15. *Organizational standards*: Meeting organizational standards to remain competitive may create challenges for the whole supply chain.
16. *Improper process synchronization*: Improper synchronization of work process between partners will create chaos and confusion.
17. *Bullwhip effect*: Improper forecast and distorted information flow at different point in supply chain can lead to wide fluctuations in upstream ordering patterns.
18. *Incompatible information technology*: Different technologies used by various partners will create complexity while sharing information.
19. *Number of suppliers*: Larger number of supplier increases supply risk and decrease supplier responsiveness. In addition, it will be difficult to manage them all efficiently.
20. *Supplier location*: Farer the supplier base from the parent company more difficult will be to monitor and control.
21. *Number of customers*: Increase in the number of customers will increase the tasks in terms of magnitude of customer relationship management and demand management thereby increasing complexity.

22. *Company culture*: Cultural difference between partners may affect the level of innovation, raise the issue of transparency and different way of thinking.
23. *Incompatible supply chain network*: Incompatible supply chain network design and incapable supply chain operations lead to complexity.

ISM Methodology

Once the factors have been identified, it is essential to know the relationship that exists between these factors. Interpretive structural modeling (ISM) is one of the most widely used tools for identifying contextual relationship between factors. The major steps involved in using ISM are as follow:

Step 1: *Factor identification*: Factors that create complexity in supply chain has been identified in section 2. These factors are based on the literature review.

Step 2: *Structural self-interaction matrix* (SSIM): A structural self-interaction matrix (SSIM) is used to identify contextual relationship that exists between factors. The relationship is identified based on the consensus of supply chain experts'. Following four symbols were used to express the type of relationship between the factors. The result of this step is as shown in Table 2.

V: factor *i* will complement factor *j* — *A*: factor *j* will complement factor *i*

X: factor *i* and *j* will complement each other — *O*: no relationship between factor *i* and *j*

Table 1: Structured self-interaction matrix for SC complexity

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	A	V	V	V	
D2	V	O	O	O	O	O	O	V	V	A	V	V	O	A	A	O	O	O	V	V	O		
D3	O	A	A	O	A	A	V	V	O	O	O	O	O	O	O	V	O	A	O	V			
D4	O	O	A	A	A	O	A	A	O	O	O	A	A	A	A	A	X	O	X				
D5	O	O	O	O	X	O	O	O	X	O	O	V	O	O	V	X	O	O					
D6	O	X	O	O	A	O	O	O	O	O	O	V	A	O	O	V	O						
D7	O	O	A	O	O	O	O	A	O	A	O	O	O	A	O	X							
D8	O	O	V	O	O	O	O	O	O	A	O	A	A	X	A								
D9	A	O	V	O	V	O	O	V	V	O	V	X	A	X									
D10	V	O	A	O	V	O	O	O	O	O	X	X	O										
D11	O	V	V	O	O	O	O	O	V	O	O	V											
D12	A	A	V	O	V	A	O	O	V	O	V												
D13	O	O	V	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	X	O	O	A	A	A	O																
D17	A	O	O	O	A	A																	
D18	X	O	A	O	A																		
D19	V	O	A	V																			
D20	V	O	O																				
D21	V	O																					
D22	V																						
D23																							

Step 3: *Reachability matrix*: Next, reachability matrix (RM) was generated from Table 1 by substituting the alphabet with binary values 1's and 0's. If (*i*, *j*) entry in the SSIM is *V*, then (*i*, *j*) entry in the initial reachability matrix becomes 1, and the (*j*, *i*) entry becomes 0. Similarly, if (*i*, *j*) entry in the SSIM is A, then the (*i*, *j*) entry in the initial reachability matrix becomes 0, and the (j, i) entry becomes 1. On the other hand, if (*i*, *j*) entry in the SSIM is X, then the (*i*, *j*) entry in the initial reachability matrix

becomes 1, and the (j, i) entry also becomes 1. If (*i*, *j*) entry in the SSIM is O, then the (*i*, *j*) entry in the initial reachability matrix becomes 0, and the (*j*, *i*) entry also becomes 0. '*' in the table represents transitivity link.

Table 2: Reachability matrix for SC complexity

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	1	1	0	1	1	0	0	0	0	0	0	1
D3	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	1	1	0	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	1	0	0	1	1	0	0	1	1	0	0	1	0	0	1	0	0	0	1	0	0	0	0
D6	0	0	1	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	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	1	0	0
D9	0	1	0	1	0	0	0	1	1	1	0	1	1	0	1	1	0	0	1	0	1	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	1*	1	0	1	0	0
D13	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	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	0	0	0	1	0	0	0	0	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	0	0	0	0	0	0	1
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	1	0	0	0	1	1	1	0	0	0	0	1
D19	0	0	1	1	1	1	0	0	0	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	0	0	1	0	0	1
D21	0	0	1	1	0	0	1	0	0	1	0	0	1*	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	1	0	0	1	0	0	0	1	1	1	0	0	0	0	1

Step 4: *Level partition*: From reachability matrix, reachability set and antecedent set were derived for each factor. The reachability set includes driver itself and others, which it may help to trigger. On the other hand, the antecedent set includes the driver itself and the other drivers that help in triggring it. Thereafter, the intersection of these two sets helps in obtaining interaction set. The drivers that have the same reachability and intersection sets in the first iteration will be given level I. The top-level drivers in the hierarchy i.e., level I, will not trigger any other drivers above its level. Once the top-level drivers were identified, its set of drivers are removed from the whole sets and repeat the same procedure to find the other level of drivers. The iteration is continued until the last driver remains in the sets. The outcome of number of iterations is as shown in Table 3.

Table 3: Levels of complexity driver 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	1,5,10,11, 21, 23	1,21,23	XI
D2	2,4,5,12,13,15,16,23	1,2,9,10,14	2	IX

D3	3,4,8,16,17	1,3,6,18,19,21,22	3	IV
D4	4,5,7	1,2,3,4,5,7,8,9,10,11,12,16, 17,19,20,21	4,5,7	I
D5	1,4,5,8,9,12,15,19	2,4,5,8,15,19	4,5,8,15,19	I
D6	3,6,8,12,22	1,6,11,19,22	6, 22	VII
D7	4,7,8	1,4,7,8,10,14,16,21	4,7,8	I
D8	4,5,7,8,10,21	1,3,4,5,6,7,8,9,10,11,12,14	4,5,7,8	I
D9	2,4,8,9,10,12,13,15,16,19,21	1,5,9,10,11,12,23	9,10,12	X
D10	1,2,4,7,8,9,10,12,13, 19,23	8,9,10,12,13,21	8,9,10,12,13	V
D11	1,4,6,8,9,11,12,15,21,22	11	11	XII
D12	4,8,9,10,12,13,15,19, 21	2,5,6,9,10,11,12,18,22,23	9,10,12	VIII
D13	10,13,21	2,9,10,12,13,15,21	10,11,21	V
D14	2,7,8,14,15,22,23	14,15	14,15	VI
D15	5,13,14,15	1,2,5,9,11,12,14,15,22	5,14,15	VI
D16	4,7,16,23	1,2,3,9,16,18,19,20,23	16,23	III
D17	4,17	3,17,18,19,23	17	II
D18	3,12,16,17,18,23	1,12,18,19,21,23	12,18,23	VIII
D19	3,4,5,6,16,17,18,19,20,23	1,5,9,10,12,19,21	5,19	IX
D20	4,16,20,23	19,20	20	IV
D21	3,4,7,10,18,19,21,23	1,8,9,11,12,13,21	21	V
D22	1,3,6,12,15,22,23	6,11,14,22	6,22	VII
D23	1,9,12,16,17,18,23	1,2,10,14,16,18,19,20,	1,16,18	III

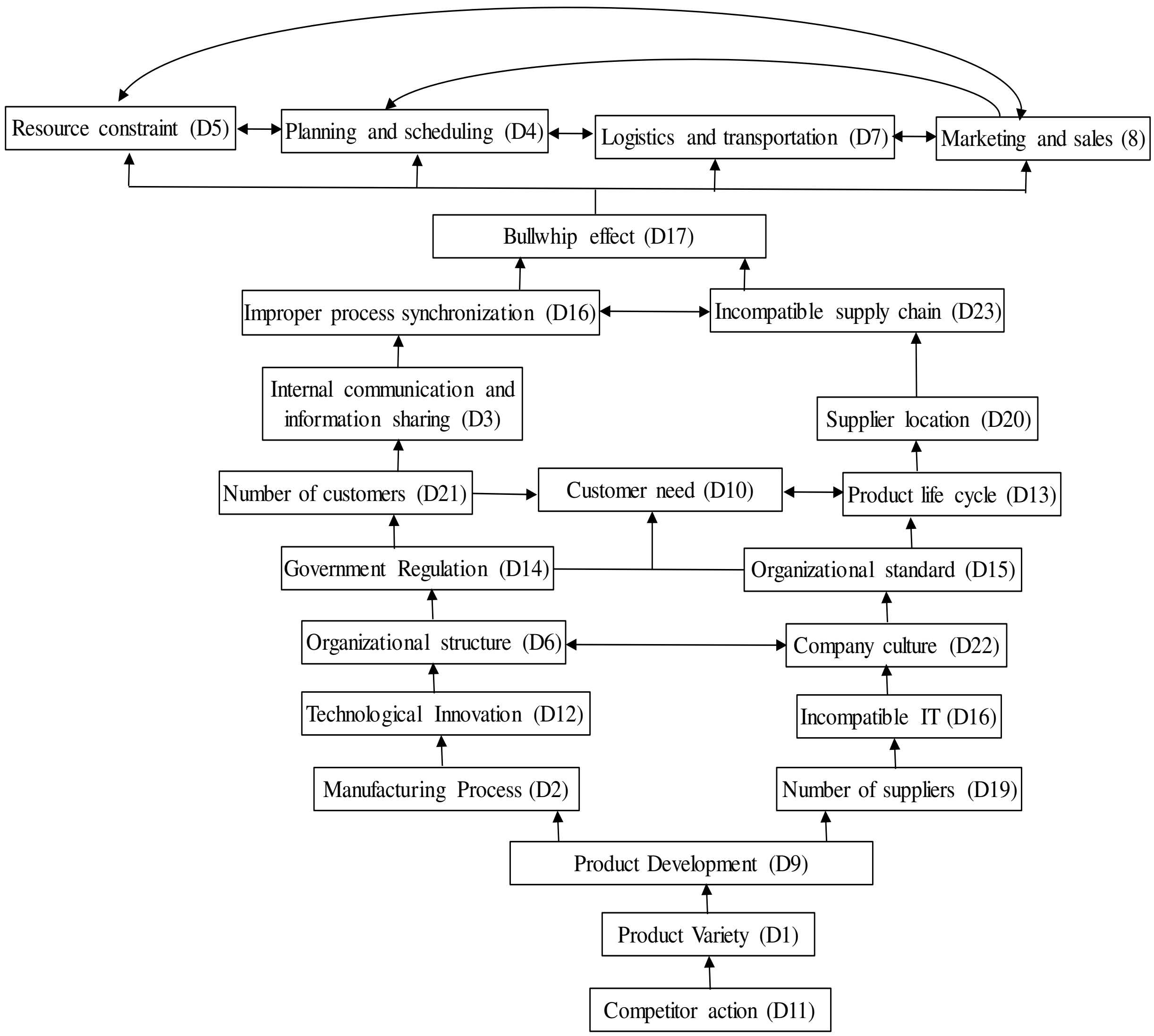

Figure 1: ISM diagraph of supply chain complexity drivers

Conclusion

In this research, at first, based on the literature review drivers of supply chain complexity are collected. Experts are consulted to understand the contextual relationship that exists between these drivers. Thereafter, Interpretative structural method is used as a tool to segregate the identified drivers into various levels. The result of ISM is presented in the form of directed graph. The graph shows that the drivers such as competitors action, product variety, product development, manufacturing process and number of suppliers are the main drivers that trigger complexity in supply chain.

The result of this research can be extended to develop a conceptual framework and a quantitative model to measure complexity in supply chain. The framework may help the company and its supply chain partners to understand the drivers on which they need more attention to minimize complexity.

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Biography

Sujan Piya is working as an Assistant Professor at Department of Mechanical and Industrial Engineering, Sultan Qaboos University, Muscat, Sultanate of Oman. He received his PhD degree in Industrial Engineering from the Hiroshima University, Japan in 2010 and Master of Science degree in Industrial and System Engineering from the Department of Artificial Complex Systems Engineering, Hiroshima University, Japan in 2007. His major research interests lie in the area of production planning and control, operations management, logistics and supply chain management, decision support system and quality control. He has published several research papers both in international journals and in conference proceedings as well as a book chapter.

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