İşletme Araştırmaları Dergisi
Journal of Business Research-Turk
10/3 (2018) 15-32

Journal Of Business Research Turk
www.isarder.org

Big Data in Mitigating Systemic Supply Chain Risks: A Systems Perspective with Case Studies

Shahnawaz MUHAMMED
American University of the Middle East
College of Business Administration
Department of Management Information Systems, Egaila, Kuwait
orcid.org/0000-0002-6031-5376
shahnawaz.muhammed@aum.edu.kw

Atik KULAKLI
American University of the Middle East
College of Business Administration
Department of Management Information Systems, Egaila, Kuwait
orcid.org/0000-0002-2368-3225
atik.kulakli@aum.edu.kw

Abstract

Supply chains are complex socio-technical systems by nature with several layers of entities interlinked with increasingly complex web of network connections of varying degrees. Today as supply chains span farther and wider across the globe, they are exposed to greater levels of risks that need to be anticipated and understood sufficiently well to be able to manage it. By taking a systems perspective, we introduce a framework to define and delineate the specific risks in supply chains. We show that supply chain risks can be classified as systemic risks, systematic risks, security risks, and idiosyncratic risks. We relate this framework to other existing frameworks of risk management, and focus on the systemic risks related to the systems characteristics. We then discuss how big data and analytics can be managed in a supply chain to mitigate the systemic risk that arise from the network, relational, and temporal characteristics that relate to the complexity of the supply chains.

Keywords: Supply Chain Management, Supply Chain Risk Management (SCRM), Supply Chain Network, Complexity, Big Data.

1. Introduction

As world becomes increasingly globalized, there is upward pressure on organizations to look for new markets and sourcing options. As a result, today's organizations interact with larger number of other organizations and entities to provide products and services than ever before. This can be attributable to several factors, but primarily due to the increasing pressure to specialize on their core competency. Further, technological improvements have reduced the transportation costs and other transaction costs significantly during the last few decades. Technologically, it is easier today for companies to link with external entities and to operate as a virtually integrated organization. Consequently, today's supply chains have become increasingly complex

Received 12 April 2018; Received in revised from 24 July 2018; Accepted 10 August 2018

and are on this path to becoming further complex as many other postindustrial systems (Huber, 1984; Cilliers, 1998; Simchi-Levi et al., 2008).

In this article, we take a perspective of supply chains as a complex socio-technical system and attempt to define complexity for the context of this research. We will then look at how the various dimensions of this complexity introduce greater risk in the successful operation of an entity's supply chain. We will further examine supply chain risk in detail and review the supply chain risk literature to identify the main themes and issues facing todays supply chain. We adopt a risk classification framework to focus on the major risk areas that affect supply chains and relate it to the existing risk management frameworks. We further focus on the system characteristics that contribute to the risks in a supply chain. We then discuss big data and related technologies that are used in today's global organizations for solving big problems. Subsequently, we examine how big data and analytics can be managed to detect and mitigate various supply chain risks introduced due to the system characteristics and its complexity. We conclude by showing how the current thinking is shifting from a mindset of competitive advantage to a more collaborative process that has the potential to reduce risk exposure and how big data and analytics is driving this paradigm shift.

2. Literature Review and Definitions

2.1. Supply Chains

Supply chains, also sometimes referred to as logistics network is a network of suppliers, manufacturers, distribution centers, warehouses, retail outlets, and other organizations that are involved in providing goods and services, as well as the systems and materials that connect them (Simchi-Levi et al., 2008). A supply chain may be defined for a product or service, such as the supply chain of a particular brand of automobile or cell phone. It could be referred to the general structure of the major organizations involved when referring to the supply chain of a particular class of product, such as the supply chain of printing paper. Supply chain can also be defined by a dominant organization within the chain such as a Dell supply chain or Wal-Mart supply chain (Min & Zhou, 2002). A more customer focused definition of supply chain may view it also as a demand chain rather than a supply chain (Vollmann & Cordon, 1999). Definition of a supply chain may also differ based on the perspective that is taken by a particular entity, for example, a firm could look at inwardly to its internal supply chain or outwardly to its external chain (Hill, 1989).

Though the scope and boundary of a supply chain may differ based on the perspective taken, it is clear that it encompasses a network of entities that exchange goods and services, information, and cash (Lee et al., 2002; Bowersox et al., 2007). Often such networks operates where its participant actions are not fully coordinated for global optimization of the system. Rather, each entity acts to maximize its gains and objectives, and coordinates with others only in so far as its interests and objectives are met. Based on different research focus various researchers have defined supply chain differently (Croom et al., 2000; Simchi-Levi et al., 2008). In spite of the inconsistencies in defining what constitutes a supply chain and taking a broad outlook, it can be viewed as network of organizations working towards creating and delivering value by transformation of goods (Muhammed, 2004).

As indicated earlier, value creation in supply chains occur through the exchange of primarily three factors which are goods and services, information, and cash between the entities in the supply chain. Hence, supply chain management involves managing resources and systems that are directed towards these three flows. Along these lines, for example, Simchi-Levi et al., (2008) provides a definition of supply chain management as "a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system wide costs while satisfying service level requirements" (p. 1). While it may be difficult to manage all aspects of a complete supply chain because of the complexity of todays elongated global supply chain (Barry, 2004), it is imperative that we understand the major elements of todays supply chain coherently. It gains further significance when we realize that global supply chains form the backbone of today's global economy, fueling trade, consumption and economic growth (World Economic Forum, 2013). To this effect, we take a systems perspective to further understand supply chains and to define the risks inherent in it.

2.2. Supply chains as a complex socio-technical system

As per our earlier definition of supply chain, it is a network of interconnected entities and subsystems that interact to exchange goods and services, information, and cash. This dynamic network of various organizations can be viewed as a system and can be understood better from a socio-technical systems perspective. Socio-technical systems theory is applicable widely for any system that involve social and technical elements and is open to its environment (Trist et al., 1963). Today's supply chains reflect the characteristics of such a system and display numerosity, diversity and interdependence (Huber, 1984). As organizations become increasingly specialized retaining only their core competencies while outsourcing their non-core functions to other entities specialized in those functions, number of organizations involved in providing a product increases in the typical supply chain contributing to the numerosity dimension. Upward pressure for specialization also increases the diversity of the organizations within the supply chain, and makes them more interdependent in delivering a product.

Rather than a linear linkage of organizations, today's supply chains are also increasingly becoming a complex network of social and technical systems and organizations. A recent study that examined factors that contribute to supply chain complexity classified it into three categories- static, dynamic & decision making complexities (Serdar-Asan, 2011). Static dimension of the complexity relates to the structural or network aspects of the supply chain, such as the number of entities and the configuration of their relationships. The dynamic aspect of the supply chain relates of the temporal factors and the randomness in demand, supply and other aspects. And the decision making complexity relates to the volume and nature of the information and other flows in the supply chain that relate to characteristic of the relationship between supply chain entities (Serdar-Asan, 2011). Similarly Barutcu et al. (2010) stated that supply chain conflict is widespreaded within and among the supply chain partners due to reasons such as differences in objectives and strategies, lack of trust, inefficient system infrastucture, instability of global business environment, and lack of collaboration among chain members. Those factors affect collaborative decision making and results in increased risks.

For the current study, we adopt a more generic view of supply chain, looking at it from outside the chain. Such a perspective will help us in identifying the fundamental characteristics that contributes to the complexity of the supply chain as a system. To achieve this we will draw parallels from systems theory that define complex systems and examine how these characteristics can be used to understand supply chain complexity. Once these fundamental dimensions of complexity are identified in the supply chain context, we can start to examine how they impact the broad risk factors of the supply chain. To do this we adopt Cilliers (1998) complexity dimension and adopt a level of abstraction at the system level of the supply chain as a whole. It is important to take an appropriate level of abstraction in defining a system to understand its complexity because, “complexity results from the interaction between the components of a system, complexity is manifested at the level of the system itself. There is neither something at the level below (a source), nor at a level above (a meta-description), capable of capturing the essence of complexity.”(pp. 2-3, Cilliers, 1998).

In differentiating a complicated system and a complex system, Cilliers (1998) gives the following characteristics of a complex system: (1) it consists of a large number of elements, (2) the elements interact dynamically, (3) the interaction is fairly rich, (4) the interactions are non-linear, (5) the interactions usually have a fairly short range, (6) there are loops in the interactions (recurrence), (7) they are open systems- difficult to define the boundaries, (8) they operate far from equilibrium (9) they have history- they evolve through time and are linked to their past, (10) each element in the system is ignorant of the behavior of the system as a whole.

For understanding the complexity in supply chains, Cilliers (1998) characteristics can be grouped under three dimensions. These are complexities introduced due to network, relational, and temporal characteristics. They also correspond to the three complexity characteristics static, dynamic & decision making complexities identified by Serdar-Asan (2011). Table-1 shows the mapping of Cilliers (1998) and Serdar-Asan’s (2011) complexity characteristics to the proposed supply chain complexity dimensions from a dynamic socio-technical systems perspective. The network complexity dimension is related to the complexity introduced by the structure of the supply chain network. The relational complexity dimension is specified by the characteristics of the relationships between the entities within the structure, such as whether they have strong or weak relationships. The temporal complexity dimension is related to the dynamic nature of the supply chain and how the network and relational aspects change over time. These three dimensions of the supply chain complexity specify its systemic characteristics.

2.3. Big Data

Today big data has passed the stage of being a buzz word. A recent survey done by IBM indicated that 28% of the companies have already implemented some form of big data solution or are in the proof of concepts phase, and 47% are in the planning stage for big data projects (Schlegel, 2014). Big data and big data analytics can be viewed as an extension of business intelligence and analytics (BI&A) field that is evolving rapidly (Chen et al., 2012). Big data is used to refer to rather large, complex and disparate data sets, that it requires special data storage, management, analysis and visualization tools that are beyond the traditional tools available as part of business intelligence (Chen et al., 2012). Dumbill (2013) defines big data as “data that exceeds the processing capacity of conventional database systems" (p.1). Data sets that fall in the range of petabytes, exabytes, and larger are typically classified as big data. Rather than the size of the data, it is the potential to generate hidden insights and to be able to connect data gathered from disparate sources that excites data scientists and the organizations they work for. Data from many sources can be aggregated to form big data and generally fall into three categories: streaming data from organizational information systems and connected devices, social media, and publically available sources (SAS, 2016).

Table-1: Systemic dimensions of supply chain complexity.

Supply Chain Complexity Dimensions	**Serdar-Asan (2011) Supply Chain Complexity Categories**	**Cilliers (1998) Complex System Characteristics**	**Related to Supply Chain**	**Increasing Complexity is Characterized by**
Network Complexity	Static complexity	Number of elements	Number of suppliers/ customers/competitors	More organizations in the network
		Range of interaction	Extent to which organizations can connect upstream and downstream	Greater
		Loops in interaction	Organizational decisions have impact on performance and other firm outcomes	More loops
		Far from equilibrium	Desire/need for organizations to improve their profitability and other performance variables	Ineqilibrium
Relational Complexity	Decision making complexity	Interaction between elements	Exchange of Information/materials/finances	More quantity
		Richness of interaction	Interaction between suppliers, customers, and other entities	Rich/Strong interaction
		Ignorance of overall system behavior	The extent to which each entity in the supply chain can understand the behavior of their entire supply chain	Higher degree of ignorance
Temporal Complexity	Dynamic complexity	Non-linear interaction	Bullwhip effect, information asymmetry among SC entities	More non-linear interaction
		Open systems	Changing customer and supplier base	More open
		Linked to and shaped by past	Level of organizational learning of entities in the SC	Higher level of connection to the past

In addition to the challenges of storing and managing big data, what is new about it is the analytics that can be used to make sense of it, and currently how AI based technologies are increasingly used to automate some of this sense-making. Though there is limited empirical evidence that investments in big data provides justifiable returns, it seems to be clear that this is a technology that is here to stay from the investments that are made by leading IT firms such as IBM, SAS, ORACLE, SAP and almost all other major IT and consulting firms. All the names mentioned above provide big data oriented solutions and there are many new entrants that are venturing into this field such as Alteryx, Cogito, Periscope Data, PHEMI, WebAction and many more. There is also some empirical evidence indicating that organizations that are data-driven and make data-driven decisions perform better than their counterparts (McAfee & Brynjolfsson, 2012; Provost & Fawcett, 2013). The increasing importance of big data is also evident from the popular searches on this topic (Figure-1), and on the academic side, through the increasing number of publications in this field in dedicated journals, special issues in leading journals dedicated to this topic, and the conferences being organized under this theme (Chen et al., 2012). It is also notable that DSI is hosting this conference under this theme.

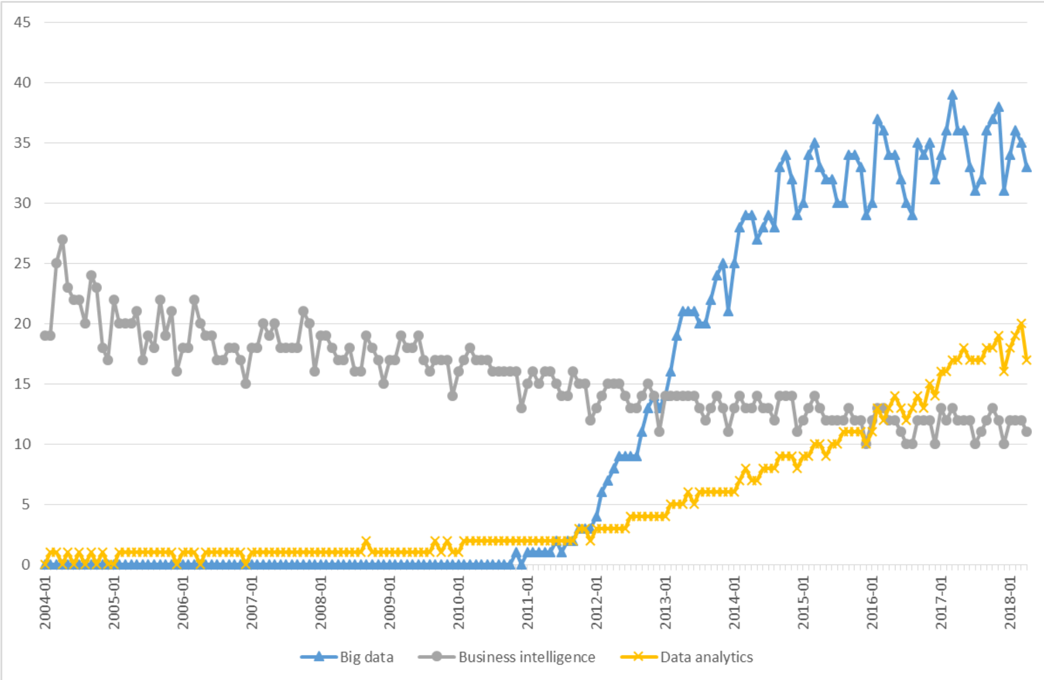

Figure-1: Relative frequency of weekly web searches for "big data", "business Intelligence" and "Data Analytics" on Google

There have been many applications of big data ranging from health care to political campaigns (Chen et al., 2012). Underlying rationale is that big data is useful in situations where the relationships are not clear due to complex interactions between various entities, a large quantity of data exists in the related domains, and potential benefits are plausible in identifying hidden patterns. From this perspective, supply chains are prime candidates where significant benefits can be derived from big data. They are complex systems that have many interacting entities; have a significant amount of uncertainty in the behavior of those entities that limit the use of traditional analytical tools for higher level decision making; as supply chains become increasingly interconnected, there is an ever greater amount of information that is being recorded throughout the supply chain; and there is great potential for better strategic supply chain decisions, decisions related to the optimization of supply chains, and thus mitigating some of the risks in supply chains.

3. Methodology

The main purpose of this study is to discuss the development of risk management issues in the Supply Chain context and namely to draw attention on Supply Chain Risk Management particularly.

Literature shows that supply chain risks can be classified as systemic risks, systematic risks, security risks, and idiosyncratic risks. To address the research questions, a deductive research method used for analyzing the content and relations in existed supply chain literature, combination of primary and secondary data used to answer the research questions. This study also provides summary of relavant cases from the literature along the line of exploratory case study design (Yin, 2009) to clarify the connection with real life business issues.

This paper also contributes to the literature with a framework of supply chain risk. This framework connects to other existing frameworks of risk management, and focus on the systemic risks related to the systems characteristics. Further, how big data and analytics can be managed in a supply chain to mitigate the systemic risk that arise from the network, relational, and temporal characteristics that relate to the complexity of the supply chains has been discussed. Specifically, this research explores the following research questions:

RQ1. What are the factors mainly considered as supply chain risks?

RQ2. How can be systemic risk defined in supply chains?

RQ3. How big data is used in terms of supply chain risk detection and mitigation?

RQ4. How big data and analytics used for mitigating systemic risk?

RQ5. What are the real life examples that support the research proposals?

4. Discussions

4.1. Supply Chain Risks

Supply chain complexity is an important factor that contributes to the risk in supply chains. However, there are other sources of risk. But first, we need to define supply chain risk itself. In the supply chain literature risk is referred under many terms such as disruption, vulnerability, disaster, peril uncertainty and hazard (Ghadge et al., 2012). Another common approach is to identify risk based on where the risk originates in the supply chain (Jüttner et al., 2003). For example, Manuj & Mentzer (2008) identify supply chain risks as: Supply risks, operational risks, demand risks, security risks, macro, policy, competitive and resource risks. Ghadge et al. (2012) provides a taxonomy of risks based on enterprise architecture which includes the risk attributes such as process, organization, location, data, application and technology, referred to as POLDAT methodology. In reviewing risk literature, Manuj & Mentzer (2008), identified three aspects of risk. (1) Risk involves some loss when it is realized, (2) likelihood of the losses is an important factor in addressing the risk, and (3) the significance of the consequence of losses.

Common risk management strategies in supply chain literature includes avoidance, postponement, speculation, hedging, control, sharing/transferring, and security (Jüttner et al. 2003, Miller 1992, Manuj & Mentzer 2008). Though there are valid strategies to adopt at an organizational level, mitigating risk at the level of supply chains require active intervention and management. In supply chains were a dominant player is evident as in the case of Wal-Mart or Dell's supply chain, the risk mitigating strategies adopted by them can have a ripple effect on their "effective supply chain".

In the wake of recent financial turmoil and enterprise scandals, risk in general have been discussed and researched quite extensively. The vast body of risk literature comes from the financial perspective (Kunreuther, 2002; Anabtawi & Schwarcz, 2011; Christoffersen, 2012) and from an enterprise perspective (Bromiley et al., 2015). Various professional bodies and non-governmental organizations have proposed risk management frameworks and processes. For example, Committee of Sponsoring Organizations of the Treadway Commission (COSO) and Casualty Actuarial Society (CAS) has proposed Enterprise Risk Management (ERM) frameworks. International Standards Organization's (ISO) also has a suite of standards related to risk management. ISO 31000:2009 is a family of standards that relate to organizational risk management. ISO also has specific standards for information security risk management (ISO 27005:2011) and security management for the supply chain (ISO 28000:2007). In a survey of Committee of Sponsoring Organizations of the Treadway Commission (COSO) member organizations jointly conducted by North Carolina State University and COSO in 2010 found that COSO's Enterprise Risk Management (ERM) framework was widely used in those organizations. Another survey that was recently conducted by the risk management society RIMS.org also found similar trends in usage of ERM frameworks by organizations (Figure-2).

There is general consensus that "recent industry trends, including outsourcing, offshoring, and lean manufacturing has significantly increased the level of risk in supply chains" (p.3, Simchi-Levi et al., 2008). In a recent report on building resilience in supply chains by World Economic Forum, which was conducted in association with Accenture (World Economic Forum, 2013), system-wide risks are defined as "those which significantly disrupt supply chains across multiple operations and a wide geographic area" (p.13). According to this report, systemic risks are assumed to be created or magnified by the way the supply chain systems are configured. From a systems perspective, we define supply chain risk as the potential disruption of any of the three flows in any segment of the supply chain system under consideration. The three flows being the flow of goods and services, flow of information, and flow of finances.

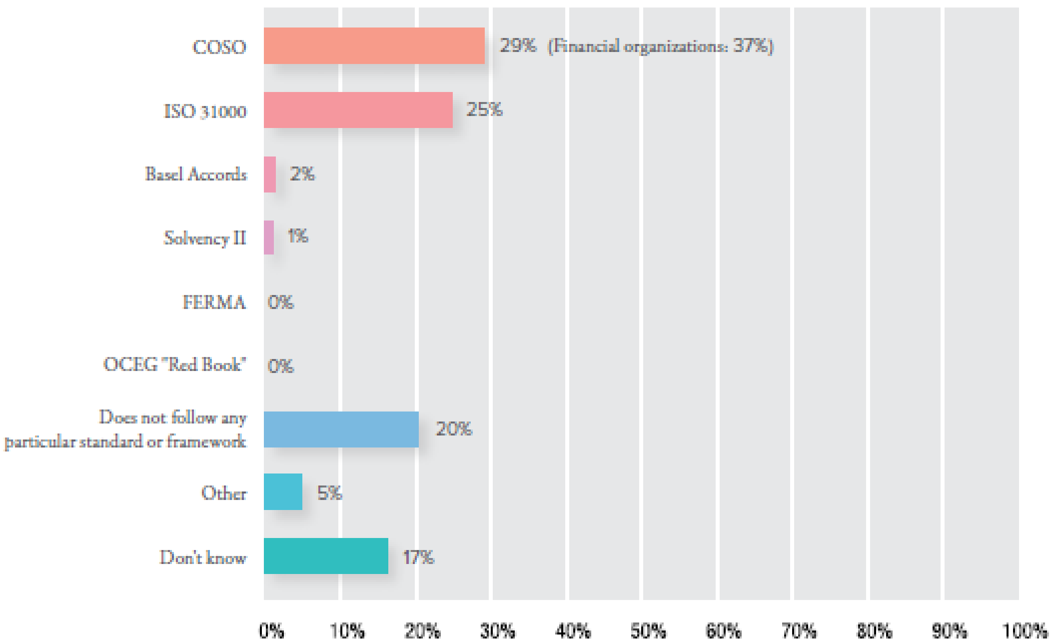

Figure-2: Frameworks Used for ERM Guidance in RIMS report on Enterprise Risk Management (p.14, RIMS, 2017).

4.2. Supply Chain Risk Framework

Based on the definition of the supply chain risk as the risk related to the potential disruption of any of the three flows, there are two origins for these disruptions. The two origins are based on what is loosely called known-unknowns and unknown-unknowns. Known-unknowns in supply chains are usually the system characteristics. They include the characteristics of the whole supply chain system and the characteristics of its parts. We call the characteristics of the whole system as systemic factors (that relate to the system) and the characteristic that relate to its parts or individual organizations as idiosyncratic factors. Risks attributable to the systemic factors are the *systemic risks* and those that are attributable to the idiosyncratic factors are *idiosyncratic risks*.

Here systemic risks are conceptualize slightly differently from the generally used perception of systemic risk in finance. Systemic risk in finance is specifically addressed for the risk of collapse of the entire financial system or the market due to the failure of a single or group of entities in the financial system because of the TBTF or TICTF nature of that entity. In supply chain, we refer systemic risk to any potential disruption that is attributable to the nature of supply chain as a system.

Factors that are relatively unknown-unknowns that affect a supply chain are factors that are beyond the control of supply chain entities and are more difficult to be anticipated and predicted. They are potential disruptions in the supply chain that are caused intentionally by some individual or entity, or are disruptions that are the result of unintentional events. To give an example, an information security breach could be an unknown-unknown that may happen in spite of all security procedures. Such disruptions that are caused because of an intentional acts can be called *security risk*. Other unknown-unknown events such as surprise political unrest or a natural catastrophe may be an unintentional event from a supply chain perspective, but can potentially have a detrimental impact throughout the supply chain system. These risks can be called *systematic risks* due to the system wide impact they may have. It is possible that in some situations such events will have only a localized impact on a particular organization or supply chain entity. In such situations, the risk impact is primarily due to the peculiarity of that organization or the entity and would fall under the idiosyncratic risk.

4.3. Systemic Risk in Supply Chains

This paper focuses on the systemic risks to explore how big data and analytics can help in mitigating those risks. As defined earlier, systemic risk are risks due to the system characteristics of the supply chain. We have already seen that these system characteristics can be defined by network, relational and temporal complexity (Table-1). It is this complexity that primarily introduces the systemic risk in supply chains. For example, it is argued that “the more complex the supply chain, the less predictable the likelihood and the impact of disruption. In other words, exposure to risk is potentially higher” (p.8, Simchi-Levi et al., 2013). As a corollary of this we can safely say that systemic risk is manifested in the supply chain as *network risks*, *relational risks*, and *temporal risks*.

Network risk in a supply chain is introduced due to the structure of the supply chain network. It may be due to the increased number of other organizations that a supply chain entity may have to connect to in order to provide the products offered. This risk increases when the supply chains become longer and wider. It may also be due to other structural characteristics such as the propensity for circular feedback effect of organizational decisions related to the sharing of information or financial actions. Multiple uncoordinated objectives of the supply chain organizations that work against the overall system efficiency can also contribute to this type of risk. Presence of organizations that are too-big-to-fail (TBTF) can also increase network risk.

Relational risk is an important element in the supply chain's systemic risk. Active interventions are most effective in reducing these types of risks in supply chain. Relational risks are manifested in supply chains because supply chain entities have to exchange goods and services, information, and financial assets as part of their operations. This exchange facilitate the type of relationships they form with other entities. Greater flow of materials and finances increase these risks but greater information flow can reduce this risk. The need for rich and strong ties between supply chain entities for the flow of materials and finances can often increase this risk. Lack of information on the demand, supply, and other key information between supply chain entities can also increase this risk. Drawing on parallels from financial literature, the presence of organizations that are too-inter-connected-to-fail (TICTF) can significantly increase the relational risk in supply chains.

Temporal risk is related to the dynamic nature of the supply chain and is the risk related to the changes that may occur in its network and relational characteristics. Non-linear interactions that propagate through the supply chain such as the bullwhip effect and those that are caused by information asymmetry can contribute to this type of risk. Both internal changes and external changes that are characteristic of open systems contribute to this risk. The inability or ability of supply chain entities to learn about its environment and its own behavior can contribute significantly to this risk.

4.3.1. Big Data in Supply Chain Risk Detection and Mitigation

There are many types of risks in supply chain; however, a major risk in supply chain is attributable due to its complexity (Simchi-Levi et al., 2008). The extant literature lacks a coherent theoretical framework to examine these risks in supply chains and to understand how big data can be helpful in mitigating these risks. This research hopes to bridge this gap by the proposed framework to conceptualize risks in supply chain and by showing how big data can help in mitigating those risks. Big data and analytics can be helpful in detecting and eventually mitigating all types of supply chain risks such as, systemic, security, systematic, and idiosyncratic risks. We focus in this paper on big data's usefulness in mitigating systemic risks. We focus on using big data and analytics for mitigating systemic risks due to the proliferation of information technology and extensive systems and processes within todays supply chains, sensing and logging a broad spectrum of data about the supply chain entities, their interactions and other externalities.

Porter and Heppelmann (2014) show how "the increasing capabilities of smart, connected products not only reshape competition within industries but expand industry boundaries. This occurs as the basis of competition shifts from discrete products, to product systems consisting of closely related products, to system of systems that link an array or product systems together" (p.74). There is an explosion of data available in supply chain systems today and it is increasing at an unprecedented rate contributed in part due to the embedded sensors and systems at the various touchpoints in the supply chains. These systems are increasingly becoming interconnected to form what is called the internet-of-things (IoT). Leading researchers in this field hold that this constitute a true paradigm shift in how we conduct business and use data. Information technology has radically reshaped competition and strategy twice over the past 50 years, by first helping automate processes, and then by integration of standalone systems, now we are at the brink of another transformation brought over by information technology becoming integrated with products-embedded sensors, processes, software & connectivity (Porter & Heppelmann, 2014).

Big data was initially conceptualized in the three V's: Volume, Velocity, and Variety by Laney (2001), it has since extended in many ways but can be viewed has having four different dimensions referred to as 4V's of big data based on the IBM model (Schlegel, 2014). The 4V's represent Volume of data available or collected, Variety of data available- which includes variety in forms, structure and content, the Velocity or speed with which the data is created and processed, and the Veracity of the data- which deals with the reliability and accuracy of the data that is collected. These four dimensions should serve as pointers while collecting data that may be considered for supply chain risk analysis, and while considering analytics appropriate for assessing and mitigating risks. In a recent article exploring the use of big data and analytics in managing supply chain risk, Schlegel (2014) indicated that the researchers feel very comfortable saying that "Big Data and Predictive Analytics will be new levers for supply chain risk managers to identify, assess, mitigate, and manage global risk going forward" (p.12).

How and what kind of big data is applied for risk mitigation in supply chain will depend on who is trying to mitigate the risks. Data that is available for a particular organization, a network of suppliers, a consortium, a government or other regulatory bodies will differ significantly. This will in turn dictate what kind of risks can be assessed and the kind of data will be available for such analysis (Table-2).

Table-2: Big data sources and analytics in supply chains.

Data Originates at	**Primary Responsibility**	**Level of Control**	**Examples**	**Big Data Sources**	**Relative Emphasis of Big Data Analytics**
Firm	Firm	High control	Production disruptions, inventory, quality issues, employee performance, equipment status, etc.	POS, ERP, Inventory systems, HR systems, Streaming data from organizational systems, IoT data from company products/equipment	Diagnostic, Prescriptive,
Immediate network	Network of suppliers	Medium control	Supplier delays, logistics data, payment data, orders, supplier inventory, etc.	EDI, SCM, CRM, Logistics & distribution systems, Shared IoT data	Descriptive, Diagnostic
Extended network	Consortium	Low control	Changes in end consumer preferences, changes in raw material prices, etc.	Social Media, 3rd party research reports,	Descriptive, Predictive
External environment	Government/ Regulatory bodies	No control	Climate change, changes in govt. policies, demographic changes, environmental catastrophes, etc.	Public Databases, Social Media, Internet Search Aggregators, Weather data, Public IoT data	Predictive

4.3.2. Using Big Data and Analytics for Mitigating Systemic Risk

To mitigate systemic risk using big data, identification, collection and analysis of such data should focus on the network, relational and temporal factors of the systemic risk. Data related to network complexity could include information about any aspect of supply chain entities. These may be data about the performance or specifications of technical entities or social entities within the supply chain. Such data could also be collected at different levels of abstraction such as at the level of key individuals, teams, organizations or cluster of organizations within a supply chain (Table-2). Data could also be about other structural characteristics at a firm, supplier/distributor or of supply chain network entities. Such data can be available from firms own systems, other systems that interact with the immediate network, or as part of a collaborative initiatives with other supply chain entities through consortium and other arrangements.

In assessing and scanning for systemic risk, big data collection may also be directed towards the aspects of supply chain system that address relational complexity. These may be data related to the exchange of materials, information and finances. They may be again collected at various levels of abstraction and may include quality and timing of movement of raw materials and finished goods, about the type of information exchanged between supply chain entities, and financial information such as payment and invoicing. Data collected regarding the relational aspects could also be about the social dimensions that indicate the type and nature of social relationships between individuals, groups, organizations, systems, and products. For example, Provost and Fawcett (2013) describe how big data analytics could be used to detect customer-product relationship to reduce churn. Analysis of such data could be using descriptive, diagnostic or even predictive tools.

Data related to the temporal dimension could also be related to network or relational complexity but collected over a period of time. Other types of temporal data that may be included in the big data analytics could include time series data and causal data regarding how various characteristics of the supply chain entities and its relationships have changed over time. This includes pattern of demand/supply variations, production, marketing and inventory data over a period of time. Data in this regard also includes data that is available about the adaptability and flexibility of social and technical systems within the firm and beyond.

5. Case Studies on Supply Chain Risk

Case study approach is a convenient tool for the exploration of complex subject areas and to bring more focus to the topic with real business scenarios. Cases are useful to determine the subject areas and provide detailed understandings. This section details the summary of some of the cases relevant to supply chain risk in the literature.

Blome and Schoenherr (2011) provided several case studies from banking, insuarance, manufacturing, automotive, energy, fashion, logistics, and electronics sectors on supply chain risk management during financial crises periods. The research model's framework consit of four steps as Risk identification, Risk Analysis, Risk Mitigation, and Risk Monitoring. Similar to our findings, supply chain risk categories are supplier/supply risk (purchasing, logistics), distruption risk, and IT risk. Major findings on the SCRM was that the risk mitigation strategies have key roles on SCRM success. Having a well implemented ERP solutions was found to provide better management in processes, source utilization, information (IT) handling and management, communication with globally dispersed suppliers, and sustainable operations.

Thun and Hoenig (2011) conducted an emprical analysis (based on survey with 67 manufacturing plants) of supply chain risk management (SCRM) issues in German automotive industry. According to their findings, they conducted the search in general context of supply chain analysis with key drivers of SCRM that likelihood occurred as risk on potential supply chain domain. They used probability matrix to visualize the outcomes, which clearly shows the relationship between internal and external SCRM. A cluster analysis was also employed to show factors affecting the risk management in automotive industry in Germany. Results show that companies which implemented the the high level of risk management issues as proactive approach have better business performances. Besides, complexity and efficiency were found as key drivers for SCRM success along with global supply chain management issues, and the necessity to provide various product offerings. Supplier quality problems was found to be the most critical risk and was supported with high probability and impact on operations. On the other hand IT infrastructure and system malfunctions were seen as severe problems but one that is less likely to occur. Price level of the materials and customer demand instability were also seen to negatively effect the SCRM with channel distruption in the supply chains. As supply chains are vulnerable in some degrees, low implementation of the programs of SCRM cause main problems. Complexity, product differentiation, outsourcing manegement and decisions, trust in the chain, and dependencies of chain intermediaries were expected to foster suply chain risks. The study showed that understanding and implementing the SCRM well had the potential and opportunity to improve supply chains in the automotive industry.

In another study proposed by Raka and Liangrokapart (2015) focused on complexity and security issues of supply chains in fresh produce industry. They found that risks management was highly important in terms of the effectiveness and management succes in this industry which included supply chain players such as growers, collectors, wholesalers, processors, retail chains and consumers. They identified risk areas as climate, demand, financial, information, operational, policy, price, and regulatory and supply risk in general. They also conduct stakeholder analysis to explore relationship among key variables. Findings show that climate, trust of suppliers, and price were severe risk factors. Using data sources proactively with proven analysis tools have the potential to posititively effect risk management success.

Ritchie and Brindley (2007) conducted a conceptual and empirical study on supply chain risk management context and developed a framework using two case studies. The study concentrated on understandings of perfomance metrics in supply chains in general and then investigated drivers that potentialy effect the researh area. Those drivers werer categoriezed as: Sources (supply chain configuration and IC); Profile (sytematic and unsytematic risks); and Risk and Performance Drivers (environmental characteristics, industry characteristics, SC configuration, members of chain, strategy, problem spesific variables, and decision making department). In order to understand the current situation and support the research framework they used emprical case study method. First case study was conducted on a multinatioanl organization that operates in 140 countries in manufacturing and selling agricultural equipments. The main risk drivers found at the strategic level were identification, evaluation, and prioritaziton of risk varibles. Environmetal issues along with new technologies for product develeopment and IC implementation and utilization were also influential factors to be taken considerations. In tactical and operational level supply chain interactions, stock manegement, and delivery times are also critical. The case study supported that maintaning dealership network enhances quality of services and provides training development to stakeholders, specifically, in terms of technical expertise, performance of dealarship, sales, and in retention of customers. Risk occurs mostly in inteactions within the supply chain if they do not participate in collaborative approach, and effective communication with the producer. In the second case study, B2C supply chain realtionship was analyzed. The findings show that structure of business conditions, processes, and information sharing are key enablers in SCRM. Effective partnership management and awareness of the risk issues could eliminate potential failures. The study also showed that there was a strong relationship between risk management implementation and perfomance success in supply chains.

Jayaram, et al. (2013) conducted a multiple case study to explore relationships among family businesses and their SCM capabilities in India. The main purpose of the research was identifying key concepts in SCM namely, risk appetite, professional management of SCM, information system (IS) capability, partnership relations, and operational effectiveness. Along with the all variables related to SCM success Information System Capability payed a key role on success. Interorganizational form of information sharing and data processing was also important. The complexity of the system perspective forced companies to implement more online communication systems rather than conventional channels. Although the IT infratructure for small companies is still in development stage in India, the reputation and understandings of information technology applications become more critical in supply chain management in terms of risk elimination. Most of the IT functions and capabilities were at the basic levels for small and medium-sized organizations. The advancement of technological implementations are still in developing stage, the results show that they effect data handling and analysis, reduction of delivery times, and reduces cost of customer services. The managers and owners aggreed and were optimistic that establishing the applications such as SAP and ERP softwares and systems would benefit their business in terms of growth and future success in global business platforms. The findings also reflected that at the implementation of these systems would bring extra risks for their business in general. Changing paradigm for technological investments are vital in near future for any size of companies. The risks are not only in implementation and utilizing the capabilties, but blid sightedness to developments in informtion systems are also a main risk in global arena.

According to McKinsey & Company's sectoral research, food supply chains focuses on big data and advanced analytics to tackle multiple challenges related to risk. and indicates that there are opportunities to use those systems for mitigating several risk factors (Magnin, 2016). Advanced analytics and usage of big data identifies the bottlenecks in infrastructure such as network optimization, warehouse location based data utilization, predictive maintenance, truck monitoring for delivery performance, input optimization, holistic production planning, and accurate forecasting for every step required for SCM. Opportunities in this area include: winning the innovation game, optimize learning operations, supply chain effectiveness, transparency in the chain, and even elimination of financial and operational risks. Alicke et al. (2016) stated that supply chain 4.0 is the highest maturity level and concentraes more on big data management which leverages improved, faster, more granular support of decision making process. Advanced analytics provides clear understandings of scenarios to mitigate risk factors. Besides, big data has potential positive effects on business performances with online trransparency, digital perfomance management, and automated root cause analysis. From predictive demand planning to physical distribution, digital technologies enables agility and collaborative actions throughout the chains. Using big data and related analytics will lead future supply chains and ensure faster, flexible, granular, and accurate, decision making in an efficient manner. Creating a modern, end-to-end supply chain organization requires sophisticated data analysis (real time data-driven) and cross-functional decision making which identifies the risks and opportunities in structured data (Glatzel et al., 2014). However IT functions (related hardware, software and ERP) and systems must support the supply chain infrastructure and enable collaboration for analytical decision making to reach operational excellence levels (Gezgin et al., 2017).

6. Conclusion

Adopting a systems perspective and drawing on the complexity literature, this paper presented a comprehensive view of supply chain risk and showed that supply chain risks in general can be classified into systemic risk, security risk, systematic risk, and idiosyncratic risk. We then discussed some of the characteristics of these risks, and focused on systemic risk being the primary risk that is introduced due to the complexity of the supply chain. Because of the proliferation of embedded and interconnected systems throughout supply chains, big data can potentially help in detecting and mitigating this risk in the supply chains (Schlegel, 2014). We provide some direction in understanding where and how data can be collected, and the analytical tools that can be used to mitigate the systemic risks in a supply chain by focusing on the three dimensions of supply chain complexity- the network, relational, and temporal dimensions. Finally, summary of cases relevant to supply chain risk that relate to big data and analytics from the literature were presented.

This research has implications for theory building and practice. Through the adoption of the proposed supply chain risk framework, this research provides greater clarity in modeling and furthering research in this area. Big data solution providers can focus on facilitating data collection and identification tools that address the specific elements of supply chain risk. The framework is helpful in developing big data analytic tools that specifically address the domain of supply chain risk. This is especially significant because there is an emerging view that data science analytics and results require careful consideration of the context (Provost and Fawcett, 2013). Further research in this area can explore in detail the available big data tools and approaches that may fit supply chain risk mitigation using this framework. Cases provided in this article provide some indication of the direction of relevant work in this area. The framework presented may also be used to develop autonomous machine learning systems based on Artificial Intelligence and big data (Dhar, 2016), that detect and warn of impending risks in an organization's supply chain. Identification of specific use cases from the industry and a more rigorous empirical testing are required to verify the validity of the proposed framework. However, the paper provides a good starting point to address the risk factors of today's fast paced global supply chain, and facilitates a more effective use of an explosive collection of big data and analytic tools to this effect through the proposed framework.

REFERENCES

Alicke, K., Rexhausen, D., & Seyfert, A. (2016). Supply chain 4.0 in consumer goods. McKinsey & Company pp. 1-11.

Anabtawi, I. & Schwarcz, S.L. (2011). Regulating systemic risk: towards an analytical framework. *Notre Dame Law Review*, *86*(4), p.1349.

Barry, J. (2004). Supply chain risk in an uncertain global supply chain environment. *International Journal of Physical Distribution & Logistics Management*, *34*(9), pp.695-697.

Barutcu, S., Dogan, H., Barutcu, E., & Kulakli, A. (2010). Supply chain-based conflict: A study from textile exporters" perspectives. *Journal of Global Strategic Management, 8*, 90-102.

Blome, C., & Schoenherr, T. (2011). Supply chain risk management in financial crises - A multiple case-study approach. *International Journal of Production Economics, 134*(1), 43-57.

Bowersox, D.J., Closs, D.J. & Cooper, M.B. (2007). *Supply chain logistics management* (2nd ed.). New York, NY: McGraw-Hill.

Bromiley, P., McShane, M., Nair, A. & Rustambekov, E. (2015). Enterprise risk management: Review, critique, and research directions. *Long range planning*, *48*(4), pp.265-276.

Chen, H., Chiang, R.H. & Storey, V.C. (2012). Business Intelligence and Analytics: From Big Data to Big Impact. *MIS quarterly*, *36*(4), pp.1165-1188.

Christoffersen, P.F (2012). *Elements of financial risk management*. Academic Press.

Cilliers, P. (1998). *Complexity and Postmodernism:Understanding Complex Systems*. Routledge.

Croom, S., Romano, P. & Giannakis, M. (2000). Supply chain management: an analytical framework for critical literature review. *European journal of purchasing & supply management*, *6*(1), pp.67-83.

Dhar, V. (2016). The Future of Artificial Intelligence. *Big Data*, *4*(1), pp.5-9.

Dumbill, E. (2013). Making sense of big data. *Big Data*, *1*(1), pp.1-2.

Gezgin, E., Huang, X., Samal, P., & Silva, I. (2017). Digital transformation: Raising supply-chain performance to new levels. McKinsey & Company pp. 1-10.

Ghadge, A., Dani, S. & Kalawsky, R. (2012). Supply chain risk management: present and future scope. *The International Journal of Logistics Management*, *23*(3), pp.313-339.

Glatzel, C., Niemeyer, A., & Rohren, J. (2014). *Three ways CEOs can improve the supply chain*. McKinsey & Company pp. 1-4.

Hill, T. (1989). *Manufacturing Strategy: Text and Cases*. Irvin, Boston

Huber, G.P. (1984). The nature and design of post-industrial organizations. *Management science*, *30*(8), pp.928-951.

Jayaram, J., Dixit, M., & Motwani, J. (2013). Supply chain management capability of small and medium sized family businesses in India: A multiple case study approach. *International Journal of Production Economics, 147*, 472-485.

Jüttner, U., Peck, H. & Christopher, M. (2003). Supply chain risk management: outlining an agenda for future research. *International Journal of Logistics: Research and Applications*, *6*(4), pp.197-210.

Kunreuther, H. (2002). Risk analysis and risk management in an uncertain world. *Risk analysis*, *22*(4), pp.655-664.

Laney, D. (2001). 3D data management: Controlling data volume, velocity and variety. *META Group Research Note*, *6*, p.70.

Lee, Y.H., Cho, M.K., Kim, S.J. & Kim, Y.B. (2002). Supply chain simulation with discrete–continuous combined modeling. *Computers & Industrial Engineering*, *43*(1), pp.375-392.

Magnin, C. (2016). How big data will revolutionize the global food chain. McKinsey & Company pp. 1-6.

Manuj, I. & Mentzer, J.T. (2008). Global supply chain risk management strategies. *International Journal of Physical Distribution & Logistics Management*, *38*(3), pp.192-223.

McAfee, A. & Brynjolfsson, E. (2012). Big data: the management revolution. *Harvard Business Review*, *90*(10), pp.60-6.

Miller, K.D. (1992). A framework for integrated risk management in international business. *Journal of International Business Studies*, pp.311-331.

Min, H. & Zhou, G. (2002). Supply chain modeling: past, present and future. *Computers & industrial engineering*, *43*(1), pp.231-249.

Muhammed, S. (2004). Towards a theory of knowledge management in supply chain, *Proceedings of the 2004 MBAA Annual Midwest Business Administration Association Conference*, Chicago, Illinois, March 18, 2004.

Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. *Harvard business review*, 92(11), 64-88.

Provost, F. & Fawcett, T. (2013). Data science and its relationship to big data and data-driven decision making. *Big Data*, *1*(1), pp.51-59.

Raka, C., & Liangrokapart, J. (2015). Supply chain risk management: A case study in Thailand. In T. B. Wolfgang Kersten (Ed.), *Innovations and Strategies for Logistics and Supply Chains* (pp. 557-580). epubli GmbH.

RIMS. (2017). *Enterprise Risk Management Benchmark Survey: Executive Report*, rims.org, Available at https://www.rims.org/RiskKnowledge/RISKKnowledgeDocs/2017_ERM_survey_1162017_84825.pdf

Ritchie, B., & Brindley, C. (2007). Supply chain risk management and performance. *International Journal of Operations and Production Management, 27*(3), 303-322.

SAS, (2016). *Big Data: What it is and why it matters?* [ONLINE] Available at: http://www.sas.com/en_us/insights/big-data/what-is-big-data.html. [Accessed 18 April 2016]

Schlegel, G.L. (2014). Utilizing big data and predictive analytics to manage supply chain risk. *The Journal of Business Forecasting*, *33*(4), p.11.

Serdar-Asan, S. (2011). A review of supply chain complexity drivers, *Proceedings of the 41st International Conference on Computers & Industrial Engineering*, Los Angeles, CA, October 23, 2011

Simchi-Levi, D., Kaminsky, P. & Simchi-Levi, E. (2008). Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies*, McGraw-Hill, 3rd ed., Boston, Mass*.

Simchi-Levi, D., Kyratzoglou, I. M., & Vassiliadis, C. G. (2013). *Supply chain and risk management*. MIT Forum for Supply Chain Innovation, MIT and PwC.

Thun, J.-H., & Hoenig, D. (2011). An empirical analysis of supply chain risk management in the German automotive industry. *International Journal of Production Economics, 131*(1), 242-249.

Trist, E.L., Higgin, G. W., Murray, H. & Pollock A. B. (1963). *Organizational choice: capabilities of groups at the coal face under changing technologies: the loss, re-discovery & transformation of a work tradition*. Tavistock Publications.

Vollmann, T.E. & Cordon, C. (1999). Building a smarter demand chain. *Financial Times-Series*, *4*, pp.2-4.

World Economic Forum. (2013). *Building Resilience in Supply Chains*, Available at https://www.weforum.org/reports/building-resilience-supply-chains/

Yin, R. (2009). Case Study Research*.* California: Thousand Oaks.