

## Conceptual Framework of Supply Chain Vulnerability

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**Abstract.** The aim of this article is to investigate the concept of Supply Chain Vulnerability and to understand its causing factors. It has been argued that environment turbulence and complexity and the increase of natural, terrorist and economic crisis are the main causing factors behind the increasing of the level of supply chain exposure to risk. However, the contribution of the use of supply chain philosophies and practices such as JIT, Lean manufacturing, outsourcing, etc. to the increase of vulnerability factors has also been highlighted in the literature. In this context, a conceptual model is developed in this article to reveal what could make a supply chain vulnerable. This article provides an outline of the vulnerability drivers in order to suggest a "conceptual framework of Supply Chain Vulnerability". The objective of such a model is not to describe another model of Vulnerability, but rather to offer a concrete structure incorporating the previous knowledge. The proposed model allows a better understanding of the vulnerability within Supply Chain Networks. Firstly, the model is analyzed through its positioning and contributions in comparison with existing frameworks in the literature. This comparison highlights the critical points overlooked in the past. Secondly, the model was applied on three case studies.

**Keywords:** Supply Chain Vulnerability, Supply Chain Risk, risk management, practices, supply chains, conceptual model

### 1 Introduction

Today there is an increasing consciousness of the vital importance of developing risk management approaches and strategies across all actors within supply chain networks. According to [1], 74% of managers stress the need to manage supply chain risks. According to the same report, organizations face today more than 24 sources of risks, with different levels of impacts and consequences. The most common consequences of these risks are the loss of productivity (58%), customer complaints (40%) and increased cost of working (39%), with annual cumulative losses of at least €1 million per year due to supply chain disruptions [1].

Unfortunately, not all risks could be prevented or managed. This is why companies are striving for more secure, resilient and less vulnerable supply chains and their strategies become more oriented risk strategies [5]. The urgent need to protect supply chains and to make them less vulnerable to different types of disruptions has been highlighted from both researchers [10-15] and practitioners [1-4], where there is a common consensus about the need to understand the causing factors of Supply Chain Vulnerability (SCV) and susceptibility to risks [6-9].

This article investigates the concept of SCV in order to improve the understanding of this field and to determine its causing factors. As a result, a conceptual model of SCV linking supply chain practices with vulnerability drivers is proposed and tested through a simple case study. Following this, the body of this article is organized as follows: Section 2 provides the background of the study, drawing a brief summary of literature about vulnerability definitions and drivers. The definition of the model is presented and discussed in section 3. Section 4 provides the application of this model to a case study and analyzes the results. Section 5 presents the conclusion, limitations and future research directions.

## 2 Literature review about SCV

There is a growing body of scientific frameworks that has studied Supply Chain Risk, Risk Management practices, and decisions related to risks [16]. However, according to literature [6], [9], [10] [14] and [31], Supply Chain Risk Management research cannot be investigated without understanding the vulnerability drivers, why certain organizations are more exposed than others, why certain companies face huge risk impacts and another more or less severe consequences (see for example, the Nokia and Ericsson case depicted in Section 4) [13]. This is where hides the importance of vulnerability analysis, which has been presented as a condition in which a disruptive event could turn (or not) into a serious risk [5], [31]. As a result, the concept of vulnerability has been considered as a critical factor in the process of risk management within supply chain networks and a powerful analytical tool for describing states of exposure to disturbance and risk, and also for guiding analysis and investigation of actions to mitigate and manage risks [9], [17], [25].

Referring to the literature, few frameworks have been developed as an essay to understand and investigate the concept of vulnerability [18]. 27 publications dealing with the topic of Supply Chain Vulnerability over 13 scientific journals have been found.

This section first investigates the concept of supply chain vulnerability, in the light of various definitions provided within the current literature. Subsequently, the research approaches undertaken in the area of supply chain vulnerability modeling, basing on the understanding of its causing factors or drivers, is discussed in more details.

### 2.1 Definitions of Supply Chain Vulnerability

The concept of SCV has recently been defined by many authors, which led to several different viewpoints. One important definition is presented by Svensson [11] in his research in which he defines this latter as "*the existence of random disturbances that lead to deviation in the supply of components and materials from normal, expected or planned schedules or activities all of which cause negative effects or consequences for the involved manufacturing and its sub-contractors*". This definition has been used by several others researchers (for instance [23], [24]). However, [19] followed by [20] have dealt with the concept of vulnerability in the production system and JIT philosophies, defining the vulnerability as a *sensitivity to external or internal events, caused by lack of robustness or resilience*. According to these authors, the vulnerability could be seen as *a set of system (i.e. supply chain) characteristics that could be used to evaluate the level of exposure to risks and the severity of its impacts by measuring the system sensitivity and ability to deal with disruptive events*". They stressed through their articles the two types of vulnerability: external and internal vulnerability. Following the same line of thoughts, [13] suggests that the vulnerability is inherent in the characteristics of the supply chain and could be defined as the susceptibility to risks. Basing on the results of their analysis, the authors confirm that vulnerability is considered as a supply chain characteristic that lead to risks [26], [28]. However, the concept of SCV is not only limited to exposure to risks [10], [24], [25] but includes also supply chain sensitivity or fragility, deviation to the expected performance and estimation of risk impacts. The literature reveals the fact that this latter can encompass various key-terms and features, which are linked to supply chain risks.

The different definitions and interpretations of SCV show that it is not clear what vulnerability stands for as a scientific concept and what makes it different regarding to the risk perception.

Another issue has been revealed in the literature which is the need to understand how supply chain vulnerability is generated, how it is increased and how it is build up. Researchers tried to provide an answer to this question using different multidimensional approaches. The following paragraph gives insights into different methodologies developed in this field.

### 2.2 Methodological approaches of SCV

In order to gain deeper understanding, several attempts have been made to model and minimize supply chain vulnerability through different modeling and analysis approaches. Two research orientations could be determined : the first deals with identifying and analyzing different causing factors of SCV and the second orientation investigates methods to measure the level of vulnerability within supply chain [14], [33], [9]. Figure 1 gives an overview of different research orientations and methodological approaches developed in the literature review.

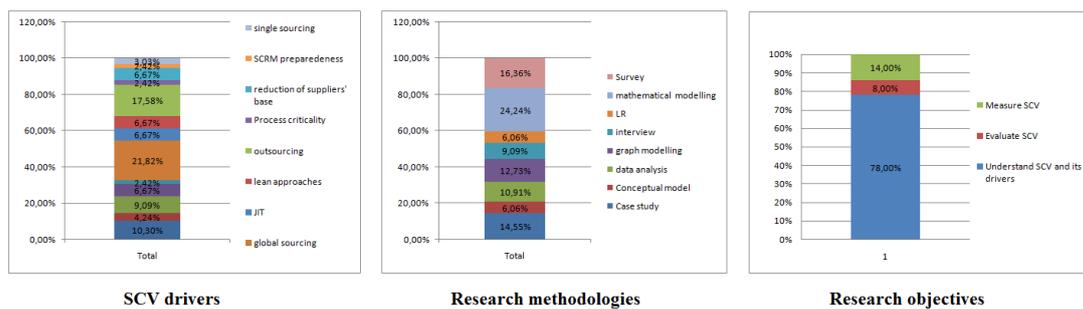


Figure 1: Supply Chain Vulnerability approaches

From Figure 1, it can be seen that the majority of frameworks have dealt with the question of defining and determining the drivers or the causing factors of supply chain (78% of articles) and only 22% of the publications have treated the question of evaluation and measure of SCV [14]. This could be justified by the fact that we cannot measure something unless we understand it and understand its factors.

Moreover, the main causing factors of supply chain vulnerability appeared to be the managerial trends applied in order to increase the performance of supply chain. Furthermore, other drivers have been mentioned in the literature review that could increase or decrease the level of supply chain vulnerability. According to [26], supply chain characteristics, such as node criticality or the design of supply chain play a major role in the variation of the vulnerability level. In the same line of research, [27] and [29] have introduced the resilience level that could decrease the level of supply chain vulnerability while presenting different possible strategies in order to mitigate supply chain risks and therefore supply chain vulnerability. Later, [9] and [33] have tried to summarize all the previous researches by developing a conceptual model called "a MISFIT model" in order to evaluate the level of vulnerability. However, this model is limited to the analysis of the downstream side of a supply chain and defines vulnerability as a type of risk.

### 2.3 Summary notes

After reviewing all these different definitions and research perspectives on SCV, a need for a holistic conceptual framework has been perceived. Many key elements have been revealed and analyzed. However, key issues related to this field (such as: the relationships among them, the links to supply chain trends, and the methodologies to manage) are poorly understood [26], [33]. Most of the reviewed researches have dealt with the key issues separately either by defining the vulnerability concept or by identifying their characteristics and components. But the causal link or relationship between them is missing.

Aiming to address this gap, section 3 proposes a new conceptual model to identify Supply Chain Vulnerability main drivers. Such a model is not just new conceptualization of vulnerability but provides continuity and integration of previous research, offering a holistic picture of Supply Chain Vulnerability to enhance a deeper understanding of this scientific area.

## 3 Proposed Model of Supply Chain Vulnerability:

Based on the statements in section 2, several research propositions with regards to the concept of Supply Chain Vulnerability are investigated in this section. The conceptual model based on existing and refined literature in order to define the vulnerability drivers is built using two steps:

1. Determining the main SCV factors: to that end, a good understanding of each factor and how it contributes to the increasing level of the SCV is required.
2. Defining the links or relationships between the set of extracting factors. The result of this step is presented in our proposed model.

The drivers or causing factors can be extracted from a deep analysis the different definitions of SCV. Thus, it is possible to reveal other conditions that play a crucial role in the evaluation of the level of vulnerability within the supply chain networks or the exposure level to risks. Despite various frameworks

developed for defining and assessing Supply Chain Vulnerability exist, it is interesting to note that some common causal factors of vulnerability have been identified [39] and listed below:

1. An exposure to serious disturbance [11], [24]
2. A set of supply chain characteristics that could either reduce the impacts of disturbance or that make the supply chain more susceptible to risks [11] [19-20], [23], [13], [26]

Accordingly, we consider SCV: "*is a function of supply chain characteristics which determine the sensitivity level and the Coping and Adaptive Capacities of supply chain, used to evaluate its exposure to risks caused by external and internal factors*".

This definition is in line with previous researches stressing that Supply Chain characteristics could increase or decrease the vulnerability level. Four key elements constitute the bottom line of this statement, which are: sensitivity, exposure, susceptibility and preparedness level. And in order to define the link and the relationships between these elements, a definition is presented for each concept:

1. Exposure: the nature and degree to which a system is exposed to significant risks (SC trends, environment' turbulence).
2. Sensitivity: the extent to which a supply chain or its components (processes, products or assets) are likely to experience risks and the magnitude of that risk. In other words, the degree to which a supply chain is affected by risks. It depends on the criticality of supply chain components that could be measure by its positioning, mission, or objective within the network [26].
3. Susceptibility: the degree to which a supply chain or its components are likely to experience losses due to an exposure to perturbations or risks. It could be evaluated in function of exposure and sensitivity.
4. Preparedness level: the set of attributes that enable the supply chain to adapt or to overcome potential disruptions. It could be linked to SC trends (to determine the possible future risks) [24], [25] and maturity level (the degree of awareness of managing supply chain risks within supply chain networks) [41].

By analyzing each key element, different conclusions could be drawn, either from the previous publications or from reports of practitioners.

- Exposure is necessary, but not sufficient to determine the level of vulnerability. It is possible to be exposed but not vulnerable [14], [9]. However it is important to understand the reasons behind an exposure to a risk. Referring to the literature review in section 2, the main factors that could influence the exposure to risk are: (1) product variants (2) outsourcing (3) lean manufacturing (4) globalization (5) single sourcing (6) decentralization (7) JIT philosophies and (8) reduction of supplier base. According to [19] and [9], these practices have been developed under specific requirements and conditions to achieve the best performance. If these conditions were not validated, these trends could turn up to be one of the vulnerability causing factors. Taking for example JIT philosophies: this approach requires a stable environment. However, Supply Chain environment is characterized by instability and turbulence, causing a high level of variability. The association of an instable environment with the use and the implementation of JIT could lead to more vulnerable supply chain networks [19].

→ *Exposure depends not only on the applied trends but also on the characteristics of their environment.*

However, researchers have demonstrated that every supply chain has different exposure degree to risk and then, different level of vulnerability [14]. So the main question is: *Why? and what makes the difference?*

By posing and seeking answers to this two-part research question, we argue that exposure to risks is not completely avoidable and, as a consequence, that all supply chains are inherently risky. However, not all firms have experienced risks within their networks. According to [1], only 74% of firms report at least 1 instance of supply chain disruption. It means that specific factors could determine if a company is susceptible to risk or conversely not. These factors represent the degree of sensitivity or fragility of the supply chain to unexpected events and could be determined through the position and/or the criticality of each node of the supply chain.

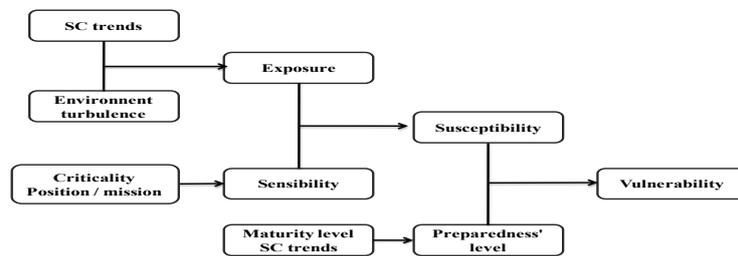
→ *The more a supply chain is sensitive to unexpected change, the more it is susceptible to disruptions.*

On the other hand, by understanding the reasons behind susceptibility and exposure to disruptions, managers are become aware of what may threaten their business and could apply different practices and strategies to protect their activities. Thus, the Supply Chain maturity level in using or implementing supply chain risk management practices could acts as a preventive way to reduce the susceptibility effect in establishing the SCV [4].

In this framework, we intend, therefore, to integrate the preparedness level of companies to risk as a fourth dimension of our model that would reduce SCV, making the following assumption:

→ *The level of preparedness to disruptions helps reduce the level of supply chain vulnerability.*

As a result, the proposed model (see Figure 2) links the four dimensions and suggests a broader understanding of Supply Chain Vulnerability. The level of this latter depends on the balance between susceptibility level and the preparedness level (see Figure 2).



**Figure 2:** Conceptual model of Supply Chain Vulnerability

Different levels of Supply Chain Vulnerability could be defined by evaluating each dimension presented in Figure 2. Moreover, in order to compare the vulnerability level resulting from the different possible combination scenarios of these dimensions, it is necessary to normalize the evaluation of each factor which could be done using either quantitative or qualitative approaches.

Our conceptual model can be used and depicted through the following steps :

1. Determine the degree of exposure
  - a) Identify the mains SC trends applied
  - b) Describe the environmental condition:
    - If the environment is turbulent, SC trends are considered as vulnerability drivers. Go to step 2.
    - Else, SC trends are not considered as vulnerability drivers.
2. Identify the susceptibility level of the SC:
  - a) If the SC is exposed and at the same time it is sensitive to disruption, the level of susceptibility to disruption will be high. (Go to step 3.)
  - b) Else, the level of susceptibility will be low
3. Evaluate the preparedness level through maturity assessment
4. Determine the level of supply chain vulnerability by a comparison of the level of preparedness with the level of susceptibility.

## 4 Case Studies

In order to test the applicability of our proposition and to evaluate the level of Supply Chain Vulnerability, three case studies are extracted from the literature. They are Nokia and Ericsson (2000) [20], Land Rover (2002)[10] and Toyota (2015), which are three of the major firms in their activity sectors.

**Table 1:** A brief overview of the three case studies

	Nokia and Ericsson (2000)	Land Rover (2002) [10]	Toyota (2015)
<b>Activity Sector</b>	Telecommunications	Car manufacturing	Car manufacturing
<b>Disruptive events</b>	Fire at supplier's plant	Supplier bankruptcy	Quality defect of "Airbag" component
<b>SC trends applied</b>	Single sourcing	Reduction of suppliers' base to single sourcing	Single sourcing + Lean manufacturing
<b>Type of risk</b>	Supplier risk	Supplier Risk	Supplier risk
<b>Impacts</b>	\$1.7 billion of annual loss for Ericsson	35 million pounds loses and the release of 1400 workers	Recall of 6.5 million cars

Despite the differences in terms of industry and company size, the three companies adopt the same supply chain practice which is single sourcing with the addition of lean manufacturing for Toyota. These trends are considered in the literature review as one of the main causing factors of an increase in the

vulnerability level. In the case of Nokia and Ericsson, the main reason for their exposure to risk is a fire which has destroyed the plant of their main single suppliers. For both Nokia and Ericsson, this has caused a production interruption for several weeks and important losses particularly for Ericsson. Despite of this, Nokia Market Shares have increased after this incident, making it the leading company in the field of telecommunication. For Land Rover, the company actively reduced its base of suppliers. Until 2000, the company has decided to keep one supplier of the chassis frame "UPF- Thompson" for its best selling model. Unfortunately, UPF lost money on others ventures into foreign markets and went bankrupt at the end of 2001. This incident has put into question the Land Rover survival in the market. Nine months is the period that Land Rover has taken to find a sustainable supplier instead of UPF. This incident has caused financial losses and the dismissal of 1400 workers.

Affected by the same type of risk, Toyota, in 2015, recalled more than 6.5 million of cars all over the world due to a defective airbag produced by one of its sole supplier. This quality issue could have threatened the life of car users. This is why Toyota has decided to voluntarily recall all its products from the market. The question raised here is: why the three companies have different level of risk impacts, although they face the same type of risk and they adopt the same SC practices? In other words, why these three companies have different level of vulnerability?

In order to determine the answer, Table 2 presents the results of application of our proposition on the three case studies. Unfortunately, the analysis of the three case studies is very restricted due to a limited amount of data related to these cases. Thus, each vulnerability factor has been positioned using a definite set {low; moderate; high; very high and critical}. Even if such an assumption disables the opportunity to establish quantitative calculations leading to a final note for the vulnerability of each case, our model allows us to understand the vulnerability causing factors and the reasons of its distinctive level across the three companies.

Despite the differences in terms of industry and company size, the three companies share some fundamental commonalities regarding their business model and supply chain strategies which single sourcing and lean manufacturing and faced the same type of risk which is supplier risk due to different raison for each company, causing severe impacts. Table 1 presents a summary of the three case studies.

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**Table 2:** The results of application model on the three case studies

	Nokia and Ericsson (2000)	Land Rover (2002) [10]	Toyota (2015)
<b>SC trends applied</b>	Single sourcing	Reduction of suppliers' base to single sourcing	Single sourcing + Lean manufacturing
<b>Turbulence degree</b>	High	High	High
<b>Exposure</b>	High	High	Very high
<b>Sensitivity</b>	High	High	Critical
<b>Susceptibility</b>	High	High	Critical
<b>Coping/adaptive capabilities</b>	For Nokia: High For Ericsson: Low	High	High
<b>Vulnerability level</b>	For Nokia: Moderate For Ericsson: High	High	Critical

The three cases developed herein have several levels of vulnerability. The difference between Nokia and Ericsson facing the same supplier problem can be found regarding their preparedness level. This led to a global impact more negative for Ericsson than for Nokia which has not been anticipated. Moreover, for Land Rover and for Toyota, the SC trends played a significant role in the vulnerability level.

## 5 Conclusion

The field of supply chain risk management is relatively nascent and the vulnerability concept is more recent. This explains the scarceness of scientific publications related to this field. The results of reviewing

the literature underline the need for more theoretical framework to understand the concept of Supply Chain Vulnerability. Most of previous research frameworks have dealt with defining the concept, determining its drivers and measurement options. However, one of the gaps revealed in the state of the art of Supply Chain Vulnerability is the missing link or conceptualization of its different constructs and their relationships.

It is extremely important for any theory development to build the knowledge related to this field by gaining a deeper understanding of the interdisciplinary phenomenon of vulnerability. This is why we conduct this research trying to understand what is Supply Chain Vulnerability? What are its causing factors? And what is the link to supply chain practices? The answers to these questions are presented in our proposed conceptual model of Supply Chain Vulnerability.

This article has firstly identified the main SC trends as Vulnerability drivers. These trends, which are recognized as drivers of supply chain performance, are also exposing the supply chain to new risks. Therefore, the conceptual model developed in this article describes the link between this statement and the vulnerability.

In order to demonstrate the applicability of such a model, a case study based on 3 supply chain major disruptions intends to show that it is necessary to properly balance vulnerability factors with practices increasing the adaptive capabilities of the supply chain.

The main perspective of this article is to develop an ability to deal with measures of each factor evocated in the model in order to find more precise information about past supply chain crisis.

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