Analysis of Supply Chain Complexity Sub-Dimensions for Automobile Industry

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Abstract

There is plenty of literature available that accounts for complexity management in a supply chain. A major fraction of this literature takes into account numerous parameters in order to devise management techniques. However, multiple such parameters do not directly affect the result and incorporating these can make the analyses overly complicated. Most of the causes of supply chain inefficiencies are due to the interconnectedness and interdependencies in the structure, processes and environment of the supply chains. The level of complexity varies across industries in terms of intensity and ease of management. After a review of the literature related to complexities in supply chains of the automobile industry, the paper attempts to build a framework to study the relative significance of these complexities. This paper aims to identify critical complexities for Automobile industry. Understanding and controlling these complexities open avenues for better supply chain management and also assist decision-makers in formulating risk mitigation strategy.

Keywords
Supply Chain Management, Automobile Industry, Complexity Analysis, Supply Chain Complexity

1.   Introduction

A supply chain is defined as a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer (Beamon, 1998). Supply chain management (SCM) involves the systemic and strategic coordination of these flows within and across companies in the supply chain with the aim of reducing costs, improving customer satisfaction and gaining competitive advantage for both independent companies and the supply chain as a whole (Cooper &Ellram 1993). Managing complexities and risks are vital for every organization to survive in a competitive environment as they majorly influence supply chains (Gunasekarana et al. 2015). Today's supply chains have increased technological disruptions and rapidly evolving customer's preferences which lead to a need for fast response time, flexible processes and increased emphasis on research and innovations. Globalization & technological advances increase the profitability and value of the organization but as mentioned in (Blecker et al 2004, Blecker et al, 2005, Kocoglu et al, 2011) also increase complexity of the supply chain (Martin 2011) due to increased number of decision nodes. In Webster's Third International Dictionary, complexity is defined as: "Complexity is being marked by an involvement of many parts, aspects, details, notions, and necessitating earnest study or examination to understand or cope with (Gove 1986)". Different categories of inter-connections exist between different components of a supply chain. The extent of these inter-connections, or complexities, is dependent upon the number of supply chain components as well as the degree of interaction between these elements. Increased complexity makes control and management of the supply chain difficult due to an increase in the amount of information available to be analyzed in relation to the structural and dynamic aspects of the value chain. There may be certain difficulties in dealing with complexity in a supply chain, however when managed correctly it leads to achieving better supply chain performances (Bonabeau 2007, Sommer et al 2009, Skaržauskienė 2010).

Effective management of supply chain networks such that system complexity is optimized, is essential for reduced costs and enhanced value of the network (Sun et al 2015). As highlighted in (Scheiter et al 2007), effective complexity management can also help in significantly increasing EBIT (Earnings before interest and tax) of an organization.

The necessary first step for effective supply chain management is identification and inspection of various complexity drivers. Supply chain complexity can arise due to multiple factors such as: nonlinearity, increased interactions or un-symmetric systems (Hearnshaw and Wilson 2013). These can lead to varied sub-dimensions, which can be cumbersome to analyze and hence, can adversely affect further analysis of complexity mitigation. It then becomes essential to not just analyze these criteria but to also find and shortlist critical parameters out of all exhaustive parameters. We developed a 5-point scale mapping of complexity sub-dimensions and performed detailed analysis that allowed us to isolate critical sub-dimensions. (Pettit et al 2013) emphasize on the fact that existing research on complexity is focused on firm level and not on supply chain level. To achieve a more holistic analysis of complexity we study the complete supply chain for different industries. In this paper, we have limited the focus to Automobile industry.

2. Literature Review
2.1 Introduction to Complexities in supply chain

According to Christopher (2012), (supply chain) complexity does not mean complicated but rather it describes a condition of inter-connectedness and inter-dependencies across a network where a change in one element can influence other elements. Growing interconnectedness and interdependencies within modern supply chains results in both opportunities and complications for the business. However, lack of proper management of these complexities reduces the efficiency and productivity of supply chains (Chopra & Sodhi 2004). Complexity in Supply chains reduces the performance and efficiency of various processes (Bozarth 2009), makes decision making processes more complicated (Manuj and Sahin 2011) and difficult to control. This makes analysis and management of such inter-connections necessary. One of the most interesting studies that highlight the relation between complexity and business performance is of (Adani et al. 2002). It focused on the diffusion of supply chain management practices over three important Italian industries-household appliances, fashion and book publishing. These authors, as a by-product of their investigation, found out that the best performing supply chains in each studied industry had lower complexity levels as compared to industry average.

2.2 Complexity Classification

Multiple factors or drivers affect supply chains and make them more convoluted and inter-connected. Complexity drivers can be classified into a variety of classes and groups based on their nature. According to an article by European CEO (2011), complexity drivers can be classified into six overall categories: External drivers (regulation, competition, economic turbulence and other factors outside the business); People (the everyday behaviors of employees and managers); Process (the complexity of the business processes that are in use); Strategic (the goals and decisions the board makes in terms of where to focus and how to win in a particular market); Organizational (how the business is structured, talent management and decision-making) and Products and services (their number, design and the structure of your portfolio).

Calinescu et al (2001) classified complexity into three categories: decision-making complexity, structural complexity and behavioral complexity. Given the exogenous and endogenous interactions and interrelationships a supply chain is exposed to, supply chain complexities have been classified based on its source- internal and external supply chain complexity drivers (Isik 2011). Internal Supply Chain complexity is associated with material and information within the organization and covers aspects such as process, product, process and organizational uncertainties. External supply chain complexity is related with material and information flows associated with other business partners (suppliers and customers) and involves drivers like globalization, technological innovation, high competition and customer demand variety. (Isik 2011) distinguishes between three types of supply chain complexity: static, that is related to the connectivity and structure of the subsystems involved in the supply chain (For example: companies, business functions and processes); dynamic, that results from the operational behavior of the system and its environment and decision making that involves both static and dynamic aspects of complexity. It further classifies supply chain complexity drivers

as: internal, supply/demand interface, and external/environmental. Serdarasan(2012) classifies complexity drivers into four major categories as upstream complexity, operational complexity, downstream complexity and external complexity drivers. Hence, there is a huge variety of complexity drivers each one capturing complexities faced at different components of the value chain, like supply, manufacturing and distribution.

3. Methodology
3.1 Methodology of choosing complexity classes

In order to identify the most critical complexity drivers that affect the supply chain of a given industry, it is important to choose the classes of complexities in such a way that the scope of each class is wide enough to capture possibly all the complexities present in a supply chain. A thorough review of research articles available on "supply chain complexities" on Science Direct in the time frame 2018-2020 was carried out. We found 92 papers linked with the keyword "supply chain complexities". To get an insight about the frequency of usage and interpretation of complexity classes, we performed keyword-based analysis of these 92 papers. Figure 1 shows the most frequently used complexity categories across the reviewed papers.
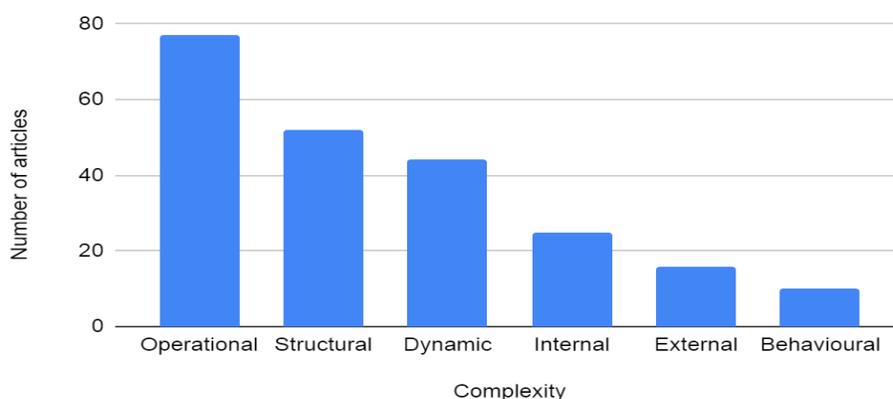

Figure 1. Histogram depicting number of articles found for different complexity categories.

Based on Figure 1, Operational, Structural and Dynamic complexities are the most frequently used terms in recent times in context of supply chain complexities. Operational complexity is defined as the uncertainty associated with managing the dynamic variations, in time or quantity, across information and material flows at the supplier–customer interface by (Sivadasan 2017). According to Friday et al. (2017), structural complexity talks about numeracy and variety whereas dynamic complexity involves uncertainty and fluctuations. Operational complexity being associated with uncertainty can be studied under dynamic complexities.

As depicted in Figure 2, we identified structural and dynamic complexity as two umbrella classes which can possibly cover most of the complexities that emerge within a supply chain. In this paper, we have restricted the study of complexity sub-dimensions to the following three independent verticals of a supply chain: Supply, Manufacturing and Distribution. Each of these verticals has different stakeholders and inter-dependencies. Frequently quoted complexity

sub-dimensions in the existing literature limited to the aspects of supply chain have been studied and categorized.
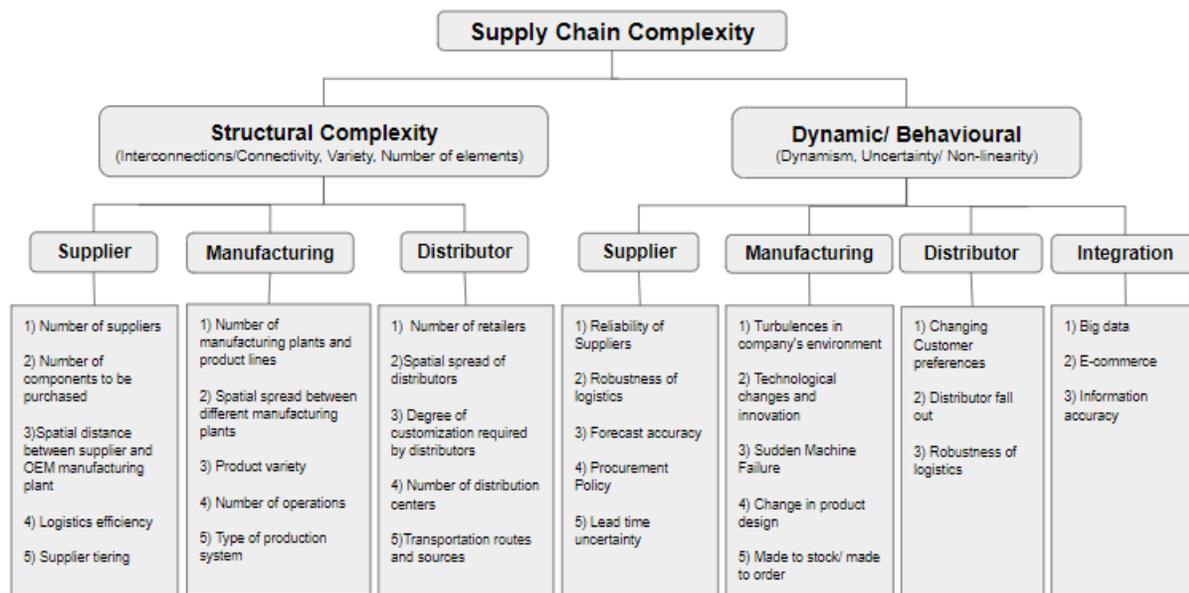

Figure 2. Hierarchy diagram for complexity sub-dimensions

Structural Complexity describes the structure of the supply chain, the variety of its components and strengths of interactions involved within these components. We have divided structural complexity further into three more dimensions - Supply, Manufacturing and Distribution in order to incorporate and comprehensively understand the various structural parameters in each subsequent section of the supply chain which adds up its complexity.

Dynamic Complexity represents the uncertainty in the supply chain and involves the aspects of time and randomness. It has been divided into four parts namely supply, manufacturing, distribution, and integration in order to study the impact of various uncertainties involved in three main sections involved in supply chain (i.e. supply, manufacturing and distribution). We have also included integration as a part of our sub dimensions in order to accommodate complexities related to data sharing and supply chain integration. Due to increased data generation and fast digital transformation of supply chain, data collection, analysis and sharing plays a significant role in effective management and coordination of supply chain (Shore 2001).

After research from multiple research papers, we have found out various parameters under each sub-dimension in structural and dynamic complexity in order to exhaustively and comprehensively understand the role of each parameter in complexity addition and its impact in the case of the automobile industry.

3.2 Complexity Analysis Approach

During the process of decision making, managers look for ways to obtain maximum productivity from minimum changes in the existing supply chain components. An issue arising in the supply chain has multiple causes and components involved behind it which makes it cumbersome and cost ineffective to make alterations to the various components of the supply chain. Due to the multiple interdependencies in the supply chain, it becomes difficult to properly resolve an issue.

The effect of this problem can be minimized if certain complexities that are causing the problem are managed properly. We conceptualized a critical complexity zone which can be defined as consisting of complexities having high intensity and high ease of management as shown in Figure 3. In order to handle these complexities, we developed a 5-point

mapping to identify top complexities from our list of complexity sub-dimensions. This enablesto prioritize efforts for their effective management and creates a huge potential for a positive impact on the supply chain. 5-point mapping is plotted to show variation in data along the x-axis (5 point scale). These mappings help us provide a clear understanding of the relative fluctuations in an entity (intensity, ease of management) based on various parameters (complexity sub-dimensions). It enables us to understand the particular characteristics of the automobile industry specific supply chains. The ease of data representation and data visualization on a snake diagram makes it a good fit for understanding the intensity of complexity and ease of managing complexity for the purpose of this study. Intensity of complexity drivers and the ease of management of complexity are measured on a scale of 1 to 5. The complexities are measured and each one is mentioned along the y-axis. As a result, the two snake diagrams help us to identify complexities which have both high intensity and ease of management. After rating the complexities, a relative complexity score for both the structural and dynamic complexities is calculated for each segment that assists us in understanding the nature and vulnerabilities in the supply chain in automobile industries.
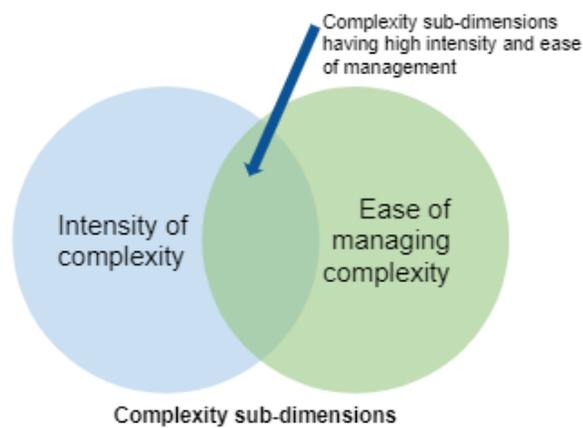

Figure 3. Venn diagram for complexity sub-dimensions

The 5 point mapping in Table 1 is backed by two pronged approach of:

(i)   Literature Review
(ii)   Recommendations from industry experts

4. Analysis

Table 1. Mapping of intensity and ease of management of supply chain complexity

Dimensions	Sub-dimensions	Sub- Sub-dimensions	5	4	3	2	1
Structural	Supply	Number of suppliers	A			A	
		Number of components to be purchased	A		A		
		Spatial distance between supplier and OEM manufacturing plant	A		A		
		Logistics efficiency	A		A		
		Supplier tiering		A	A		
	Manufacturing	Number of manufacturing plants and product lines		A	A		
		Spatial spread between different manufacturing plants		A	A		
		Product variety	A		A		
		Number of operations (Manufacturing time)	A	A			
		Type of production system	A		A		
		Product design (Point of differentiation)		A	A		
	Distribution	Number of retailers		A		A	
		Spatial spread of distributors		A	A		
		Degree of customization required by distributors		A		A	
		Number of distribution channels			A	A	
		Type of distribution channel		A	A		
Dynamic	Supply	Reliability of Supply (Quality, delivery schedule)		A A			
		Robustness of logistics	A	A			
		Forecast accuracy	A A				
		Procurement Policy			A	A	
		Lead time uncertainty				A	
	Manufacturing	Company's environment	A		A	A	
		Technological changes and innovation	A			A	
		Machine Failure	A	A			
		Changes in product design	A	A			
		Made to stock/ Made to order	A			A	
		Changing Customer preferences (Demand fluctuations)			A	A	
		Distributor fall out			A	A	
		Robustness of logistics			A	A	
	Integration	Big data	A	A			
		E-Commerce	A			A	
		Information Antiquity/ Information Accuracy (Bullwhip effect)			A	A	

Key for Table 1:
Red: Intensity of complexity sub-dimensions
Black: Ease of complexity management

5. Explanation of Complexity Mapping (Table 1)
5.1 Explanation for Intensity of Complexity sub-dimensions

Automobile industry's supply chain consists of multiple tier 1 and tier 2 companies that directly or indirectly supply to the OEM (Original Equipment Manufacturer). Any automobile requires several components ranging from small nuts and bolts that hold the seat together with the frame to larger components like tyres. As a result, automobile supply chains have added complexities on the supplier side. Inefficiency of suppliers can be very expensive for the OEM as this industry often uses JIT manufacturing. Delay in component delivery or bad quality delivery can stop the entire production line. High intensity of complexity sub dimensions is observed on the supplier side. In manufacturing, use of continuous production lines makes it necessary that all factors required for production work smoothly. A single machine failure could halt the entire assembly line. The final product is a vehicle, it has a certain level of customisation but speaking from manufacturing point of view, such customisations seldom require added operations. This reduces the intensity of operations related to complexity sub-dimensions. The distributors for the automobile industry are spread over large spatial distances. Due to the bulky nature of the product, a robust logistic network is required. Such added interconnections may increase complexity of the supply chain. Dependence on distributors is much less as compared to dependence on suppliers. Both number and efficiency requirements for distributors and distribution channels are significantly lower, hence the complexity intensity is comparatively lower for this section.

5.2 Explanation for Ease of managing Complexity sub-dimensions
The Automobile Industry has many suppliers and a complex supplier tiering. Consequently, they cannot be easily managed due to difficulties in the supplier integration and ensuring traceability across tiers. The reliability of supply is difficult to manage but the forecast accuracy can be greatly improved by big data analytics. On the manufacturing side, the automobile industry does not have many plants and less product variety. Due to lack of customization and highly automated processes leads to ease of management of these complexities. The automobile industry involves a large degree of automation as a result of which machine failures and changes in product design becomes a critical part leading to disruption in supply chains. These complexities can now easily be managed through predictive maintenance and software for product design. The technological changes and company's environment are complex and depend on various external factors and hence, cannot be easily managed. The number of distribution channels is less but it involves a vast network of distributors and retailers to ensure proper distribution. The higher reliability of distributors ensures less risk of distributor fallout and changing customer and distributor preferences can be easily dealt with the help of trend analysis and customer feedback.

6.Results and Discussion
6.1Analysis for Complexity Intensity and its Ease of Management

Table 2. Results summarised for Table 1

Dimension	Sub-dimension (Max complexity score) *	Intensity**	Ease of Management***
Structural	Supply (25)	24 (96%)	13 (52%)
	Manufacturing (30)	17 (56.6%)	26 (86.6%)
	Distribution (25)	9 (36%)	18(72%)
Dynamic	Supply (25)	19 (76%)	17 (68%)
	Manufacturing (25)	18 (72%)	20 (80%)
	Distribution (15)	7 (46.6%)	11(73.3%)
	Integration (15)	9 (60%)	12(80%)
Total score (160)		103 (64.3%)	117(73.1%)

Maximum complexity score = 5(Total number of sub-sub-dimensions within a category). For example: There are 5 complexity sub-sub-dimensions considered in the supply category. So, the maximum possible score is 5x5=25.
**Intensity Value= Sum(Score of each sub-sub-dimension on 5 point scale within that sub-dimension / category)
***Ease of Management Value: similar to Intensity Value calculations.

Key for Table 2:
0-25%   - Very low complexity zone (white)
25-50%   - Low complexity zone (light green)
50-75%   - High complexity zone (green)
75-100% - Very high complexity zone (dark green)

In Table 2, we understand the intensity and ease of management value for each sub-dimension. Further, the table highlights the relative significance of each sub-dimension within a supply chain. For example, there is a higher degree of inter-connectedness in the supply sub-dimension whereas manufacturing sub-dimension is relatively easier to manage for a supply chain in the automobile industry.

Sub-dimensions that have high intensity add a higher degree of connectivity in the supply chain, either in the form of enhanced inter-dependence of dynamic factors or increased structural nodes in the supply chain. Complexity sub-dimensions having higher intensity are more crucial and need to be worked on for better supply chain operations, higher productivity and control. Though, from a practical standpoint it is difficult to work on certain sub-dimensions and hence, it is essential to identify those dimensions that have a higher ease of management. Using these two criteria, the critical complexity sub-dimensions are identified and categorized. The break-up of different sub-dimensions is depicted with 4 sections handling different combinations of ease of management and complexity intensity.

In Figure 4, a decision matrix has been created for the automobile industry.The decision matrix provides insights regarding scope of improvement and opportunities for the automobile industry. The matrix is divided into four distinct regions handling different combinations of ease of management and complexity intensity namely- Priority zone, Strategy Zone, Operational Zone and Ignorable Zone. Each sub-sub-dimension lies in one of these zones and hence carry different importance and needs to be dealt with according to the zone in which it lies:

1.   **Priority Zone** –Intensity value>=4; Ease of Management Value > = 4
The sub-sub-dimensions in this section not only heavily impact the supply chain but also can be operated easily. Hence, they carry top priority in supply chain management.

2.   **Strategy Zone**- Intensity value > = 4; Ease of Management Value < 4
The sub-sub-dimensions in this zone heavily impact the supply chain. But due to low ease of management, these complexities demand strategic solutions so as to be effectively controlled.

3.   **Operational Zone -** Intensity value< 4; Ease of Management Value > = 4
The sub-sub-dimensions in this section can be operated easily. But, since they have low intensity, they do not greatly impact the supply chain and hence are not priority.

4.   **Ignorable Zone -** Intensity value<4; Ease of Management Value < 4
Complexities in this zone even if handled properly will not yield much benefit. Hence, it is a non-actionable or ignorable zone.
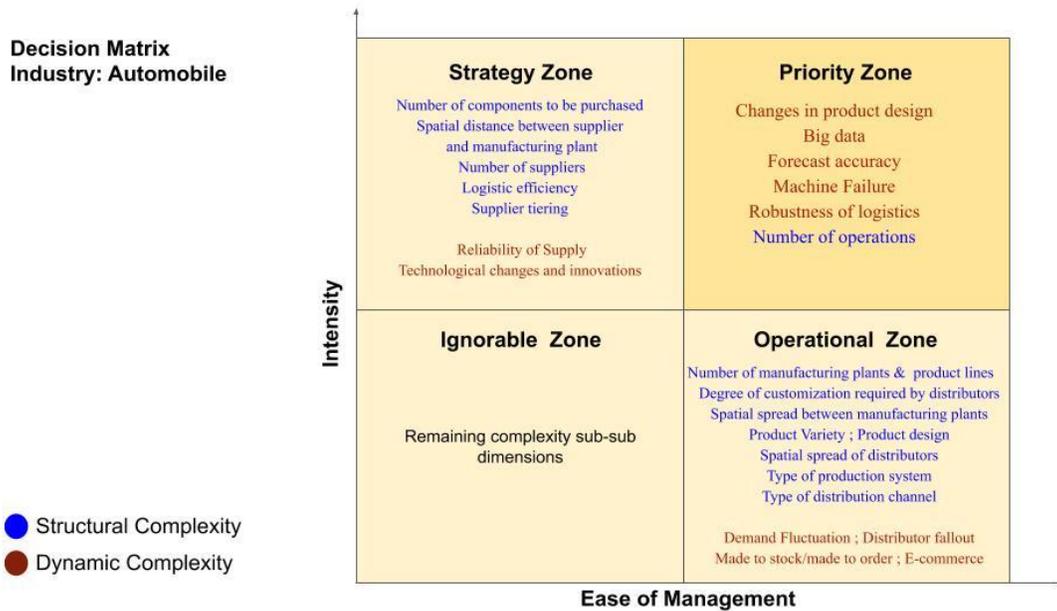
6.2 Sub-Dimension Analysis

Figure 4. Matrix for Automobile Industry

For the Automobile industry, figure 4, sub-sub-dimensions like changes in product design, forecast accuracy, machine failure or number of operations required to make the product are identified as critical. For the automobile industry product design has a high impact on sales of vehicles. The automobile industry has a continuous assembly line with independent operations, making it easier to accommodate certain design changes. For example, if the engine design is to be modified only those operations relating to engine assembly/ manufacturing need to be modified, rest will operate unaffected. Certain supply side complexities such as number of components to be purchased, number of suppliers or supplier reliability have high intensity but are difficult to manage. Large number of components is required in the automobile industry, all essential to complete the manufacturing task. Such a high number greatly increases complexity of the supply chain but removing these components, in order to reduce complexity, is also not always feasible. Fluctuating demand, product variety, spatial spread of distributors and type of production system; are some of the factors that lie in low intensity but high ease of management zones. Hence, managing them will not produce higher impact compared to the complexities lying in the critical zone.

7. Conclusion

These illustrations and tables help us identify the top complexity criteria from an expansive and exhaustive list of complexities identified before. This criterion has huge implications.We can reduce complicacies within a supply chain by acting on these easy to manage complexities. The analysis done clearly divides complexities into regions of high and low intensity as well as easy and tough to manage. These bifurcations help understanding complexity trends within different sectors of a supply chain as well as across supply chains for different industries. The visual analysis of 5 point mapping diagrams helps us find four distinct zones in which complexity sub-sub-dimensions can be divided, of these zones the most critical one for our research is the one having high complexity intensity and high ease of managing complexity sub-dimensions. Though this analysis gives multiple insights into supply chain complexities, it does not quantify the relative importance of the highlighted complexity sub-dimensions. For future work on this, a quantitative approach, to rank the chosen sub-dimensions may be adopted, to get a clearer picture for introducing complexity mitigation strategies for different industries. This multi- criteria ranking could be implemented using approaches such as TOPSIS, Fuzzy Promethee or Fuzzy AHP.

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