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Measuring supply chain resilience using a deterministic modeling approach

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ABSTRACT

To achieve a competitive edge in an uncertain business environment where change is imperative, one of the significant challenges for an organization is to mitigate risk by creating resilient supply chains. This research proposes a model using graph theory which holistically considers all the major enablers of resilience and their interrelationships for analysis using an Interpretive Structural Modeling approach. The uniqueness of this model lies in its ability to quantify resilience by a single numerical index. The quantification of resilience will help organizations assess the effectiveness of various risk mitigation strategies. This will provide tools for managers to compare different supply chains while offering a deeper knowledge of how supply chain characteristics increase or decrease resilience and consequently affect supply chain risk exposure. Thus, the research supports organizations in measuring and analyzing supply chain resilience and facilitates supply chain decision-making. The proposed method could simplify the dynamic nature of environment for managing disruptions in a supply chain. This novel approach for determining the supply chain resilience index (SCRI) advocates the consideration of resilience aspects in supply chain design, thus giving a competitive advantage to achieve market share even during a disruption.

1. Introduction

Supply chain activities have an intrinsic risk of unpredicted disruptions. The globalized, more lean and just-in-time supply chain networks have reduced the slack available to deal with uncertain events. If not well designed and managed these can trigger potential negative consequences due to the risk they cause, which can lead to monetary losses. Recent global events show frequent reminders that we live in an unpredictable and changing world, e.g. Tsunami 2004, 2011, Hurricane Katrina 2005, Taiwan earthquakes 1999, 2009, 2010, Turkey earthquake 2012, Thailand flood 2011, diseases (SARS 2003, avian/bird flu 2005, swine flu 2009), terrorist attacks (New York 2001, Madrid 2004, London 2005, Jakarta 2009, Mumbai 2008) and the economic recession.

There is general acceptance that global supply chains are suffering from the disruption of supply chain functions and reduced supply chain efficiencies (Bogataj & Borgata, 2007; Myers, Borghesi, & Russo, 2006). To reduce this risk, supply chains must be multidimensional and multidisciplinary, designed to incorporate event readiness, provide an efficient and effective response and be capable of recovering to their original state or improved state after a disruption; this is the meaning of supply chain resilience (Ponomarov & Holcomb, 2009). The term resilience is used in a wide variety of fields as shown in Table 1.

Among all the definitions given in literature, the perspective of the phrase may alter but the core concept of resilience is related to the ability of a system to return to a stable state after disruption. This involves both the ability to withstand systematic discontinuities, as well as, the capability to adapt to new risk environments (Starr, Newfrock, & Delurey, 2003). It is a subject of interest in relatively new emerging disciplines such as supply chain risk management and sustainable supply chain management (Soni & Jain, 2011). Resilience is also termed as an intersection of robustness, flexibility and adaptation (Ivanov & Sokolov, 2012). Yadav et al. (2011) model the supply chain cost, sales profit and product design complexity as three criteria that altogether determine the robustness of the supply chain. But the point of concern is why do some organizations collapse in the face of high levels of ongoing strain,

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Table 1
Definitions of Resilience.

Author	Context	Definition
Holling (1973)	Ecological systems	The measure of the persistence of systems and of the ability to absorb change and disturbance and still maintain the same relationships between state variables
Gunderson (2000)	Ecological systems	The magnitude of disturbance that a system can absorb before its structure is redefined by changing the variables and processes that control behavior
Carpenter et al.(2001)	Socio–ecological systems	The magnitude of disturbance that a system can tolerate before it transitions into a different state that is controlled by a different set of processes
Coutu (2002)	Individual	Resilient individuals 'possess' three common characteristics These include an acceptance of reality, a strong belief that life is meaningful and the ability to improvise
Hamel and Valikangas (2003)	Organizational	Resilience refers to the capacity for continuous reconstruction
Bodin and Wiman (2004)	Physical systems	The speed at which a system returns to equilibrium.
Luthans, Vogelgesang, and Lester (2006)	Psychology	The developable capacity to rebound from adversity

while others thrive and grow more resourceful becoming ready to tackle future challenges? The concept of supply chain resilience (SCR) proposed in this paper symbolizes a multidimensional phenomenon and is based on the underlying assumption that not all risk events can be prevented; meaning that resilience should be designed in. In other words, there are certain features that if engineered into a supply chain, can improve its resilience. Classifying those features, analyzingand comparing the 'level of resilience' and realizing the scope of improvement is a challenge attempted in this research.

1.1. Need for evaluation of supply chain resilience

Supply chain disruptions are "unplanned events that may occur in the supply chain which might affect the normal or expected flow of materials and components" (Svensson, 2001). Supply chain managers need improved methods to analyze the factors that determine the resilience of supply chains against disruptions. Many organizations currently lack an awareness of the need to consider the resilience of their supply chains as part of their overall approach to risk and business continuity management (Christopher & Peck, 2004). The organization rarely considers the effect between the determination of business strategy and identifying the impact of those strategic decisions upon SCR.

Available literature on SCR is informative and is primarily focused on presenting several theoretical viewpoints of the phenomenon (Bhamra, Dani, & Burnard, 2011; Christopher & Lee, 2004; Christopher & Towill, 2002; Juttner & Maklan, 2011; Sheffi, 2001). These viewpoints provide some understanding and importance of the topic for supply chain research. Rosenhead, Elton, and Gupta (1972) proposed that robustness is a criterion of flexibility in achieving near-optimal solutions in conditions of uncertainty. Peng, Snyder, Lim, and Liu (2011) designed reliable networks using mixed-integer programming model. Bertsimas and Sims (2004) flexibly adjust the level of conservatism of the robust solutions in terms of probabilistic bounds of constraint violations. Wagner and Neshat (2010) developed an approach based on graph theory to quantify supply chain vulnerability. But, the measurement of SCR has not been attempted so far and it still needs to be addressed. Thus, motivation for this research was to propose an approach to measure the level of resilience of the supply chain and finding the scope of improvements to better design it to handle uncertainties and risk. The SCRI developed is unique for its kind as no attempt has been recorded in literature, so far, to measure and compare resilience of supply chains. Christopher and Lee (2004) suggested that one of the best ways to deal with supply chain risk is to increase confidence in the supply chain. Confidence in the supply chain cannot be gained unless it has the ability to recover from or adjust easily to adversity or change. This clearly reflects the need of SCR. It is frequently quoted that "you can't control what you don't measure". Thus, evaluation of SCR would be of significant help to understand the risk exposure of supply chains and to further categorize the areas in which risk management and mitigation are required. In addition, it facilitates organizations to assess their resilience prior to and after the implementation of risk management measures, re-examine the level of resilience in uncertain environments, and track it over time.

1.2. Objectives of research

It is apparent from the literature that SCR is an emerging concept (Christopher & Peck, 2004; Peck et al., 2003; Ponomarov & Holcomb, 2009). Only conceptual works can be cited to date which either review the literature or provide definitions (Bhamra et al., 2011; Brian, Caballini, & Revetria, 2009; Ponomarov & Holcomb, 2009; Rice & Canioato, 2003). There are studies which address various issues related to vulnerability, supply chain risk and risk mitigation (Blos, Quaddus, Wee, & Watanabe, 2009; Matook, Lasch, & Tamaschke, 2009; Norrman & Jansson, 2004; Peck, 2006; Sinha, Whitman, & Malzahn, 2004; Wagner and Bode, 2008; Zsidisin & Smith, 2005). But, limited research exists which focuses on resilience and the variables which affect it. Ponomarov and Holcomb (2009) stated that measurement of supply chain resilience represents a future potential research stream that will provide important knowledge regarding the outcomes of this phenomenon. This paper attempts to develop a framework that holistically considers all the major variables of resilience and their interrelationships.

The main objectives of this research can be summarized as follows:

- To identify and rank the enablers of SCR.
- To find out the interaction among identified enablers using Interpretative Structural Modeling (ISM).
- To develop a conceptual framework that could effectively evaluate the interrelationships among the enablers.
- To propose an index to quantify the supply chain resilience.
- To compare various supply chains.

2. Material and methods

In this section, graph theory is explained, steps involved in developing supply chain resilience index are outlined and enablers of the index are proposed.

2.1. Measuring supply chain resilience using graph theory

In this sub-section, the underlying basis for choosing graph theory to measure resilience is explained by outlining capabilities and limitations of prominent methods used for decision making.