Understanding Supply Chain Resilience: a Dynamic Approach Using Theory of Constraints Current Reality Tree

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Abstract

Supply chain management involves adapting to changes in complex global network of organizations, and thus we will not examine it as a set of sequential, vertically organized transactions representing successive stages of value creation but as a whole system. Operational complexity and dispersion are making the supply chain more vulnerable to risks. In recent years, there have been a number of high-profile events and persistent problems that have severely disrupted the ability of firms to produce and distribute their products, including devastating earthquakes, political turmoil, fuel crises, diseases and terrorism. Evidence suggests that a firm that responds to a disruption better than its competitors could improve its market position. Our study focus on identifying critical success factors in supply chain resilience and understanding causal relationships between them. In This paper we consider the supply chain resilience as a complex system as we describes it with an application of a systems approach known as the current reality tree from the theory of constraints, the study was conducted in a group-based model-building environment with a group of students who specialized either in supply chain management or process engineering science. We developed our conceptual model including supply chain robustness, agility, flexibility and visibility to deal with resilience complexity and we suggest that understanding the dynamic nature of supply chain resilience through cause and effect relationships is critical to build future resilient strategies.

Keywords

Supply chain, Resilience, current reality tree

1. Introduction

Over the course of history, supply chains have emerged to meet the diverse needs of human societies, to exploit natural resources, and to enable humans to engage profitably in commerce and trade. (Casson, M. (2013). The very extensive supply chain literature addresses supply chain practices and performance (e.g., Swink et al., 2007; Flynn et al., 2010), supply chain strategies and their dynamics over time (e.g., Ketchen & Giunipero, 2004; Skjøtt-Larsen et al., 2007), and to some degree addresses changing supply chain configurations (e.g., Halldorsson et al., 2007; Ülkü & Schmidt, 2011), as manager strive to improve factory performance, the trouble is that often the meaning is lost (Zeng et al.; 2017), while interest in SCM is immense, it is clear that much of the knowledge about SCM resides in narrow functional silos such as purchasing, logistics, IT and marketing(burgess et al.,2006), Mentzer et al. (2001)
proposed a definition that is broad, not confined to any specific discipline area and adequately reflecting the breadth of issues that are usually covered under this term. We decided to use this definition to start our research: “Supply chain management is defined as the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole” (Mentzer et al., 2001). The different interactions constitutes a complex set of relationships among buyers and suppliers, between a buyer and a supplier as well as between competing suppliers (Nair et al, 2008), so the supply chain management involves adapting to changes in a complicated global network of organizations (pathak et al, 2007), and thus we will not examine it as a set of sequential, vertically organized transactions representing successive stages of value creation (Mabert & Venkataramanan, 1998) but as a whole system. Managers must possess a mental model of a supply chain management that more accurately reflects its true underlying complexity and dynamism. (Choi et al, 2006), so due to our natural lack of understanding of organizational, functional and evolutionary aspects in supply chains. A key realization to tackle this problem is that supply-chain networks should be treated not just as a ‘system’ but as a ‘Complex Adaptive System (Surana, 2005), and naturally it should be managed as such (Choi, 2006), however the dynamic and complex evolution of markets has encouraged many firms to implement various supply chain initiatives to try to boost efficiency (Saenz, 2017). As a result, aspects such as operational complexity and dispersion are making the supply chain more vulnerable to risks that negatively affect both short- and long-term operational and financial performance (Saenz, 2017; Craighead et al, 2007; Rao & Goldsby, 2009; Sheffi, 2005; Thun & Hoenig, 2011). In recent years, there have been a number of high-profile events and persistent problems that have severely disrupted the ability of firms to produce and distribute their products, including devastating earthquakes, political turmoil, fuel crises, diseases and terrorism (Chen et al 2013; Sodhi 2016; Mandal 2014; Singhal et al 2011). Indeed, a firm that responds to a disruption better than its competitors could improve its market position (Tukamuhabwa, 2015), so The potential impact of disruptions on a firm and its supply chain make a clear case for the importance of building resilience (Carvalho, 2012), there are even extreme cases where supply chains have completely collapsed and never recovered from a disruption (Xu et al 2014).

1. Supply Chain resilience.

1.1 Building knowledge

One of the substantiated issues in supply chain dynamics is resilience, which refers to development of the ability to remain robust and change (adapt) system behavior in dynamic environments in the case of severe disruptions with the achievement of acceptable performance (Craighead et al. 2007; Ivanov et al. 2016; Benyoucef et al. 2013; Ho et al. 2015; Gunasekaran et al. 2015; Tukamuhabwa et al. 2015; Khalili et al. 2017; Ivanov, 2017). To have a better understanding of the concept we adopted the literature review methodology, that has been encouraged by Wilding and Wagner (2014), a systematic procedure for retrieving and selecting the reviewed articles has been applied, following Tranfield, Denyer, and Smart (2003) and Denyer and Tranfield (2009), we reported only on research of a high quality, three and four star operations management journals, selected from the Association of Business Schools journal ranking guide as we used search strings such as ‘supply chain resilience’, ‘resilient supply chain’, ‘supply chain resiliency’, ‘supply network resilience’, ‘resilient supply network’ and ‘supply resiliency’ (and substrings of these terms); and we directed our search to ‘all fields’(Tukamuhabwa,2015), and we selected a total of 35 articles to start a constructive brainstorming.Most existing frameworks are too abstract; detailed studies of what actually constitutes resilience capabilities are sparse (kaulio, 2016). Ideally, supply chains need to recover as quickly as possible from operational disruptions so as to preserve the continuity of operations and their place in the competitive landscape (Sheffi and Rice 2005). The methodical elaborations on the evaluation and understanding of low-frequency/high-impact disruptions are vital for understanding and further development of network-based supply concepts in a broader sense and from a cross-disciplinary perspective. (Linton et al. 2007; Carter et al. 2008).

1.2. Definition

The Canadian ecologist Holling (1973) was one of the first researchers to note that systems have two distinct properties: resilience and stability, Ponomarov et al. (2009) define resilience as the ability of systems to absorb changes, and stability and it’s capacity to return to an equilibrium state after a temporary disturbance. There is an
implicit assumption of stability in the system; without stability there would be no presumed return to the pre-
disturbance state, but rather an adjustment to some new equilibrium level that could be better or worse than the
previous state (Clapham, 1971). Carpenter et al (2001) expanded the concept of resilience through the introduction
of the notion of the adaptive cycle. According to adaptive cycle theory, dynamic systems do not tend towards a
stable or equilibrium state. Instead they evolve through four states – rapid growth and exploitation, conservation,
creative destruction, and renewal or reorganization – adapting to the disturbance(s) as they considered the
ecosystems as ever-changing and they are embedded in a world in which many other things are also changing
continuously at various spatial scales (Levin, 2000). Consequently, relationships fitted to extant observations will
always become outdated as system change makes them irrelevant and misleading. Ponomanov (2017) stress the
importance of this adaptive capacity while describing proactive resilience that accepts the inevitability of change and
tries to create a system that is capable of adapting to new conditions and imperatives.

As to understand the dynamic complexity of the supply chain resilience we adopted the system dynamics
methodology in this work for its merits in solving complicated systematic problems (Cai, 2008) as a modeling and
analysis tool tackling the complicated issues of the supply chain resilience as a complex adaptive system (choi et al,
2001), System dynamics models capture information feedback and time delays to allow the simulation of complex
and dynamic behavior (Senge, 1990; Sterman, 2001). As such, they can model complex business decisions with
real-world characteristics (Forrester, 1961; Senge, 1990; Sterman et al., 2015).

2. Supply chain resilience: a dynamic model

2.1. Description of the System Dynamics model:

System dynamics is a method to enhance learning in complex systems. “Just as an airline uses flight simulators to
help pilots learn, system dynamics is, partly, a method for developing management flight simulators, often computer
simulation models, to help us learn about dynamic complexity (Sterman, 2001)

J.W. Forrester developed System Dynamic methodology in 1961 to model and simulate dynamic management
problems of operation and stock in companies (Forrester, 1961). And then, he gave out the structure and principles
of System Dynamics model in 1968 (Forrester, 1968), in 1969, Forrester introduced System Dynamics model to the
wider area of social science and summarized the evolution of American cities (forrester, 1969), In the 1970s,
Forrester together with the Club of Rome published “World Dynamics”, in which they analyzed the interactions and
feedbacks of the five fundamental factors (population, agriculture, natural resource, industrial production and
pollution) of global development. Researches of System Dynamics was booming since 1970s, which is being
applied to areas of natural science, social science and engineering etc., Because we apply these tools to the behavior
of human as well as physical and technical systems, system dynamics draws on cognitive and social psychology,
economics, and other social sciences (Sterman, 2001).

2.2. Dynamic of a system

It has long been acknowledged that people seeking to solve a problem often make it worse (More, 1956); this is
what forrester (1971) called “counterintuitive behavior of social systems.” Often our policies may create
unanticipated side effects. The unexpected dynamics as a whole complex often lead to policy resistance, the
tendency for interventions to be delayed, diluted, or defeated by the response of the system to the intervention itself
(Meadows 1982). As Thomas stated in the early 1974,” You cannot meddle with one part of a complex system from
the outside without the almost certain risk of setting off disastrous events that you hadn’t counted on in other,
remote parts. If you want to fix something you are first obliged to understand . . . the whole system.”

To avoid policy resistance and find high leverage policies requires us to expand the boundaries of our mental models
so that we become aware of and understand the implications of the feedbacks created by the decisions we make. We
must learn about the structure and dynamics of the increasingly complex systems in which we are embedded.
(Sterman, 2001). To use a mental model to design a new strategy or organization we must make inferences about the
consequences of decision rules that have never been tried and for which we have no data. (Simon, 1982), Every link
by which we might learn can be weakened or cut by a variety of structures. Some of these are physical or
institutional features (Yoo et al, 2016). Following convention, the structure of a system in System dynamics
methodology is exhibited by causal-loop diagram (Qui et al, 2015) to map relevant variables, associated
interrelationships, and delays (Gray et al., 2015).
Much of the art of system dynamics modeling is discovering and representing the feedback processes, which, along with stock and flow structures, time delays, and nonlinearities, determine the dynamics of a system, and most complex behaviors usually arise from the interactions (feedbacks) among the components of the system, and not only from the complexity of the components themselves. (Sterman, 2000 p12)

3. Theory of constraint and thinking process

The working principle of TOC provides a focus for a continuous improvement process (Rahman, 1988); TOC antecedents are rooted in the development of enterprise resource planning (ERP) computer software systems. A software package developed by Goldratt and others during the late 1970s to early 1980s (Oglethorpe et al, 2013) was based upon dynamic analysis of proprietary algorithms, a system of rules, steps and metrics transacted to accomplish specific goals. This software package, originally known as optimized production timetables (Goldratt, 1980), but which later became optimized production technology (OPT), Goldratt illustrated the concepts of OPT in the form of a novel, The Goal, Goldratt and Cox, (1984), According to Goldratt (1990), managers are required to make three generic decisions while dealing with constraints. These are: what to change; what to change to and how to cause the change and he prescribes a set of five tools in the form of cause-and-effect diagrams. To understand the concept as a whole, we propose the same methodology as Shams-ur Rahman, (2002), where he used a system approach known as the thinking process from theory of constraint not only to identify critical success factors in supply chain management, but also to understand causal relationships between these factors and to conclude with a global framework that “not only to identify the critical success factors in a supply chain, but also the causal relationships between these factors. Management can use these relationships to develop growth strategies for their companies. “Shams-ur Rahman (2002).

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<tr>
<th>Generic questions</th>
<th>Purpose</th>
<th>TP Tools</th>
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<td>What to change ?</td>
<td>Identify core problems</td>
<td>Current Reality Tree</td>
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<td>What to change to</td>
<td>Develop simple, practical solutions</td>
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<td>How to cause a change</td>
<td>Implement solutions</td>
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<td>Transition Tree</td>
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4. Building CRT for supply chain resilience

4.1. Scenario

Students undertaking a course in international logistics and supply chain management at the international university of Rabat, were invited to participate in a group-based model building exercise in supply chains. The purpose of this exercise was to:

1. Identify the characteristic of a resilient supply chain;
2. Determine possible causes of these consequences;
3. Develop causal relationships between causes and effects.

The group-based model building exercise was run in two sessions. In the first session, students used nominal group technique (NGT) to brainstorm the problem and identify five to ten characteristics of a resilient supply chain. Groups then identified factors most likely to cause such effects and developed cause-effect relationships in the form of a casual diagram. The actual models were developed in the second session. The CRT was applied to develop the casual relationship between causes and effects. Since the students had no prior knowledge of CRT, the author of this paper developed the causal trees on white board with feedbacks and suggestions agreed by the groups.

4.2. Results of the brainstorming session

The number of characteristic identified by these groups in the first session of the exercise ranged between four and eight. The first task in the second session was to decide which ones were to be considered for the model building process. The groups agreed on the following:
Robustness is the ability of the supply chain to resist change, and entails proactive anticipation of change before it occurs (Wieland, 2013), a robust supply chain can function despite some disturbances as it withstands and copes with shocks by retaining its stability when changes occur (Meepetchdee and Shah, 2007; Wallace and Choi, 2011; Wieland, 2013; Durach et al., 2017).

Visibility serves as a warning strategy that provides valuable time for firms to align their capabilities to minimize disruptive impact (Stecke and Kumar, 2009). Situation awareness involves an understanding of supply chain vulnerabilities and planning for such events, and requires the ability to discern a possible disruption by sensing and interpreting events (Datta et al., 2009).

Flexibility: The operations literature describes several types of flexibility that are relevant to a customer-focused supply chain (Vickery, 1999). Increasing flexibility provides the ability to adapt to changes quickly and readily in the case of disruption and to facilitate operational efficiencies in normal conditions (Sheffi and Rice, 2005). Flexible decisions help firms to adjust to rather than withstand disruptions (Wallace and Choi, 2011) by redeploying dedicated capacity (Rice and Caniato, 2003).

Agility refers to the ability to respond rapidly to changes (Ali, 2017). Braunscheidel and Suresh, (2009) stated that agility improves the time of response to variations in both risk mitigation and market response, so an agile supply chain possesses qualities, such as increased velocity, to quickly adapt to unexpected changes in demand or supply (Christopher and Peck, 2004; Jüttner and Maklan, 2011).

The branches of the CRT were developed choosing one characteristic at a time at random and following the guidelines mentioned earlier. When all the effects were considered and branches were constructed, these branches were put together and developed into a CRT for the entire supply chain resilience system. The following paragraphs discuss the construction of each of the branches.

Robustness

Machuca (2015) highlighted two distinct dimensions to describe robust supply chains: avoidance and resistance, and proposed a general framework that resume robustness characteristics:

1. Leadership Commitment: Leadership commitment to strategic initiatives is the foundation for the effective implementation of common goals within an organization (Speier et al., 2011). Their cognitive style impacts the organization’s attitude towards anticipation, pro-activeness and, in turn, pursuit of robustness actions (Grötsch et al., 2013).

2. Human Capital: as pointed out by Blackhurst et al. (2005), if employees are well educated and properly trained, they are equipped with the “necessary skills to know when it is appropriate to take action.” Human Capital is a valuable resource, necessary to achieve intra-organizational robustness (Machuca, 2015).

3. Intra-organizational Relationship Magnitude: strategic and operational sharing of information and are argued to enable better intra-organizational coordination and management (Hall et al., 2012) and the magnitude of interaction and exchange of information between different intra-organizational entities is central for enabling intra-organizational robustness (Machuca, 2015).

4. Risk Management Orientation: Zsidisin and (2010) find that understanding a firm’s risk helps to better implement measures to hedge and An increased risk management orientation is suggested to foster intra-organizational robustness (Machuca, 2015).

5. Node Criticality: some nodes are typically more critical than others. The measure of node criticality is relative to other nodes within a supply chain (Craighead et al., 2007). Machuca (2015) suggested that increased criticality of a single supply chain node is negatively related to supply chain robustness.
FIGURE 3: Robustness Model

(6) Bargaining power: supply chains with increased relative bargaining power of single nodes can be detrimental for inter-organizational robustness if the powerful node is not willing to support its supply chain partners (Machuca, 2015). Nodes with high bargaining power within a supply chain are, for example, single suppliers of a product or buyers of products that are readily available in the market (a situation often experienced in the automotive industry, cf. Thun et al., 2011).

Visibility

Supply chain managers can make the implications of strategic decisions more transparent for the board and can prioritize on identifying and avoiding emerging problems (Peck, 2005) and all of the definitions in the literature relate SC visibility to information sharing (Caridi et al; 2007). Visibility is therefore one outcome of external integration (Frohlich and Westbrook, 2001; Schoenherr and Swink, 2012) and internal integration (Williams, 2013; Sawhney, 2006; Wong et al., 2011). The basis of integration can therefore be characterized by cooperation, collaboration, information sharing, trust, partnerships, shared technology, and a fundamental shift away from managing individual functional processes, to managing integrated chains of processes (Akkermans et al., 1999).

Flexibility

Researchers have argued that the management of both demand- and supply-related information plays an important role in building the capability to flexibly respond to changes in upstream and downstream market (Duclos et al., 2005; Sinkovics et al., 2011). Frohlich and Westbrook, (2001) stated that integration activities regarding information sharing and logistics coordination, are not sufficient to achieve supply chain flexibility and that a lack of communication and coordination is detrimental for building a flexible supply chain. (Lambert and Cooper, 2000; Prajogo and Olhager, 2012; Manders, 2016)

Agility

Agile supply chains have been characterized as: communicating real-time data via information systems to all parties in the supply chain (White, 2005); synchronized integration across a firm’s internal functions, flexibility (Swafford, 2008) and speed (Al-Mudimigh et al., 2004)
4.3 The big picture

The conceptual CRT map developed during the group model building exercise is shown in Figure 7, we tried to link these characteristics and their effects so that we could summarize the whole picture and define a global framework. Risk-sharing partnerships between two integrated firms are not something new in supply chain literature (Rose-Anderssen et al.; 2010). Mattson (2003) argues that supply chain integration in the global environment may have positive synergetic effects if the differences of expertise are coordinated efficiently through dynamic exchange relationships of co-controlled resources in common activities. Power differences may create boundaries (Engestrom, 2000) but Trust produces mutual expectations (Harland et al., 2003) and, encourage sharing by coordination communication and synchronization (Zahir et al. 2013) As we were building our framework, some of us started to argue that integration could be one of the main cause for building resilient supply chain and there we tried to link “integration” as the core characteristic for supply chain resilience.

5. Limitations and suggestions for future researches

To date, most of the studies undertaken on supply chain resilience have focused on a wide range of issues and are generally quantitative in nature. This research applied a qualitative approach not only to identify the critical success factors in supply chain resilience, but also the causal relationships between these factors. Management can use these relationships to build and develop resilient strategies for their companies. However, these relationships need to be tested by large-scale empirical studies. As with any relatively new research area, the conceptual model presented in this paper is just one of the possible views. As such, it is an obvious limitation. The idea of establishing a meaningful linkage between resilience, flexibility, agility, visibility and robustness was a central concept for this research and in order to justify the need for resilient supply chains, one needs to have an understanding and clear definition of the phenomenon of resilience. The increased risks that are the result of complex and geographically disperse global supply chains necessitates that companies gain a better theoretical understanding of this emerging critical topic in order to effectively manage in this business environment. The opportunities for further research are abundant. Further conceptualization using different research perspectives would be highly recommended.

The next phase of research is to test the proposed model empirically. After operationalizing selected constructs, specific measures should be developed, and the hypothesized relationships should be tested and a simulation model could be applied for companies in specific field and assess how a resilient supply chain can respond to a certain disruption.
FIGURE 7: The big picture

Table 1. Name of the table

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Biographies

Abdelaziz Berrado is a faculty member of Industrial Engineering at Ecole Mohammadia d'Ingenieurs (EMI), University Mohammed V, Rabat, Morocco. His research interests are in the areas of Supply Chain Management, Data Mining, Quality, Reliability and Safety. His research work is about developing frameworks, methods and tools for systems’ diagnostics, optimization and control with the aim of operational excellence. He published several papers in international scientific journals and conferences’ proceedings. In addition to academic work, he is a consultant in the areas of Supply Chain Management, Data Mining and Quality Engineering for different Industries. He was also a senior engineer at Intel.

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