Università Politecnica delle Marche

Scuola di Dottorato di Ricerca in Scienze dell'Ingegneria

Corso di Dottorato in Ingegneria Industriale

The Ripple Effect within Supply Chain Resilience: a sectoral and modular study

Ph.D. Dissertation of:

Giulio Marcucci

Supervisor:

Prof. Maurizio Bevilacqua

Assistant Supervisor:

Prof. Filippo Emanuele Ciarapica

Ph.D. Course coordinator:

Prof. F. Mandorli

XVII edition - new series

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Dipartimento di Ingegneria Industriale e Scienze Matematiche

Via Brecce Bianche — 60131 - Ancona, Italy

Acknowledgements

To Mom
She asked me, "Son, when I grow old
Will you buy me a house of gold?
And when your father turns to stone
Will you take care of me?"

To Dad
There goes my hero
Watch him as he goes
There goes my hero
He's ordinary

To Me
And you may find yourself
Living in a shotgun shack
And you may find yourself
In another part of the world
And you may find yourself
Behind the wheel of a large automobile
And you may find yourself in a beautiful house
With a beautiful wife
And you may ask yourself, well
How did I get here?

To Everyone Else
Oh, if the trip and the plan come apart in your hand
You can turn it on yourself, you ridiculous clown
You forgot what you meant when you read what you said
And you always knew you were tired, but then where are your friends tonight?

Abstract

This research work aims to contribute to the academic study of Supply Chain Resilience, through the study of the causal relationships between the various factors that influence the Resilience of a Supply Chain. These causal connections, in fact, can create a ripple effect: a disturbance, instead of remaining localized or contained in a single player of the Supply Chain, can propagate downstream or upstream, influencing the performance of the entire Supply Chain. Such an impact could include, for example, lower revenues, delays in deliveries, loss of market share and reputation.

The proposed study offers a modular approach: these connections are studied through the Fuzzy Cognitive Maps, and this methodology is applied to different case studies: first in the household appliances sector, and second in the fashion sector.

Finally, the Supply Chain Resilience Triangle is shown: a simple and intuitive tool to measure the performance of a Supply Chain during a disturbance, in each of its different phases.

Abstract

Questo lavoro di ricerca ha lo scopo di contribuire allo studio accademico della Supply Chain Resilience, attraverso lo studio delle relazioni causali che accorrono tra i vari fattori che influenzano la Resilienza di una data Supply Chain. Queste connessioni causali, infatti, possono creare un effetto domino: un disturbo, invece di rimanere localizzato in un singolo attore della Supply Chain, può propagarsi a valle o a monte, influenzando le prestazioni dell'intera Supply Chain. Tale impatto potrebbe includere, ad esempio, minori entrate, ritardi nelle consegne, perdita di quote di mercato e di reputazione.

Lo studio proposto offre un approccio modulare: attraverso le Fuzzy Cognitive Maps, verranno infatti studiate queste connessioni, e saranno applicate a casi studio differenti: uno riguardo il settore degli elettrodomestici, e uno nel settore della moda.

Infine, verrà illustrato il Supply Chain Resilience Triangle: uno strumento semplice e intuitivo per misurare le prestazioni di una Supply Chain durante una perturbazione, in ognuna delle sue diverse fasi.

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1 Introduction

This PhD dissertation aims to extend the current study on Supply Chain Resilience (SCR), a subject that has been studied in the scientific literature since the beginning of the new millennium. Some crucial episodes, both from an industrial and an economic point of view, have in fact guided the scientific community into the re-thinking of some doctrines.

One of these episodes has been the attack at the Twin Towers on 2011 September 11th, an event which caused a dramatic death toll of 2974 people, and, in addition, triggered a series of events that caused short and medium-term influences in the economic, financial and industrial worlds, as confirmed by the report for the American congress written by Gail Makinen (2002).

Additionally, according to Ernst and Young estimates (2002), the attacks resulted in a $13 billion loss of destroyed private equity and government bonds, along with an estimated $35 to $50 billion loss of insured losses and extreme equity market volatility that wiped out $1.2 trillion of equities in the first week after trading resumed. These figures are just a few examples of the macroeconomic consequences that could be observed in the short term.

Some case studies also exemplify the consequences that this event has had at a widespread level. For example, due to the immediate closure by the

United States of its borders and all incoming and outgoing flights, there was an immediate impact on many Supply Chains (SCs). Ford Motor Co. had to run several assembly lines intermittently empty, as trucks loaded with components were delayed arriving from Canada and Mexico: Ford's fourth quarter 2001 production decreased by 13% compared to its production plan. Toyota suffered similar consequences too, since the production stopped at its Indiana plant, as it was waiting for steering sensors that usually came by air from Germany. (Yossi Sheffi and James B. Rice Jr., 2005).

Another emblematic episode happened right at the beginning of the new millennium has been the "fire that changed an industry" (Mukherjee, 2008): on March 17, 2000, a lightning bolt struck a semi-conductor manufacturing plant in New Mexico, U.S., owned by Philips. This plant was one of the primary suppliers of, simultaneously, Ericsson and Nokia. Both companies were informed of the plant's disruption and both were notified that production would resume regularly in a week.

The behaviour of both companies in the following days would irreparably affect their future.

The Nokia executives, in fact, immediately checked if the damage could be solved in a week: once they knew the opposite, that the damage would be solved in more than a month and that this would have delayed the production of millions of mobile phones, they implemented three key actions:

- A team of executives and engineers focused on Philips, looking in the development of alternative plans and putting pressure on Nokia's case with Philips executives. Philips responded by reorganizing its plans in their Eindhoven and Shanghai factories;
- A second intercontinental team redesigned some chips so that they could be produced in other Philips facilities and not Philips. Where appropriate, they consulted with Philips to assess the possible impact of their actions;
- A third group worked to find alternative manufacturers to reduce the pressure on Philips. Two current suppliers responded within five days.

On the other hand, Ericsson's executives began to take action more than a month after the incident, when the damage was now unrecoverable.

Then, on July 20, 2000, Ericsson reported that the fire and component shortages had caused a second-quarter operating loss of $200 million in its mobile phone division. As such, annual earnings would be lower by between $333 million and $445 million. While Nokia's initial sensing of the problem and its rapid and effective response carried the day: in the third quarter of 2000, its profits rose 42% as it expanded its share of the global market to 30%.

The face of the mobile phone industry had changed forever, all because of a fire that had been contained in ten minutes.

These events have guided the evolution of the study of risk, in parallel, under two aspects, which will be explained separately in the following paragraphs.

1.1 From Risk Management to Resilience

The first aspect is mainly concerned with the evolution of the concept of risk study itself. According to, in fact, the definitions reported by ISO 31000 (International Organization for Standardization, 2018, p. 31000), "Risk management" refers to "a coordinated set of activities and methods that is used to direct an organization and to control the many risks that can affect its ability to achieve objectives". The term risk management also refers to the programme that is used to manage risk. This programme includes risk management principles, a risk management framework, and a risk management process.

In particular, according to ISO 31000, a risk management process systematically applies management policies, procedures, and practices to a set of activities intended to establish the context, communicate and consult with stakeholders, and identify, analyse, evaluate, treat, monitor, record, report, and review risk.

A typical view of the traditional risk management process is shown in Figure 1.1, depicting a continuous cycle of hazard identification, risk

assessment, control analysis, choice of controls, implementation of controls and review (Manuele, 2005; Pettit et al., 2010).

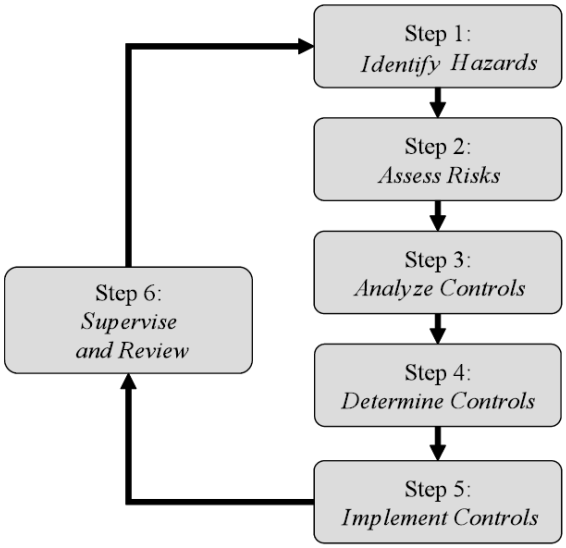

Figure 1.1: Classic Risk Management Framework (Manuele, 2005; Pettit et al., 2010)

By focusing the analysis on step 2, it can be said that risk assessment is the formal process of calculating the risk of an event and making a decision on how to react to that risk. This risk assessment process is a useful technique to conduct a probabilistic risk assessment, which uses many techniques to identify and analyse risks to the system. These risks are quantified, and their consequences determined. Then the risk is assessed, and, on the basis of this information, the risk manager is able to decide whether it is justifiable to accept the risk.

The first step of the risk assessment methodology is to define the objectives of the assessment: in defining the assessment objectives, the objective, the scope, and the states of damage that are of interest should be clearly indicated.

In both research and industrial management environments, however, it has been realised that this classic risk management approach is often insufficient. The classic approach, in fact, sees risk assessment as a fundamental step: it is therefore flawed if, in some cases, the risk is not predictable and subsequently not assessable.

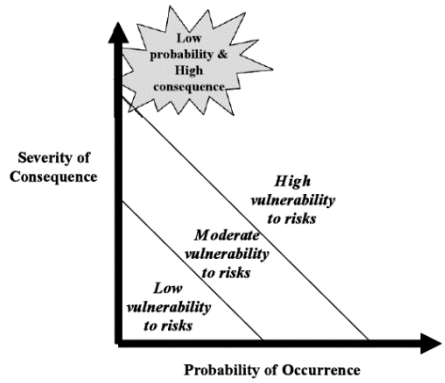

Figure 1.2: Traditional Risk Assessment (Manuele, 2005; Pettit et al., 2010)

The greatest weakness of risk management is its inability to adequately characterize low-probability, high-consequence (LP/HC) events (see Figure 1.2).

Consequently, the concept of Resilience has made its way into the research and general approach to the issue, understood as a complementary and innovative step to the classic approach of risk management in order to

adapt the methodology to the needs of modern businesses. For companies, it is crucial to show flexibility and ability to react positively and proactively to the changes that the market imposes, such as the different needs of consumers, the intrinsic competitiveness of the market itself, and all the disruptions that can happen and change the normal performance of the company.

Through this resilient approach, it is possible to go beyond traditional risk management, by learning to overcome challenges and taking advantage of the opportunities with a strong-willed attitude, by reshaping the management standard and by taking care, in this perspective, of staff training in order to create a collaborative environment in respect of the efficiency and production vocation of the company.

1.2 Organizational or Supply Chain Resilience?

The second aspect to research, which emerged from the case studies that have taken place over the recent years, consists in the fact that studying organizational resilience, or resilience limited to a single actor in the SC, is often not enough. While business architecture in fact has changed, the business environment has also evolved, increasing the risk connected to SC disruptions, as many authors suggest (Urciuoli 2010; Pettit, Fiksel, and Croxton 2010).

In fact, the need to guarantee competitiveness in a global market has led many SCs to expand geographically and consequently SC structures have been facing an increased exposure to a larger set of uncertainties (Ribeiro and Barbosa-Póvoa 2018).

This is because, due to this evolution of the economic and industrial world, the degree and number of connections between operating companies automatically increases: this evolution causes then the intensification of some trends. For example, is safe to assume that a low level of connectivity within a system can only cause a gradual change in the network as a whole, rather than a sudden response to a small change. This is due to the fact that the actors of this system are relatively isolated. However, as conditions change, highly connected systems can reach a tipping point where a local disturbance can cause a ripple effect on the total, or on a part, of the system (Scheffer et al., 2012). This phenomenon has led the world of research to carry out a very significant number of studies on the disturbances and their repercussions on the performance of the whole SC, thus placing greater emphasis on the so-called ripple effect (Dolgui et al., 2018; Ivanov, 2018; Liberatore et al., 2012).

The ripple effect in fact occurs when a disturbance, instead of remaining localized or contained in a part by a single player of the SC, falls downstream and affects the performance of the entire SC.

1.3 Research Question

The purpose of the present dissertation is to further study how different factors influence SCR and how the same factors influence themselves: In order to do so, the thesis is organized as follows:

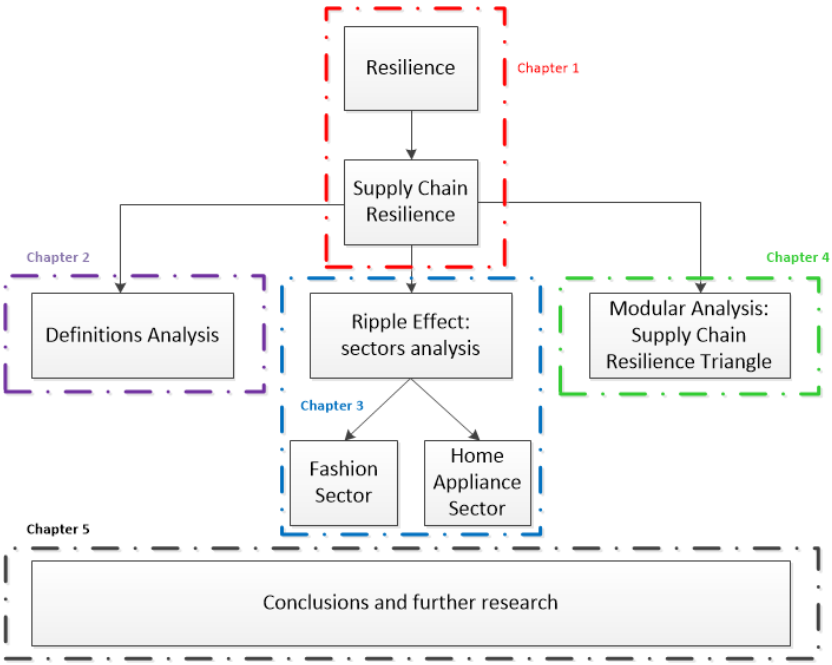

Figure 1.3: PhD Dissertation Research Structure

The first chapter introduces the concept of SCR. The second chapter examines in more detail the many facets of the concept, in order to lay out the basis of the overall study.

The third chapter exemplifies SCR sectoral study, in relation to the Ripple Effect, with the application of the FCM methodology, which is introduced in the same chapter. Subsequently, the occurrences of the different factors cited in the SCR literature are shown and FCM are used to show the

connections among these factors and SCR. This approach can unveil the connections among the various factors that influence SCR, and the factors themselves. The key added value offered by this approach is the analysis of the causal relationships through which decision makers can examine step by step the ripple effect that from a trigger event "A", exogenous or endogenous to the SC, can consequentially bring an undesirable event "D", through intermediate events (for instance "B" and "C" in figure 1.4). The knowing of this events chain can help make targeted measures in order to prevent the happening of the event "D". Sometimes, in fact, if events "A", "B" or "C" do not happen the final event "D" cannot begin at all, and therefore its negative consequences cannot take place.

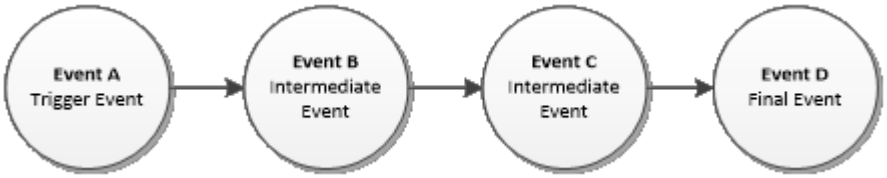

Figure 1.4: Events Chain

The fourth chapter exemplifies the Supply Chain Resilience Triangle, a tool to quantify SCR in an intuitive and figurative way. This tool can support the research, by differentiating how one factor can influence SCR, e.g. is a factor influencing, positively or negatively, the recovery phase or the mitigation phase?

Finally, the last chapter shows the conclusions and possible further research.

2 From Resilience to Supply Chain Resilience: concept evolution

The word “resilience” has its roots in the latin word “resiliens”, present participle of resilire "to rebound, recoil," from re- "back" (see re-) + salire "to jump, leap and nowadays, according to the “Oxford Advanced Learners Dictionary”, “resilience” is the ability of a substance to return to its original shape after it has been bent, stretched or pressed.

Many research fields borrowed then the term “resilience”, in fact this concept is multidimensional and multidisciplinary, since it has been the subject of scientific research for many years in disciplines e.g. psychology and ecosystems.

In ecology, Holling proposed systems to have two distinct properties: resilience and stability. He associated in fact “resilience” to the ability of systems to absorb changes, opposed to “stability” as the ability of the latter systems to return to a state of equilibrium after a temporary disorder (Holling, 1973).

From a social point of view, Timmerman (1981) was one of the first to define the resilience as “the measure of a system’s, or part of a system’s capacity to absorb and recover from the occurrence of a hazardous event”.

This definition has been then evolving: the United Nations Office for Disaster Risk Reduction, for example, provided a more complete definition i.e. “the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure” (*Living with risk*, 2004).

In order to exemplify the importance of resilience in modern society, a parallelism can be created, for example, between a company and a human being needs: the needs of an individual and the order of the priority with which they are met are listed in the "Maslow Pyramid", which is shown in Figure 2.1. As it can be seen, every individual first satisfies those who are his or her physiological needs, i.e. those necessary for its survival (such as breathing, eating, sleep), and only after having satisfied those, the same individual care to satisfy next level needs: those concerning its security, and progressively, those of membership, estimate and self-realization. Each level of the pyramid is taken into consideration and satisfied only when it is the one

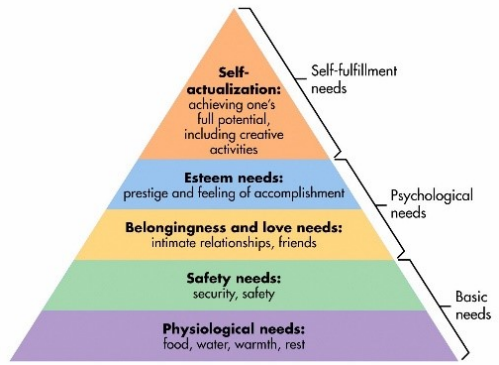

Figure 2.1: Maslow pyramid of needs

that precedes it. This because needs do not have the same degree of importance. Some aspects, compared to others, have greater priority to be taken into account.

Even if a business company is a more complex system then a human being, since it consists of multiple processes and activities, the same dynamic characterizes it: processes and activities have not all the same priority. That's why, as well as to a human being, a pyramid of needs can be applied to business: in this pyramid, resilience should occupy the level dedicated to safety. Therefore, it holds a position of some importance, and essential to the survival of a business, which justifies the attention that should be given to its study and its development.

During the last decades, the resilience concept was then adopted by SC specialists researcher in order to outline the new performance requirement of companies, as players of a SC. Given the evolution of modern business society in fact, the characteristic of resilience has become a very important competitive factor (Annarelli and Nonino, 2016; Ponomarov and Holcomb, 2009).

Tukamuhabwa et al. (2015), in their work, summarized the most important SCR definitions developed so far. Among these definitions, the most concise reads as follows: "The ability of a system to return to its original

state or move to a new, more desirable state after being disturbed" (Christopher and Peck, 2004).

2.1 SCR Resilience definition literature review

In order to best conduct this research, a literature review on the various SCR definition has been conducted. The concept of SCR has in fact emerged several times in literature.

A number of 25 definitions have been found (see Table 2.1), supporting the hypothesis that there is a lack of consensus among the scientific community regarding the definition of SCR (Spiegler et al., 2012; Mensah and Merkuryev, 2014).

Ponomarov and Holcomb (2009) define SCR as the SC adaptation capability to prepare for unexpected events, respond to interruptions, and recover from them to maintain continuity of operations at the desired level of connection and control over the structure and function. Ponomarov and Holcomb also state that SC managers strive to reach the fully integrated, efficient and effective SC ideals that can create and sustain a competitive edge. To this end, they must balance the downward pressure on costs and the need for efficiency, with effective means, all to handle market demands and the risks of bankruptcy in the SC.

According to Ponis and Koronis (Ponis and Koronis, 2012), SCR is the ability to plan and design the SC network in order to anticipate disruptive and unexpectedly negative events, proactively respond in an adaptive manner to interruptions, maintain control over structure and function and arrive at a robust final state of operation, if possible, more favorable than before interruption, thus gaining a competitive edge.

Arguably, the latter two definitions are the most complete: these two definitions incorporate in fact the most features, including adaptation, preparation, response, connection, and control capabilities, as well as timely recovery to return to the original state or, preferably, to a better state.

An additional point of view is offered by Wieland and Wallenburg (2013), which claim that a SC can be resilient if its conditions remain stable at the original state or if a new stable situation is obtained. Resilience is therefore understood as the ability of a SC to cope with change. In Wieland and Wallenburg's paper, compared to other authors, relationship skills are more thoroughly analyzed. If companies build collaborative relationships with other members of the SC, in order to gain a competitive advantage, these relationships can be exploited to improve SCR. Consequently, relational vision is applied, which results in three types of relational skills, namely communication, cooperation and integration that facilitate the resilience of a

SC. The two authors distinguish proactive and reactive strategies to achieve resilience, which can be referred to as robustness and agility, respectively.

Carvalho et al. (2011) in one of their works offer a study of SCR, defining it as the system's ability to return to its original state or to a new more desirable one after experiencing a disturbance and avoiding occurrence of failure modes. The goal of SC resilience analysis and management is to prevent the shifting to undesirable states, i.e., the ones where failure modes could occur.

#	Source	Definitions
1	Carvalho et al. (Carvalho et al., 2012)	To survive, organizations and their supply chains must be resilient: they must develop the ability to react to an unforeseen disturbance and to return quickly to their original state or move to a new, more advantageous one after suffering the disturbance
2	Brandon-Jones et al. (Brandon-Jones et al., 2014)	SCR is defined as the ability of a system to return to its original state, within an acceptable period of time, after being disturbed.
3	Carvalho et al. (Carvalho et al., 2011)	SCR is concerned with the system's ability to return to its original state or to a new more desirable one after experiencing a disturbance and avoiding occurrence of failure modes. The goal of supply chain resilience analysis and management is to prevent the shifting to undesirable states, i.e., the ones where failure modes could occur.
4	Christopher and Peck (Christopher and Peck, Helen, 2004)	The ability of a system to return to its original state or move to a new, more desirable state after being disturbed.
5	Closs and McGarrell (Closs and McGarrell, 2004)	SCR refers to the supply chain's ability to withstand and recover from an incident. A resilient supply chain is proactive – anticipating and establishing planned steps to prevent and respond to incidents. Such supply chains quickly rebuild or re-establish alternative means of operations when the subject of an incident.
6	Datta (Datta, 2007)	SCR is not only the ability to maintain control over performance variability in the face of disturbance but also a property of being adaptive and capable of sustained response to sudden and significant shifts in the environment in the form of uncertain demands.
7	Datta et al. (Datta et al., 2007)	Resilience of the supply network is the ability of the production–distribution system to meet each customer demand for each product on time and to quantity.
8	Erol et al. (Erol et al., 2010)	Resilience is a response to unexpected or unforeseen changes and disturbances, and an ability to adapt and respond to such changes.
9	Falasca et al. (Falasca et al., 2008)	Resilience is defined as the ability of a supply chain to reduce the probabilities of a disruption, to reduce the consequences of those disruptions when they occur and to reduce the time to recover normal performance.
10	Gaonkar and Viswanadham (Gaonkar and Viswanadham, 2007)	SCR is the supply chain with the ability to maintain, resume and restore operations after a disruption.
11	Guoping and Xinqiu (Guoping and Xinqiu, 2010)	SCR is the ability of the supply chain to return to its original or ideal status under emergency risk environment.
12	Longo and Oren (Longo, F. and T. Oren, 2008)	Resilience is a critical property that, in a context of supply chain change management, allows the supply chain to react to internal/external risks and vulnerabilities, quickly recovering an equilibrium state capable of guaranteeing high performance and efficiency levels.

13	Ponis and Koronis (Ponis and Koronis, 2012)	SCR is the ability to proactively plan and design the supply chain network for anticipating unexpected disruptive (negative events), respond adaptively to disruptions while maintaining control over structure and function and transcending to a post robust state of operations, if possible a more favourable one than that prior to the event, thus gaining a competitive advantage.
14	Ponomarov and Holcomb (Ponomarov and Holcomb, 2009)	The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function.
15	Sheffi (Yossi Sheffi and James B. Rice Jr., 2005)	Reducing vulnerability means reducing the likelihood of a disruption and increasing resilience - the ability to bounce back from a disruption. Resilience, in turn, can be achieved by either creating redundancy or increasing flexibility.
16	Shuai et al. (Shuai et al., 2011)	Resilience as the rapidly recovery ability to equilibrium after the supply chain is attacked by a disturbance and we use the recovery time to measure the ability.
17	Xiao (Xiao et al., 2012)	SCR can be defined as the supply chain's ability of returning to the original or ideal status when this supply chain system has been disturbed by external interruption, and resilient supply chain shows that this supply chain has the two abilities on adaptability to environment and recovering ability of the system.
18	Yao and Meurier (Yao and Meurier, 2012)	Supply resilience is defined as the ability to bounce back from disruptions and to permanently deal with and respond to the changing environment.
19	Ambulkar et al. (Ambulkar et al., 2015)	Firm's resilience to supply chain disruptions is defined as the capability of the firm to be alert to, adapt to, and quickly respondto changes brought by a supply chain disruption.
20	Hohenstein et al. (Hohenstein et al., 2015)	SCR as the ability to avoid/reduce the probability of disruptions and to respond and recover quickly.
21	Purvis et al. (Purvis et al., 2016)	Supply chain resilience increases a firm's readiness in dealing with risks that can emerge from the customers' side, the suppliers' side, the internal processes adopted and the supply chain integration mechanisms employed.
22	Wieland, A. and Wallenburg, C.M. (Wieland and Marcus Wallenburg, 2013)	A supply chain can be resilient if its original stable situation is sustained or if a new stable situation is achieved. The resilience is understood as the ability of a supply chain to cope with change.
23	Blackhurst et al. (Blackhurst et al., 2011)	A firm's resiliency enhancers are defined as: attributes that increase a firm's ability to quickly and efficiently recover from a disruptive event.
24	Scholten, K., Schilder, S. (Scholten and Schilder, 2015)	As the frequency and impact of supply chain disruptions remain stubbornly high, resilient supply chains that are able to absorb such shocks via visibility, velocity, flexibility and collaboration.
25	Stevenson, M., and Busby, J. (Stevenson and Busby, 2015)	SCR is the ability to build resilience to natural disasters, terrorist attacks and other fundamental threats to the supply chain, it is the ability to cope, recover or maintain continuity in the face of vulnerability or interruption of operations.

Table 2.1 SCR Definitions

3 Sector Analysis

This chapter exemplify the two case studies addressed during this analysis, and the methodological approach this research is based upon.

3.1 Literature Review

Different empirical studies have been conducted to analyze the perspectives of SCR, along with SC Robustness and Business Continuity theories. Kim et al. (2015) summarized the most relevant research about Supply Network resilience and disruption, outlining existing definitions, measures and the subject level of analysis. Christopher and Peck (2004) offered a conceptual model to classify some sources of SC risks and suggest how to overcome those risks. Craighead et al. (2007) employed structured interviews and critical incident techniques to understand why disruption severity varies among SCs. Wu et al. (2007) utilized a modeling approach to understand the propagation of disruptions across SC systems.

Furthermore, many qualitative and quantitative studies were conducted to examine SCR and its characteristics. Carvalho et al. (2011), for example, conducted a study exploring the connections between four important factors with an important role in SC: lean, agile, resilient and green paradigms. Ponis and Koronis (2012), after contextualizing resilience within

the context of the SC, studied when SC capabilities could decrease the presence of interruptions and how these abilities affect SCR. Datta et al. (2007) developed an agent-based computational framework, in order to improve operational resilience into a worldwide SC, providing a case study example. Wieland and Marcus Wallenburg (2013), in their work, explored the SCR concept, analysing the connection between relational competencies and SCR and the effect of the latter to the SC final costumer. An interesting aspect of this research was the conceptual division between the proactive and reactive dimension of resilience.

This analysis of literature, as Rajesh and Ravi state (2015), reveals that most of the works in SC risk management and risk mitigation strategies are rather qualitative or empirical. Rajesh and Ravi (2015) tried to quantify the enablers for SC risk mitigation, in order to find the causal relationships among them. In their research, they have identified fifteen enablers of SC risk mitigation, and have then used the Grey–DEMATEL methodology to find the causal relationships among them. This framework did not provide a validation-second-step of the fifteen enablers: the research was conducted only by finding those enablers in various works.

Pettit, Fiksel, and Croxton (2010) presented a similar framework, but they used a two-step method to create resilience factor taxonomies, by

performing an extant literature analysis and then refining and validating such analysis through a panel of experts.

Many studies highlight factors that influence SCR by conducting interviews to panels of experts and/or operators of the SC itself (Bueno-Solano and Cedillo-Campos, 2014; Colicchia et al., 2010; Pettit et al., 2010). These authors connected SCR to capabilities and vulnerabilities highlighting that SCR is reached not only through the SC's capabilities, but mainly by finding a balance between capabilities and vulnerabilities.

Literature is abundant in terms of connections between these factors and SCR. For example, Brusset and Teller (2017) tested a conceptual model that proposes a relationship between SC capabilities and resilience through variance-based structural equation modelling. Chowdhury and Quaddus (2016), after an extensive literature review, explore and validate the antecedents of SCR through quantitative and qualitative analysis.

What literature lacks are the links between those factors. For example, many researchers point out the connection between Just in Time (JIT) practices and SCR, and many others point out the unfortunate economic environment as an inhibitor of SCR; but does the economic environment influence the application of JIT practices and therefore SCR through these relationships? In this paper, we aim at filling the gap between those factors,

interleaving the causal relationship between them by developing a resilience analysis based on FCMs, which are shown in the next section.

3.2 Materials and Methods

3.2.1 Fuzzy Cognitive Maps

Medicine (Froelich et al. 2012), neurocomputing (Papageorgiou and Poczęta 2017), social economics (Roban and Secme, 2005), and agriculture (Papageorgiou et al. 2013) are only some of the fields of studies in which FCMs have been used as predictive instruments.

FCMs provide a graphical model of the behavior of a dynamic system through a graph representation. In the graph, concepts are represented as nodes and the associations between the concepts are represented as weighted edges. The nodes are connected by signed and weighted edges representing the causal relationships that exist among concepts. Concepts that represent the cause or the means to achieve a given goal are situated at the arrow's tail and concepts that represent the effect or the end are situated at the arrow's head. The structure of an FCM is shown in Figure 3.1: C_i is a concept with a state value and the weight e_{ij} of an arrow indicates the influence degree from the cause concept C_i to effect concept C_j; e_{ij} can assume a fuzzy value within [−1, 1]. The FCM shown in Figure 3.1 can be also represented by the adjacency matrix reported in Figure 3.2.

The FCM construction, the identification of concepts and their influence degree, requires the input of human experience and knowledge on the system under analysis through semi-structured interviews (Eden 1988; Laukkanen 1998) or the input from documents and historical data (Azelrod, 1976).

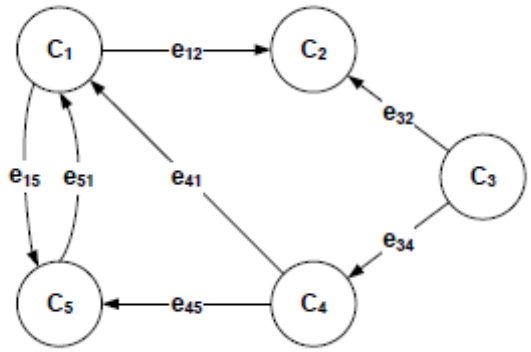

Figure 3.1: The structure of a FCM

	C_1	C_2	C_3	C_4	C_5
C_1	0	e_{12}	0	0	e_{15}
C_2	0	0	0	0	0
C_3	0	e_{32}	0	e_{34}	0
C_4	e_{41}	0	0	0	e_{45}
C_5	e_{51}	0	0	0	0

Figure 3.2: Adjacency matrix

The interconnections between concepts are defined according to expert opinion and they are evaluated through linguistic values. In this work, all the proposed linguistic values for the same interconnection, are aggregated

using the SUM method (Fang, 2006) and an overall linguistic weight is produced. With the use of the defuzzification method of the centre of gravity - COG (Lin and Lee, 1996) the overall linguistic weight is transformed to a numerical weight. The negative, the null and the positive e_{ij} values represent the three possible types of causal relationships between concepts;

- $e_{ij}=0$ indicates no causality relationship between concepts C_i and C_j;
- $e_{ij}>0$ indicates positive causality between concepts C_i and C_j: an increase/decrease in the value of C_i leads to an increase/decrease in the value of C_j;
- $e_{ij}<0$ indicates negative causality between concepts C_i and C_j: an increase/decrease in the value of C_i leads to a decrease/increase in the value of C_j.

In order to allow an in-depth analysis of the map, FCM provide the study of two indexes, such as the indirect effect and total effect.

The indirect effect is defined now by the operation:

$$I_k(C_i, C_j) = \min\{e(C_p, C_{p+1})\} \quad (3.1)$$

The symbol (C_p, C_{p+1}) indicates the path (or paths) between concepts C_p and C_{p+1}. In fact, it is necessary to identify a concept concatenation as a chain of concepts, where the weight $e(C_i, C_j)$ represents the “strength” of each connection of this chain.

The equation (3.1) can be explained with the metaphor “a chain is only as strong as its weakest link”. If in the chain a weak connection exists, it is not possible to consider the chain as a "resistant chain", but the total “strength” of the chain is quantified with the “strength” of the weak connection (Bevilacqua et al., 2012).

When there is more than a concatenation among the cause node and the effect node, it is useful to define the total effect TE(x,y). According to Axelrod (2015), causal variable C_i's total effect on effect variable C_j is the aggregate sum of all the paths’ indirect effects from each causal variable associated with each effect variable, as shown in Equation (3.2).

$$\mathrm{TE}(\mathrm{C_i}, \mathrm{C_j}) = \max\{\mathrm{I_k}(\mathrm{C_i}, \mathrm{C_j})\} \quad (3.2)$$

$\mathrm{I_k}(\mathrm{C_i}, \mathrm{C_j})$ and $\mathrm{TE}(\mathrm{C_i}, \mathrm{C_j})$ have to be interpreted according to the fuzzy mathematics and $\mathrm{e}(\mathrm{C_p}, \mathrm{C_{p+1}})$ with the relationship weight expressed using fuzzy values. Indeed, according to Kosko (1986), $\mathrm{I_k}(\mathrm{C_i}, \mathrm{C_j})$ and $\mathrm{TE}(\mathrm{C_i}, \mathrm{C_j})$ can be identified with t-norm (triangular-norm) and t-conorm (triangular conorm). Alsina et al. (1983) introduced the t-norm and the t-conorm into fuzzy set theory and suggested that the t-norm and the t-conorm be used for the intersection and union of fuzzy sets. Consider for instance, the connections between concepts C_1 and C_5 as reported below:

$$I_1(C_1, C_5) = \min\{e_{13}, e_{35}\} = \min\{much, lot\} = much$$

$$I_2(C_1, C_5) = some$$

$$I_3(C_1, C_5) = some$$

The presence of three different paths connecting the same nodes (C_1 and C_5) implies that the concept C_1 can affect in several ways the final node (C_5) with different effects. For this reason, with the TE calculus, it is possible to identify the maximum effect of C_1 on C_5:

$$TE(C_1, C_5) = \max\{I_1(C_1, C_5), I_2(C_1, C_5), I_3(C_1, C_5)\} = \max\{much, some, some\} = much$$

Finally, the concept C_1 affects "much" the concept C_5. At the same time, if a more complex evaluation scale is considered, taking into account a symmetric scale with negative connections, i.e. ranging from Very Low to Very High (see Figure 3.4), it could be possible to identify situations in which some indirect effects manifest positive effects while others manifest negative effects: "an indeterminate effect". If $I_1(C_1, C_5) = Very\ Low$ and $I_2(C_1, C_5) = Very\ High$, in absolute terms, both the connections have a high impact on the concept C_5 but, in reality, they show different behaviours on the final concept: the first connection has a negative impact, and the second one is positive. In this case, it is not possible to consider just one of them but the analyser has to distinguish all the possible situations according to the point of view of the analysis.

3.3 Research Approach

The structured research approach proposed in this work consists of 2 phases divided into steps as shown in Figure 3.3. The first phase, the "Development of a Cognitive Modelling Group", aims at defining a general framework that can be applied to other SCs. This framework identifies the most important SC concepts and how these concepts affect each other and SCR. The second phase, "Development of an FCM", is developed for analysing a specific SC and it allows SC managers to identify the most important disruptions and to define SC design strategies to increase the resilience of the specific SC.

It will be applied to each of the two case study subsequently shown in this chapter.

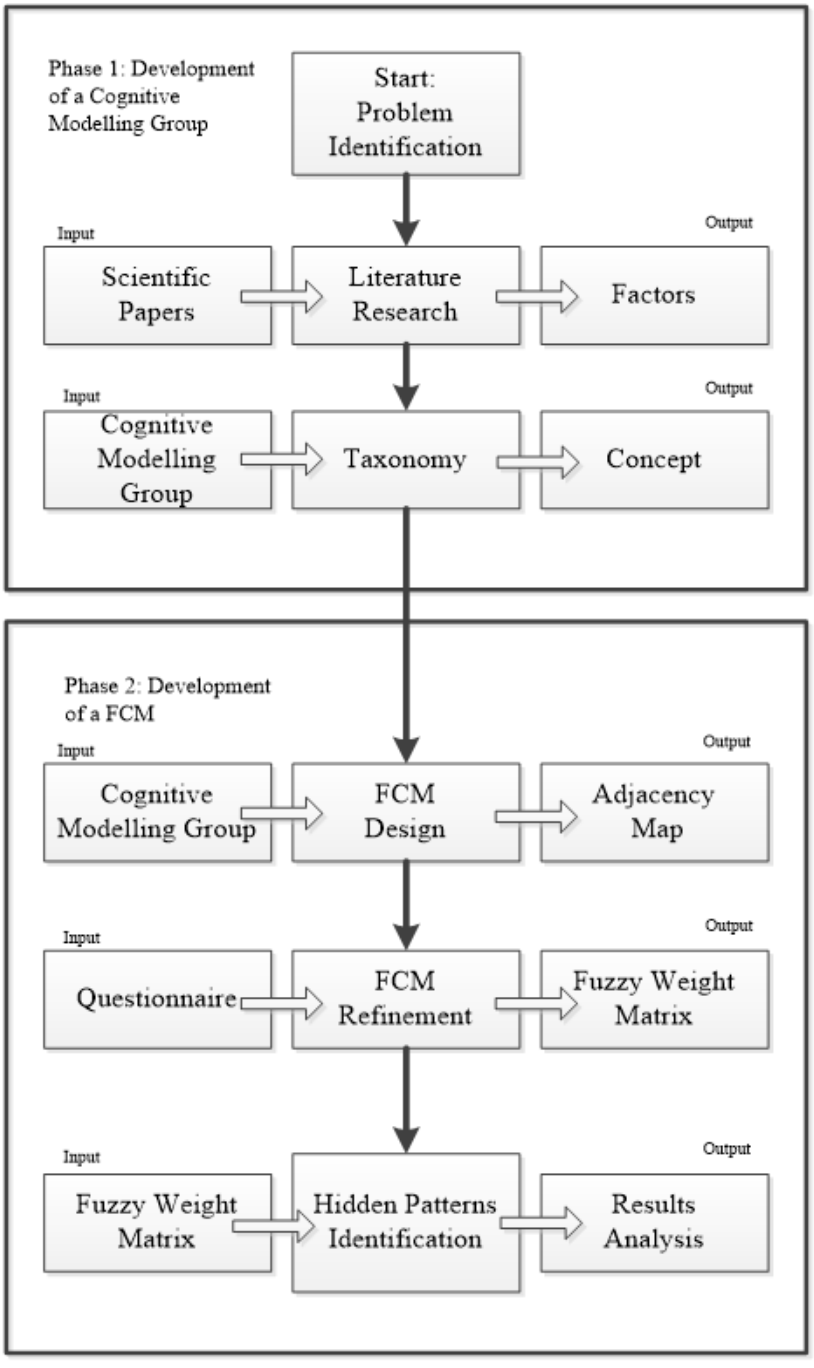

Figure 3.3: Research Approach

3.3.1 First Phase: Development of a Cognitive Modelling Group

The first phase consists of three steps:

I. The first step of the proposed method, i.e., the "Problem identification", is necessary to define the scope and focus of analysis as well as to set all the relevant parameters of the model;

II. The second step, the "Literature Research", is based on the research in extant literature and it aims at finding all factors that influence SCR and analysing how these factors impact on it;

III. The third step, "Taxonomy", is necessary in order to group these factors, since many factors referred to similar topics and moreover to develop a shorter and more comprehensible questionnaire for experts not to affect the likelihood of obtaining an incomplete questionnaire from the experts.

3.3.2 Second Phase: Development a Fuzzy Cognitive Map

The second phase also consists of three steps:

3.3.2.1 IV step: Fuzzy Cognitive Map Design

In the fourth step, called "FCM Design" (figure 3.3), the Cognitive Modelling Group found the links existing among the concepts outlined during the taxonomy step to build the Cognitive maps and the adjacency matrix.

In the "FCM Design" step, each expert provides its personal cognitive map, in the form of a weighted matrix. Specifically, they have to rate the various relationships using fuzzy labels: very low, low, medium, high and very high. In order to facilitate the experts in the questionnaire filling out phase (concerning the possibility to express negative and positive connection between concepts), the Fuzzy Likert scale labels have been indicated with numbers ranging in [-5 5] (the label 0 means no correlation between concepts). Table 3.1 is an excerpt from the evaluation sheet provided for the interviewees.

SC Visibility is influenced by:											
Concept Name	Negative Connection					No Connection	Positive Connection				
	Very High	High	Medium	Low	Very Low		Very Low	Low	Medium	High	Very High
Risk Management	-5	-4	-3	-2	-1	0	1	2	3	4	5
SC Length	-5	-4	-3	-2	-1	0	1	2	3	4	5
Organization	-5	-4	-3	-2	-1	0	1	2	3	4	5
….											

Table 3.1: An excerpt from the questionnaire regarding the concept SC visibility

The weight sign allows researchers to define e_{ij} values. As suggested by Bevilacqua et al. (2016), in order to obtain a unique assessment of the individual concepts, semantic values were attributed to the relationships between concepts.

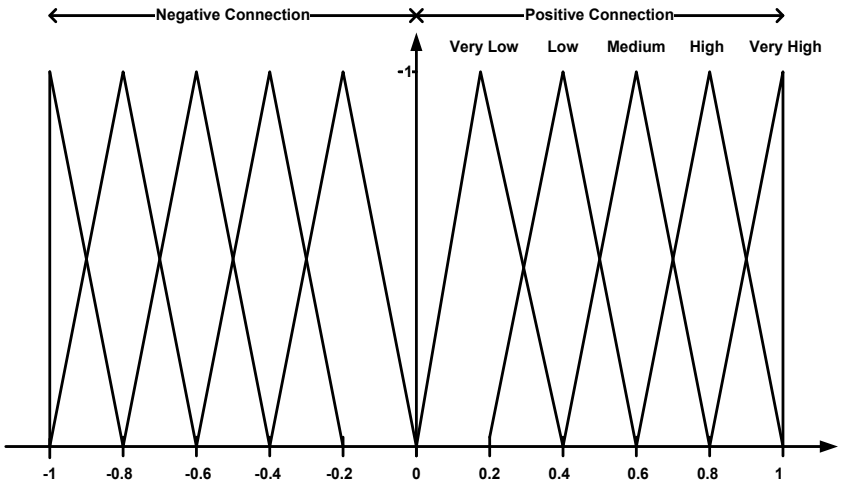

Figure 3.4: Membership function for the fuzzy weights

Subsequently, each assessment was converted into a numerical format using the appropriate triangular fuzzy functions (figure 3.4). The triangular fuzzy sets play a particular role since they appear as the natural fuzzy counterpart to uniform probability distributions on bounded intervals. In particular, as asserted by Pedrycz (1994) the cuts of triangular fuzzy sets contain the "confidence intervals" of a symmetric probability distribution with the same mode and support. For these reasons, triangular fuzzy sets are often used to quantify linguistic data. The use of triangular fitness functions is fairly common in literature (Chan and Wu, 2005; Karsak, 2004) as

triangular fuzzy sets are among the few fuzzy sets forms that are easy to manage from a computational point of view, yielding the optimal distribution-free confidence intervals for symmetric probability distributions with bounded support.

The final assessment was derived from values l_b (lower bound), m_b (medium bound) and u_b (upper bound) of the triangular functions shown in Fig. 3.4. The evaluations of the interviewees have then been weighted as shown in eq. (3.3):

$$\frac{\sum_{i=1}^{n} x_i \, \mu(x_i)}{\sum_{i=1}^{n} \mu(x_i)} \qquad (3.3)$$

where n is the number of experts, $\mu(x_i)$ is the membership value for the i-th expert evaluation x_i.

As an example, analysing Figure 3.5, it is possible to identify in (a) and (b) the fuzzified input 1 and 2 (i_1 and i_2). The result is the grey trapezoid for each of them. The application of the specific fuzzy rule defines the output fuzzy set, represented in step (c), consisting in the union of the two fuzzified inputs (the grey composed shape). The black point represents the center of gravity for the designed shape and its abscissa value (o_1) is the numerical weight.

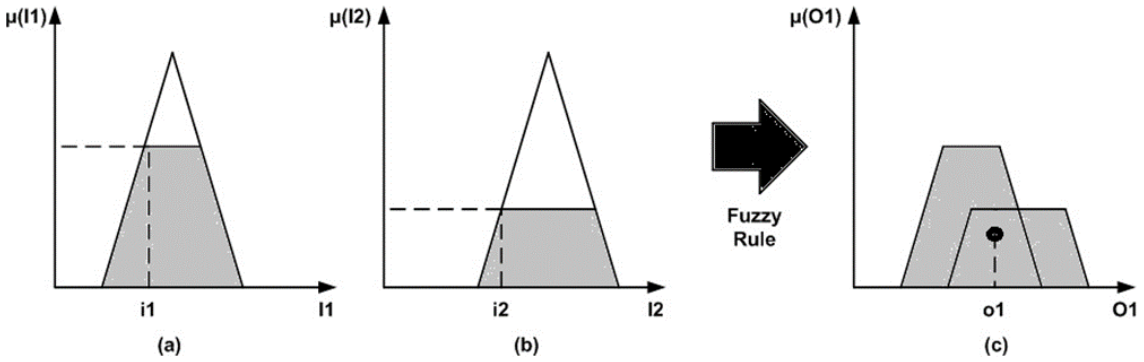

Figure 3.5: Example of Center of Gravity method application

3.3.2.2 V Step: Fuzzy Cognitive Map refinement

In the following step, the "FCM refinement", the Cognitive Modelling Group defined the relationship weight between every pair of linked concepts. The Cognitive Modelling Group was asked to explain in-depth the relationship meaning and weight between every pair of linked concepts.

This methodological approach consists in the analysis of potential conflicts between the various identified concepts and relationships by assessing the differences between the different mental models. To this end, it was intended to estimate the relative importance of semantic distance that the actors attributed to an unusual feature of the issue. The opinion expressed by the players about the significance of a specific concept is different; more likely is the emergence of conflicts concerning the information associated with that factor. The decision group has to consider the meaning and significance of each node carefully to determine any redundancy that was

presented by different experts viewing the problem domain with a different perspective and expressing the same concepts using different verbal expressions. The decision to refine the FCM, eliminating or grouping some concepts (Cole and Persichitte, 2000) should be carried out after considering each of them regarding the relevance of its removal on the map.

3.3.2.3 VI step: Hidden patterns identification

The sixth and last step, "Hidden patterns identification", allows researchers to identify all hidden concepts concatenations inside the generated FCM. The term "hidden" is due to the involvement of different experts with different experiences to the problem in question (Kandasamy and Smarandache, 2003). Indeed, analysing the final FCM, experts have knowledge about the strength of all the considered concepts and of the domino effects among them. The Indirect and Total Effects quantify this strength.

3.4 Home Appliance Case Study

A case study for a home appliance SC has been used to illustrate the application of the proposed method in an operating context. A case study is the most appropriate tool to test the research approach object of this study since it focuses on a contemporary phenomenon within a real-life context, i.e. resilience of Supply Networks around the globe (Yin, 1981).

Table 3.2 provides a description of the SC players analyzed in this case study.

SC players	Typology	Location	Description
Tier two supplier	Semi-finished electrical products supplier	Germany	It supplies electromechanical components, which are essential for the embedded boards that the tier one suppliers #1 supplies to the manufacturer.
Tier one supplier	Finished electrical products supplier	Germany	"Custom" industry electronics for home appliance, light and well-being
Manufacturer	Electrical appliance producer	Italian company	Italian corporation that produces electrical appliance systems and related products.
Shipper	Global transportation and logistics company	Switzerland	It provides sea freight and airfreight transport, contract logistics, and overland businesses with a focus on providing IT-based logistics solutions
Distributor	House furniture company	Marche Region, Italy	There are kitchens and bathroom furniture among their product lines. In order to provide an "all-inclusive" product to their clients, they have to deal with upstream partners for a steady supply of household appliances.

Table 3.2: Home Appliance SC Players

3.4.1 I Step: Problem identification

As already stated earlier in this chapter, the aim of this research is to identify the connection between the various factor affecting SCR. This section will investigate a Home Appliance sector case study.

3.4.2 II Step: Literature research, factors affecting SCR

To identify the main factors affecting SCR, a literature review has been carried out. The literature search has been carried out in relevant literature databases including Emerald, Metapress, Science Direct, Scopus, and Web of Science, using these keywords: “Supply Chain”, “Resilience”, “Risk”, “Disruptions”, “Sustainable” and “Supply Uncertainties”. Subsequently, different filters helped to select relevant studies constituting the core set of articles for selecting the main concepts to include in FCMs. The filters were defined as follows:

- Ensure substantive relevance, defined as adequacy of the articles in addressing, and capturing the phenomenon under investigation, by requiring that they contain the keyword search in their title, abstract or keywords;
- Consider only English language articles;
- Remaining abstracts should be read for substantive relevance;
- Remaining full articles should be read for substantive relevance;

No time limit or limit in publication type was adopted in these searches.

In this study the meaning of “Factors” is general. We aim at analysing connections between different aspects. Therefore, we summarized as “Factors” sources of risk (e.g. terrorism, war), conceptualizations of SCR

(e.g. visibility, velocity,), SC practices (e.g. lean production, outsourcing) and other aspects (e.g. organizational relationships, sustainable development).

Through the application of the first two filters, 86 papers were identified, of which 39 were defined as relevant. Considering the 39 articles selected, we listed all the factors mentioned in them (see table 3.3).

Source	Factors	Factors
Suarez-Villa and Rama (1996)	Outsourcing	1
Cooper,Lambert,and Pagh (1997)	Planning and control, Information flow, Management methods, power and leadership culture	4
Suarez-Villa and Walrod (1997)	Outsourcing	1
Boekholt,Patries,and Thuriaux (1999)	State aid	1
Rice and Caniato (2003)	Security people in leadership, BC planning, Intensive training/education, Sound strategy, Deeper relationship SC Collaboration, Organizational Capabilities, Flexibility, Redundancy	8
Bernauer and Caduff (2004)	Product regulation	1
Christopher and Peck,Helen (2004)	Awareness of actual/potential disturbances, SC Risk, SC risk assessment, Risk Awareness, Risk management culture, SC understanding, SC Intelligence, Information, Visibility, Collaboration, Organizational structure, Flexibility and adaptability, Redundancy	14
Perrings (2006)	Sustainable development	1
Tang (2006)	Economic Crises, Devaluation of currency, Marketing tactics, Risk Assessment Methods, Recovery Planning System, Terrorist Attack War, Measures applied after terrorist attack, Workforce availability constraint, Flexible Transportation Multimodal Transportation Multicarrier Transportation Multiple Routes, Global SC	10
Craighead et al. (2007)	Warning capability, SC complexity	2
(Pettit et al., 2013)	JIT, Insurance, Portfolio diversification, Financial reserves and liquidity, Price margin, Product differentiation, Customer loyalty/retention, Market share, Brand equity, Customer Relationships, Customer communications, Risk Management, Visibility, Collaboration, Increasing outsourcing, Theft, Terrorism/sabotage, Labour disputes, Espionage, Political Change, Regulatory Change, Accountability, Creative problem solving, Cross-training, Substitute leadership/empowerment, Learning/benchmarking, Culture of caring, Technological innovation, Part commonality, Modular product design, Multiple uses, Supplier contract flexibility, Multiple source Alternate distribution channels, Risk pooling/sharing, Multi-sourcing, Delayed commitment/Production postponement, Inventory management, Globalized SC, Centralized Distribution, Centralized Production, Specialized Factories	44
Stolker,Karydas,and Rouvroje (2008)	Quick response	1
Blos et al. (2009)	Debt, Theft, Property damage, Union regulation	4
Boin,Kelle,and Clay Whybark (2010)	Financial Meltdown, Disaster Management, Research Planning, Terrorist Attack, Natural disaster, Infrastructural Dramas, Exploding Factories, Hostage Takings, Media, Many Actors	10
Lengnick-Hall,Beck,and Lengnick-Hall (2011)	Flexibility, Agility, Adaptability	3
Zhao et al. (2011)	Availability, Connectivity, Accessibility	3
Scheffer et al. (2012)	Domino effect	1
Klibi and Martel (2012)	Political economy	1

(Adenso-Diaz et al. 2012)	Node Complexity, Suppliers Complexity, Sources Criticality, Density, Variance Density, Node Criticality, Flow Complexity, Node Reliability, Flow Reliability, Cluster Reliability, Variance Node Reliability, Variance Flow Reliability, Variance Cluster Reliability	13
Wieland and Marcus Wallenburg (2013)	Robustness, Agility	2
(Jüttner and Maklan 2011)	Visibility, Collaboration, Flexibility, Velocity	4
Johnson,Elliott,and Drake (2013)	Flexibility, Velocity, Visibility, Collaboration	1
Brandon-Jones et al. (2014)	SC Connectivity, Information Sharing, SC Visibility, SC Robustness, Environmental Dynamism, Scale Complexity, Differentiation, Delivery Complexity	8
Mensah and Merkuryev (2014)	Lean Production, Credit Crunch, Purchase price risk, Natural disaster	4
Kristianto et al. (2014)	Assess and understand effect of disruptions, Redundancy	2
Scholten,Sharkey Scott,and Fynes (2014)	Knowledge assessment, Risk assessment, Visibility Collaboration	3
Bueno-Solano and Cedillo-Campos (2014)	Economic crises, Change in client behaviour, Risk Management, Terrorist Attack, Terrorism, Natural disasters, Challenging political-administrative context	6
Derissen (2014)	Sustainable development	1
Madadi et al. (2014)	Tainted Materials Delivery	1
Soni,Jain,and Kumar (2014)	Lean Production, Risk management culture, SC Visibility Risk and revenue sharing, Collaboration among partners, Trust Among Players, Adaptive capability, Globalized SC	7
Bruno and Clegg (2015)	Power Blackouts	1
Rajesh and Ravi (2015)	Flexible processes, Responsive pricing, Strategic risk planning, Collaborative partner relations, Visibility, Integrated SC, Flexible supply strategies, Flexible supply contracts	8
Green (2015)	Cyber-attack/data breach, Adverse weather, Tsunami, Embargoes, It/Communication outage, Transport/network disruptions, Product quality accident, Loss of talent/skills, Energy scarcity, New laws/regulation, Product quality accident, Risk Management	12
Sitterle et al. (2015)	Flexibility, Adaptability	2
Torabi,Baghersad,and Mansouri (2015)	Fluctuations of price and value	1
Hosseini and Barker (2016)	Geographical Segregation, Surplus Inventory, Backup Supplier Contracting, Physical Protection, Rerouting, Restoration Budget, Technical Resource Restoration	7
Annarelli and Nonino (2016)	Economic Crises, International terrorism	2
Azevedo,Carvalho,and Cruz-Machado (2016)	SC Visibility, Sourcing Strategies (to allow switching of suppliers), Flexible Supply base/flexible Sourcing, Strategic Stock, Lead Time Reduction, Flexible Transportation, Inventories/Demand Conditions, Agility, Collaboration, Information Sharing	10
Hsu and Lawrence (2016)	Brand Equity, Product recall, Social Media, Product recall	4
Khan and Estay (2015)	Cyber-attack	1

Table 3.3: Factors affecting SCR

The literature review on factors affecting SCR allowed us to highlight some aspects: some factors were cited many times more than others. Risk management, for example, has been cited 9 times throughout all the papers: in fact, risk management is seen as a key factor both to prevent and mitigate SC disruptions.

Among the sources of risk, "Terrorism" is the most recurrent: this threat has been mentioned more than 10 times throughout all of the sources. Solano and Cedillo-Campos (2014) aimed, for example, to understand how disruptions produced by terrorist acts on the performance of global SC. Also, Boin et al. (2010) outlined the extreme circumstances that terrorist attacks create.

Moreover, economic crises were cited many times. This aspect, like terrorism, is a common denominator in all recent researches, due to the recent financial events that have struck the entire globe. This factor has been cited along with its direct consequences like the devaluation of currency (24 times) and fluctuations of price and value (12 times).

3.4.3 III Step: Taxonomy

The literature review, as highlighted in section 2, generated a massive amount of data and more than 180 factors (table 3.3) have been identified. In the "Taxonomy" step all these factors have been clustered into few concepts. In this research, the taxonomy of factors that affect SCR has been built on

extant literature (Pettit et al., 2010), then refined and validated by a Cognitive Modelling Group following the Delphi method criteria.

In this work, the group included two academics, whose research studies mainly focus on SC Management and three managers for every player of the SC (17 people for the SC analyzed in this paper). Taking into consideration the multidisciplinary competencies required for company managers to develop a cognitive map, the three managers have been selected from different company functions: SC managers, marketing managers and administrative function managers. This ad hoc panel was created to encourage communication and meetings, during which the members could contribute their knowledge and information about the processes.

The first activity of this group is to identify concepts to be included in the cognitive map. The factors list (table 3.3) has been given to the Cognitive Modelling Group. The instructions were to regroup the factors into few concepts in an efficient way. The optimal breakdown point should have been a number big enough to maintain the detail level, but small enough to make the analysis simple. The procedure was designed as a group communication process which aims to achieve a convergence of opinion on a specific issue using a series of questionnaires delivered using multiple iterations. More specifically, the feedback process allows and encourages the experts to reassess their initial judgments about the information provided in previous

iterations. Sometimes the experts changed their statements assessing the comments and feedback provided by the other Delphi panelists. Consensus has been reached after three iterations of Delphi analysis with the identification of 29 concepts (table 3.4). A “top event” is described as a single event that is influenced by all other events. In this case, the top event is the concept “SC Resilience” (C29).

Code	Concept	Description	Factors involved
C1	Operation Management strategies	All practices connected to Lean Production and Agility	JIT, Lean Production, Agility, Lead Time Reduction
C2	External Financial Risk	Risks linked to the financial sector in which the SC operates	Credit Crunch, Purchase price risk, Devaluation of currency, Economic Crises, Financial Meltdown, Risk pooling/sharing
C3	Internal Financial Risk	Risks linked to the financial situation of the enterprises.	Debt and lack of Insurance, Portfolio diversification, Financial reserves and liquidity, Price margin
C4	Market Volatility	Uncertainties linked to market developments	Fluctuations of price and value, change in client behaviour
C5	Market Position	Place that the brand occupies in the mind of the customer and how it is distinguished from competitors' products	Product differentiation, Differentiation, Customer loyalty/retention, Market share, Brand equity, Customer relationships, Customer communications, Responsive pricing
C6	Risk Management culture	All of the risk management branches developed by the company: prevention techniques, risk evaluation, reduction of action plans to face sudden disturbances	Risk management culture, Strategic risk planning, Risk Assessment Methods, Recovery Planning System, Disaster Management, Research Planning, Security people in leadership, BC planning, Intensive training/education, Knowledge assessment, Risk assessment
C7	SC Visibility	The ability of parts, components or products in transit to be tracked from the manufacturer to their destination	SC Visibility, Collaboration among partners, Trust Among Players Collaborative partner relations, Visibility SC, Communication, Cooperation, Relationship with suppliers, SC understanding, SC Intelligence, Information, Visibility, Collaboration, Warning capability, Deeper relationship, Information flow, Geographical Segregation, Creating total SC visibility, Developing visibility to clear view of own stream inventory and demand conditions
C8	SC Vertical Integration Degree	A SC is vertically integrated when all activities from the raw material to the finished products are carried out by the same company.	Integrated SCs, Integration
C9	Deliberate threats	Intentional attacks aimed at disrupting operations or causing human or financial harm	Theft, Terrorism/sabotage, Espionage, Cyber-attack/data breach
C10	Natural phenomena	An environmental danger to which risk of damage to people or things is associated	Natural disasters: earthquakes, flooding, tsunami, adverse weather
C11	Government restrictions	National policies that apply to all sectors of free trade	Regulatory state, Embargoes, Environmental law
C12	Loss of infrastructure and/or connection	Physical loss of infrastructures: productive plants, physical connections (roads), telecommunications	Property damage, Infrastructural Dramas, It/Communication outage, Transport/network disruptions, Physical protection
C13	Materials flow interruption	Interruption of the normal flux of materials or final products	Interruption of raw materials and products delivery, Product recall, Tainted Materials Delivery, Product quality accident
C14	Manpower availability	Availability of human resources to carry on normal activities inside the SC	Manpower availability, Labour Disputes, Union regulation, Workforce availability constraint, Hostage Takings, Strikes, Loss of talent/skills, Technical resource restoration

C15	Energy sources availability	Availability of energy sources to carry on normal activities	Power Blackouts, Energy scarcity
C16	Political Economy	Relationships between production and trade with law, custom, and government.	Political Change, State aid
C17	Institutional Policies	Formal restrictions regarding products in the electronics sector	Regulatory Change, Product regulation, New laws/regulation
C18	Media and public opinion response towards the SC	Refers to the level of interest of the press regarding events related to the SC	Old and new media
C19	Organization	Human resource structures, policies, skills and culture	Accountability, Cross training, Substitute leadership/empowerment, Learning/benchmarking, Culture of caring
C20	Connectivity	Degree of dependence among SC players	Domino effect, SC Connectivity, Connectivity, Cluster reliability
C21	Technology dependence	Degree of dependence among external players	Technology dependence, Technological innovations,
C22	Flexibility in outsourcing	Ability to quickly change inputs or the mode of receiving inputs	Multi-sourcing, Supplier contract flexibility, Flexible supply strategies, Multimodal Transportation, Part commonality, Sourcing strategy to allow switching suppliers, flexible supply base/flexible sourcing, Suppliers complexity, Sources criticality, Backup supplier contracting
C23	Flexibility in order fulfillment	Ability to quickly change outputs or the mode of delivering outputs	Alternate distribution channels, Delayed commitment/Production postponement, Inventory management, Re-routing of requi-rements, Flexible Processes, Flow complexity
C24	Redundancy	How much has been invested in resources compared to how much was needed	Redundancy, Surplus Inventory, Strategic stock
C25	SC Length	Refers to how many players are parts of the SC	SC Length, SC complexity, Many Actors, Accessibility, Node complexity
C26	Degree of centralization of asset and/or facilities	Degree of concentration of SC assets	Centralized Distribution, Centralized Production, Density, Variance density
C27	Claims and Product liability	Product defects able to damage the user	Product recall, Tainted Materials Delivery, Product quality accident
C28	Sustainable development	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs	Sustainable development, Environmental dynamism
C29	SC Resilience	The ability of a system to return to its original state or move to a new, more desirable state after being disturbed (Christopher and Peck,Helen 2004)	Top Event

Table 3.4: Taxonomy analysis: concepts definition

3.4.4 IV Step: FCM Design

During the FCM, as already exemplified in section 3.3.2.2 the Cognitive Modelling Group found the links existing among the concepts outlined during the taxonomy step to build the Cognitive Map, shown in Figure 3.6:

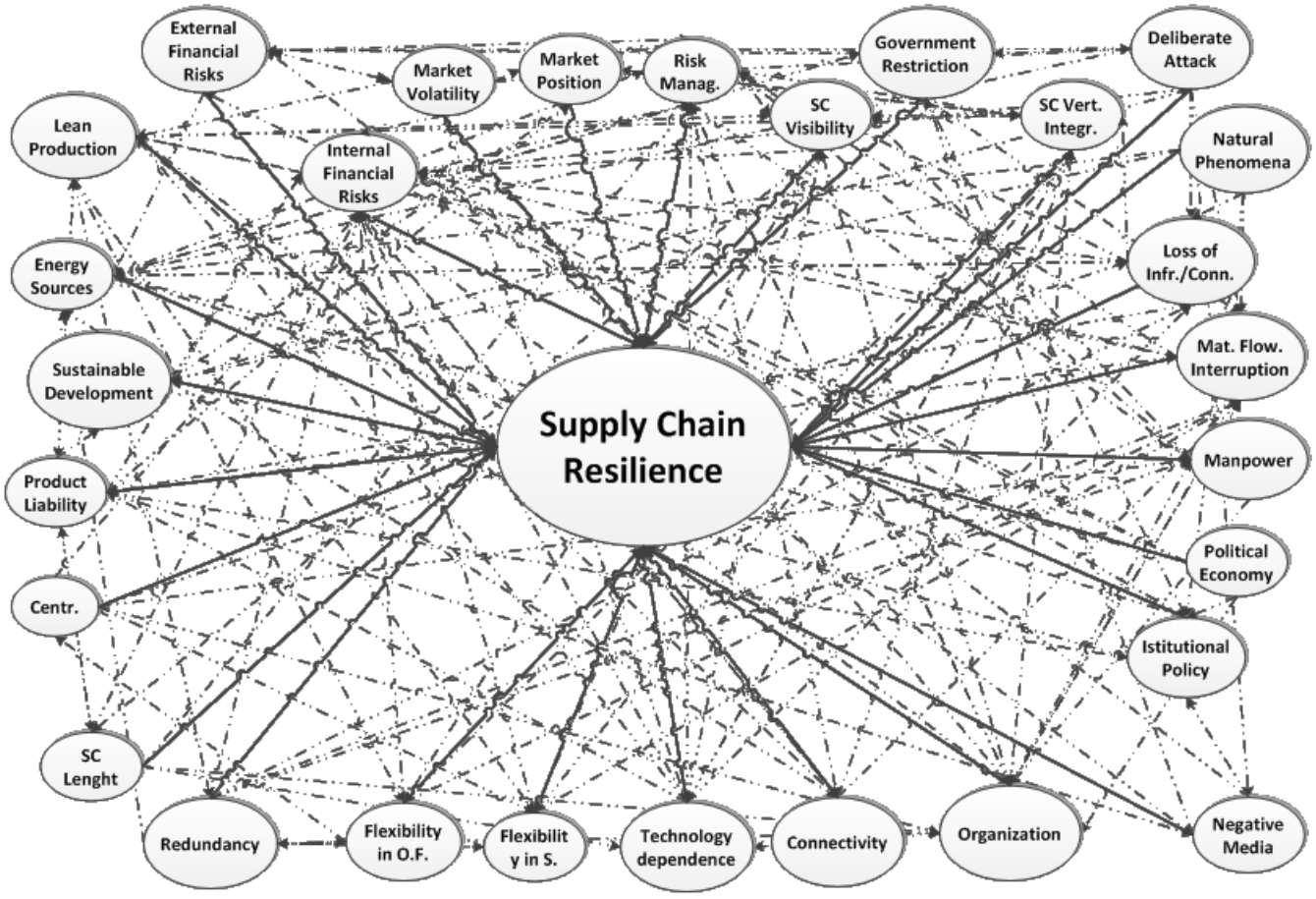

Figure 3.6: Home Appliance Case Study Fuzzy Cognitive Map

3.4.5 V Step: Refinement Phase

As exemplified in the previous section, during this step the analysis of potential conflicts between the various identified concepts and relationships was carried out, by assessing the differences between the different mental models. The result is the Fuzzy Cognitive Maps, shown in a matrix format in Appendix A.

3.4.6 VI Step: Hidden pattern recognition phase

According to the methodology shown above, it is possible to analyse the results and to highlight the most relevant concepts within the route that leads to SCR by evaluating the IE (Indirect Effect) of every path. Thus, it is possible to highlight how a concept could affect the top event through different concatenations. The most important paths (with an indirect effect higher than 0.5 or lower than -0.5) have been reported in tables 3.5-10 with reference to every player of the SC analysed in this work. This approach aims at analysing the domino effect among SC concepts.

In table 3.5 principal paths with an indirect effect higher than 0.5 or lower than -0.5 have been reported with reference to the whole SC.

Principal Paths of the whole SC							
#Path	Starting Node						IE
1	Flexibility in outsourcing	SCR					0.73
2	Operation Management strategies	SCR					0.68
3	SC Visibility	SCR					0.65
4	Materials flow interruption	SCR					-0.65
5	Natural phenomena	Materials flow interruption	SCR				-0.63
6	External Financial Risk	Market Volatility	Internal Financial Risk	SCR			-0.62
7	External Financial Risk	Market Volatility	SCR				-0.62
8	Deliberate threats	External Financial Risk	Market Volatility	Internal Financial Risk	SCR		-0.62
9	Risk Management culture	SCR					0.61
10	Risk Management culture	Product liability	Internal Financial Risk	SCR			-0.61
11	Risk Management culture	Negative media and public opinion Response towards the SC	Market Volatility	SCR			-0.60
12	SC Vertical Integration Degree	SC Visibility	SCR				0.58
13	Deliberate threats	Loss of infrastructure and/or connection	Energy sources availability	Materials flow interruption	SCR		0.56
14	SC Length	SC Visibility	Technology dependence	Risk Management culture	SCR		0.54
15	SC Length	SC Visibility	SCR				0.54
16	Government restrictions	Materials flow interruption	Internal Financial Risk	Manpower availability	Organization	SCR	-0.54
17	Government restrictions	Materials flow interruption	Internal Financial Risk	Flexibility in outsourcing	SCR		-0.52
18	Government restrictions	Materials flow interruption	Internal Financial Risk	SCR			-0.51
19	Government restrictions	Materials flow interruption	SCR				-0.51

Table 3.5: Principal Paths of the whole SC

Tier Two Supplier - Principal Paths						
#Path	Starting Node					IE
1	Operation Management strategies	SCR				0.88
2	Flexibility in outsourcing	SCR				0.8
3	Loss of infrastructure and/or connection	SCR				-0.76
4	Natural phenomena	Materials flow interruption	SCR			-0.72
5	Negative media and public opinion response towards the SC	Market Volatility	Risk Management culture	SCR		-0.68
6	External Financial Risk	Internal Financial Risk	Flexibility in sourcing	SCR		-0.66
7	Market Volatility	Internal Financial Risk	SCR			-0.65
8	Risk Management culture	Organization	SCR			0.64
9	Manpower availability	Organization	SC Vertical Integration Degree	Flexibility in order fulfillment	SCR	0.63
10	SC Vertical Integration Degree	Flexibility in order fulfillment	SCR			0.63
11	Risk Management culture	Organization	Manpower availability	Internal Financial Risk	SCR	0.62
12	Energy sources availability	Government restrictions	Materials flow interruption	SCR		-0.58

Table 3.6: Tier Two Supplier - Principal Paths

Tier One Supplier - Principal Paths								
#Path	Starting Node							IE
1	Operation Management strategies	Organization	SCR					0.76
2	Market Volatility	Internal Financial Risk	SCR					-0.64
3	Market Volatility	Internal Financial Risk	Flexibility in outsourcing	SCR				-0.63
4	Deliberate threats	Loss of infrastructure and/or connection	Energy sources availability	SCR				-0.61
5	Deliberate threats	Loss of infrastructure and/or connection	Product liability	SCR				-0.60
6	Risk Management culture	SCR						0.57
7	Market Position	SC Vertical Integration Degree	Technology dependence	Product liability	SCR			-0.55
8	Degree of centralization of asset and/or facilities	SC Vertical Integration Degree	Flexibility in outsourcing	SCR				0.52
9	SC Length	SC Visibility	Technology dependence	SCR				-0.52
10	SC Length	SC Visibility	SCR					-0.51
11	Political Economy	External Financial Risk	Market Volatility	SC Length	SC Visibility	Flexibility in sourcing	SC R	-0.51

Table 3.7: Tier One Supplier - Principal Paths

Manufacturer - Principal Paths						
#Path	Starting Node					IE
1	Flexibility in outsourcing	SCR				0.95
2	SC Vertical Integration Degree	SC Visibility	SCR			0.89
3	Political Economy	Flexibility in outsourcing	Materials flow interruption	SCR		-0.76
4	External Financial Risk	Internal Financial Risk	Operation Management strategies	SCR		0.76
5	External Financial Risk	Market Volatility	SC Length	SCR		0.75
6	Operation Management strategies	SCR				0.73
7	Natural phenomena	Materials flow interruption	SCR			-0.73
8	Risk Management culture	SCR				0.71
9	Risk Management culture	Negative media and public opinion response towards the SC	Market Volatility	SCR		-0.69
10	Government restrictions	Energy sources availability	Materials flow interruption	SCR		-0.68
11	Energy sources availability	Materials flow interruption	SCR			-0.68
12	SC Length	SC Visibility	Technology dependence	Risk Management culture	SCR	-0.68
13	SC Length	SC Visibility	Risk Management culture	SCR		-0.68
14	Risk Management culture	Product liability	Internal Financial Risk	SCR		0.66
15	Energy sources availability	Loss of infrastructure and/or connection	SCR			-0.65
16	Political Economy	External Financial Risk	Internal Financial Risk	Energy sources availability	SCR	-0.64
17	Political Economy	Redundancy	SCR			0.62
18	Political Economy	Redundancy	Materials flow interruption	SCR		-0.62
19	Institutional Policies	Degree of centralization of asset and/or facilities	Internal Financial Risk	SCR		-0.57
20	Negative media and public opinion Response towards the SC	Degree of centralization of asset and/or facilities	Loss of infrastructure and/or connection	SCR		-0.52
21	Sustainable development	Market Position	SCR			0.51

Table 3.8: Manufacturer - Principal Paths

Shipper - Principal Paths							
#Path	Starting Node						IE
1	SC Visibility	SCR					0.95
2	Government restrictions	Materials flow interruption	Internal Financial Risk	Manpower availability	Organization	SCR	-0.85
3	Government restrictions	Materials flow interruption	SCR				-0.82
4	Flexibility in outsourcing	SCR					0.80
5	Risk Management culture	SC Visibility	Flexibility in order fulfillment	Internal Financial Risk	Flexibility in outsourcing	SCR	0.79
6	Risk Management culture	Organization	SCR				0.78
7	Market Volatility	External Financial Risk	Internal Financial Risk	SCR			-0.67
8	Natural phenomena	Technology dependence	Organization	SCR			0.63
9	Loss of infrastructure and/or connection	SC Length	SC Visibility	Internal Financial Risk	SCR		-0.60
10	Degree of centralization of asset and/or facilities	SC Vertical Integration Degree	Flexibility in sourcing	SCR			0.57
11	Materials flow interruption	Internal Financial Risk	SCR				-0.57
12	SC Vertical Integration Degree	SC Visibility	SCR				0.56
13	Redundancy	Organization	SCR				0.53
14	Technology dependence	SC Visibility	Flexibility in sourcing	SCR			0.51
15	Material flow interruption	SC Length	SC Visibility	Internal Financial Risk	SCR		-0.51

Table 3.9: Shipper - Principal Paths

Distributor - Principal Paths							
#Path	Starting Node						IE
1	SC Visibility	SCR					0.74
2	Flexibility in outsourcing	SCR					0.71
3	Government restrictions	Materials flow interruption	Internal Financial Risk	Manpower availability	Organization	SCR	-0.70
4	Government restrictions	Materials flow interruption	Internal Financial Risk	Flexibility in outsourcing	SCR		-0.69
5	Government restrictions	Materials flow interruption	Internal Financial Risk	SCR			-0.67
6	Government restrictions	Materials flow interruption	SCR				-0.67
7	Materials flow interruption	SCR					-0.64
8	SC Length	SC Visibility	SCR				-0.59
9	SC Vertical Integration Degree	SC Visibility	SCR				0.54
10	Market Position	SCR					0.54

Table 3.10: Distributor - Principal Paths

The first three paths of Table 3.5 are directly linked to the top event "SCR". Among them, "Flexibility in outsourcing", with an IE of 0.73, is the most relevant concept for the SC analysed in the case study. All players of the electrical appliance SC highlighted that the flexibility in the procurement of raw materials or semi-finished products is fundamental in order to keep the continuity of the business. This concept is particularly important for the manufacturer. Indirect Effect of this concept for the manufacturing company is equal to 0.95 (see Table 3.8). This company usually moves production among different plants relying on similar plant designs and processes across the company. Interchangeable production plants allow the manufacturer to respond quickly to a disruption by switching production among facilities if the need arises.

In Table 3.5 Operation Management strategies and SC Visibility follow with an IE of 0.68 and 0.65 respectively. This result shows that these two concepts positively contribute to SCR. The relationship between Lean Production and SCR has been widely studied in literature. Our results disagree with results obtained by Soni et al. (2014). These authors stated that the introduction of JIT practices in Supply Networks reduced the slack available to deal with uncertain events and doing so reduced SCR. On the other hand, Carvalho et al. (2011), highlighted that trade-offs between lean, agile, resilient and green (LARG) management paradigms are actual issues,

and may help SCs to become more efficient, streamlined and sustainable. Managers of tier one and tier two suppliers analysed in this work believe that the efforts to achieve leanness or agility may help the efforts to achieve resilience.

SC Visibility (paths #3 and #12 in table 3.5) is another key capability that contributes to building up the resilience of a SC. According to Sinha et al. (2004) a collaborative partnership helps increase visibility and manage risks effectively. In this context, Soni et al. (2014) suggested that managers should try to avoid sourcing and other primary business operations in collaboration with firms which are new to them, since these organizations may not have the willingness to share even sensitive risk and risk event-related information, which could increase the risk and reduce the resilience of their SC.

In our work, the shipper (table 3.9) and the distributor (table 3.10) highlighted the importance of SC Visibility with regard to inventory levels and processes in order to improve organizational performance. Moreover, Manufacturer posits the relationship between SC Vertical Integration and SC Visibility (path #2 in table 3.8). This player found that in recent years, business environments have dramatically increased in dynamic complexity, requiring organizations to adapt more quickly and frequently. This player

underlines that the area of interest where SC Visibility and SC Integration are of relevance is reverse logistics.

In Table 3.5, the path "Natural phenomena" – "Materials flow interruption" – "SCR" (#5) as well as the path "Materials flow interruption" – "SCR" (#4) have an IE of -0.63. In fact, a natural catastrophe can seriously damage the everyday activity of the SC. Tier Two Supplier highlighted this relationship (path 4 in Table 3.6). This player has had experience with flooding phenomena that affected the regular flow of materials. This event produced a negative impact on the whole SC.

An interesting connection can be found in Table 3.9 – shipper principal paths, within the path "Risk Management Culture" – "SC Visibility" – "Flexibility in order fulfilment" – "Internal Financial Risk" – "Flexibility in outsourcing" – "SCR" (#5) and analysing the link between "Flexibility in order fulfilment" and "Internal Financial Risk". In the SC analysed in this case study, it is fundamental to achieve a good and reliable flexibility into fulfilling clients' orders. This capability can bring a significant added value for a SC shipper, and therefore decrease the internal financial risk of such SC players.

Another interesting aspect can be observed analysing paths #6-#8 in Table 3.5, each with an IE of -0.62. All these paths highlight a connection between "External Financial Risk" and "Market Volatility": these two

concepts are deeply interconnected as far as household appliances are concerned. In fact, these are durable goods, which have high price elasticity: consequently, when an economic crisis occurs, they are the first products to be affected by the money crisis.

Considering table 3.5, which exemplifies the result of the entire SC, when the initial node is Risk Management culture, the paths always end or include Product Liability, Market Volatility or Internal Financial Risk (paths #9-#11). This means that the Risk culture is a trigger concept of each of these event chains. According to our experts' opinion, an efficient enterprise risk management could prevent Product Liability by an effective supervision of all the product life cycle, and, what's more, could aid the company into overseeing the evolution SC internal and external factors, such as the financial situation of the actors within the SC, and the uncertainties linked to the market developments that could affect the performance of the enterprises involved.

In the analysed SC, the Manufacturer and Tier One Supplier underlined that SC environment (demand and supply side risks) affects the selection of a mitigation strategy and are moderated by the composition of the risk management team. The study conducted by Soni et al. (2014) again reached the same conclusion. Above all, regarding logistics significance, these results suggested that top managers should work vigorously in SC risk planning and management.

Paths #14 and #15 in table 3.5 highlight interesting connections among SC Length, SC Visibility, Technology dependence and SCR. The Manufacturer and the Distributor underlined that challenges arise because of SC length (i.e., geographical distances involved) and depth (i.e., the number of tiers involved). Managers of these companies affirm that enterprises need to increase visibility in their own operations and those of their suppliers. They also need to gather a complete risk picture and uncover potential disruptions. Managers proposed a new platform enabling multi-tiered SCs to be mapped and data to be shared beyond tier one. While companies that monitor and understand their SC data are better placed to quickly identify and mitigate risks, the benefits of taking a multi-tier approach to SC management go beyond negating possible issues and saving money. This approach also helps businesses identify positive trends, replicate good practice and build a web of SC partners, ultimately helping to achieve long-term profitability and maintain a solid competitive advantage.

If we look at the paths with “Government Restrictions” as starting node (#16-#19, table 3.5), we can underline that “Government Restrictions” always result in Materials Flow Interruption. This aspect has been highlighted from Shipper (paths #2-#3 in table 3.9) and Distributor (paths #3-#6 in table 3.10) and this is due to the latest events regarding difficult economic and

political relationship among countries. These frictions often resulted in trade restrictions between countries, i.e. embargoes.

3.5 Fashion Case Study

A case study for a fashion industry SC has been used to illustrate the application of the proposed method in an operating context.

Table 3.11 provides a description of the SC players analyzed in this case study.

SC players	Typology	Location	Description	Company Size
Tier one supplier	Leather supplier	Italy	Company that offers all types of leather needed to produce goods to the next actor in the SC	As of 2016, it had more than 1000 employees and a revenue of € 350 million
Manufacturer	Global apparel manufacturer	Spain	Product industrialization and production	As of 2016, it had approximately 1,200 employees and a revenue of €400 million
Shipper	Global transportation and logistics company	Italy	Provides sea freight and airfreight transport, contract logistics, and overland services.	As of 2016, it had more than 1,000 offices in over 100 countries, with over 63,000 employees.
Retailer	National Clothing Retailer	Italy	Multi-brand company providing finished products to consumers	As of 2016, it had approximately 6,600 employees and their revenue was of over € 1.34 billion

Table 3.11: Fashion Industry SC Players

3.5.1 I Step: Problem identification

As already stated earlier in this chapter, the aim of this research is to identify the connection between the various factor affecting SCR. This section will investigate a Fashion sector case study.

3.5.2 II Step: Literature research, factors affecting SCR

To identify the main factors affecting SCR, a literature review was conducted. The literature search was carried out in relevant literature databases, including Emerald, Metapress, Science Direct, Scopus, and Web of Science, using two sets of keywords. In order to find cross-sectorial research studies, the first set included keywords regarding only the topic: “Supply Chain”, “Resilience”, “Risk”, “Disruptions”, “Sustainable” and “Supply Uncertainties”. The second set also included the fashion sector and its sub-sectors: “Fashion”, “Textile”, “Apparel”, “Footwear”, “Leather”, “Jewelry”, “Perfumes” and “Cosmetics”, in accordance with the definition by Brun et al. (2008).

Subsequently, to both two results different filters, as in the previous chapter, were applied to select relevant studies constituting the core set of articles for selecting the main concepts to include in the Cognitive Map. The filters were defined as follows:

- Ensure substantive relevance, defined as adequacy of the articles in addressing and capturing the investigated

phenomenon, by requiring that they contain a keyword in their title, abstract or keywords;

- Consider only English-language articles;
- Read remaining abstracts for substantive relevance;
- Read remaining full articles for substantive relevance.

No time limit or limit on publication type was adopted in these searches. Through the application of the first two filters, 95 papers were identified, of which 52 were defined as relevant (27 and 25 papers resulting, respectively, from the first and second sets of keywords). We list all the factors mentioned in the 52 selected articles (Table 3.12), classifying papers according to 5 different topic: Supply Chain Management, Supply Chain Risk Management, Supply Chain Resilience, Factors influencing Supply Chain and Supply Chain Disruption.

Several authors have sought to identify factors positively or negatively affecting SCR. A noteworthy list was developed by Pettit et al. (2008). These authors connected SCR to capabilities and vulnerabilities, highlighting that SCR is achieved through not only the SC's capabilities but also, and primarily, identifying a balance between capabilities and vulnerabilities. The vulnerability is the incapacity of the SC, at a given moment, to react to the disturbances and consequently to attain its objectives. Among the vulnerability factors is connectivity. This factor is related directly

to the SC design and allows strong capabilities in the areas of collaboration, visibility, and flexibility to be created, contributing to balanced resilience through management of interrelated operations between multiple tiers of suppliers and customers.

The literature review on factors affecting SCR allows us to highlight some aspects: some factors were cited many times more than others. Risk management, for example, was cited 7 times throughout all of the papers: In fact, risk management is seen as a key factor to both prevent and mitigate SC disruptions. Fostering risk management culture among the top managers of the SC is seen as a key factor in increasing resilience.

Flexibility has also noted by many authors. Pettit et al. (2008) conducted an interesting analysis dividing flexibility into two branches: flexibility in sourcing and flexibility in order fulfillment. This distinction was very useful to appropriately analyze upstream and downstream information and material fluxes.

Among the vulnerabilities, “Terrorism” was the most recurrent and cross-sectorial: this threat was mentioned 8 times throughout all of the sources. Solano and Cedillo-Campos (2014) aimed, for example, to understand how disruptions produced by terrorist acts affect the performance of global SCs. This was a common denominator in almost all the studies noted above, probably due to the recent events worldwide and the long-studied

consequences of the 9/11 bombing to worldwide SCs. Additionally, Boin et al. (2010) outlined the extreme circumstances that terrorist attacks create. Terrorist attacks can in fact disrupt critical infrastructure, such as electricity, water, communications and transportation, which makes it more difficult to satisfy basic needs. Boin et al. (2010) addressed an interesting aspect: the reaction of the government to these severe events. In fact, special measures applied after such events can create a political-administrative context that makes it very difficult to meet SC challenges, as already exemplfied in the introduction. Moreover, economic crises were cited many times. This aspect, similar to terrorism, has been a common denominator in all recent research, due to the recent financial events that struck the globe as a whole.

Another important factor arising is environmental sustainability: The keywords "environment" and "sustainability" were cited more than 9 times combined. This frequency can be attributed to the importance of this aspect in the fashion industry: the growing consumer sensitivity to environmental issues (Macchion et al., 2015), combined with the high environmental impact throughout all the production phases of a fashion SC (Caniato et al., 2012) are becoming influential drivers of SC performance. Two more noteworthy factors are Market Competition and Fast Fashion: The literature demonstrated that these two factors are deeply marking the fashion industry.

	Cross-sectorial research studies																										Fashion sector research studies																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Lean Production Practices	F	R		R																								K					F																		F	
Portfolio Diversification	F																																																			
Financial Reserves and Liquidity	F																																																	R		
Price Margin	F																																																			
Market Share	F													D																									K													
Brand Equity	F											D																											K						K							
Customer Relationships	F														D															S																						
SC Visibility	F			R	R			R	M		R								R	R																																
Collaboration	F			R				R			R						R			R									F											F							F					
Theft	F																																																			
Terrorism	F		R					R						D	D	R											D															K										
Political Economy Change	F																																											F								
Cross-Training	F																																																			
Substitute Leadership/Empowerment	F																																																			
Learning/Benchmarking	F																																																			
Technological Innovation	F																												F													K										
Modular Product Design	F																																																			
Supplier Contract Flexibility	F																																																			
Alternate Distribution Channels	F																																																			
Multi-Sourcing	F																																																			
Lack of Credit		R																									D																									
Natural Disaster		R			R	R									D	R							K				D																									
Economic Crises		R	R											D	D	R																F			F						R		K	F								
Risk Management Culture	F			R	R			R						D	D				R				K																													
Domino Effect						R	D																																													
Awareness of Disturbances								R																																												
War								R						D																																						
Flexibility				R				R			R		R				R			R																																
Redundancy								R									R		R																																	
Planning and Control									M																																											
Management Methods									M																																											
Power And Leadership Culture									M																																											
Warning Capability										D																																										
SC Length				R						D						R																																				
Product Recall												D																																								
Social Media												D																																								
Recovery Planning System														D																																						
Measures Applied after Terrorist Attack														D																																						
Workforce Availability Constraint														D		R											D																									
Multimodal Transportation														D																																						
Challenging Political Context															D																	F							K					F								
Disaster Management																R																																				
Research Planning																R																																				

	Cross-sectorial research studies																										Fashion sector research studies																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Infrastructural Disruptions																R																																	R			
Media Influence																R																																				
Security People in Leadership																	R																																			
BC Planning						R											R																																			
Sound Strategy																	R																																			
Organizational Capabilities																	R																																			
Assess Effect of Disruptions																		R																																		
Knowledge Assessment																			R																																	
Strikes	F																		R																																	
State Aid																					R	S																															
Cyber-Attack/Data Breach																							K				D																									
Embargoes																							K																					F								
It/Communication Outage																							K				D																									
Transport/Network Disruptions																							K				D																									
Product Quality Accident																							K				D																									
Loss of Talent/Skills																							K				D																									
Energy Scarcity																							K				D		F																							
New Laws/Regulation	F																						K																													
Collaborative Communication																								R				K							F									F		S	F					
Mutually Created Knowledge																								R																												
SC Integration	F																									S									F											S						
Currency Exchange Rate Volatility																											D																									
Insolvency in The supply chain																											D																									
Establish Relationship with Suppliers																												K																								
Highly Competitive Structure																												K		S						K	F		K						K							
Environmental Protection Policies																													F																							
Demand Unpredictability																														S	F	F	F			K		S		F		K	K		K	S				R	F	
Counterfeits																									D					S																						
Short Product Life Cycles																															F			F		K	F	S		F					K			F				F
Product Variety																															F					K	F	S							K							
Intensive Training in Risk Management																	R																																			

Table 3.12: Factors affecting SCR

Legend: S=Supply Chain Management; K=Supply Chain Risk Management; R=Supply Chain Resilience; F=Factors influencing Supply Chain; D=Supply Chain Disruption

(1) Pettit (2008); (2) Mensah and Merkuryev (2014); (3) Annarelli and Nonino (2016); (4) Soni et al. (2014); (5) Bruno and Clegg (2015); (6) Stolker et al. (2008); (7) Scheffer et al. (2012); (8) Christopher and Peck Helen (2004); (9) Cooper et al. (1997); (10) Craighead et al. (2007); (11) Jüttner and Maklan (2011); (12) Hsu and Lawrence (2016); (13) Lengnick-Hall et al. (2011); (14) Tang (2006); (15) Bueno-Solano and Cedillo-Campos (2014); (16) Boin et al. (2010); (17) Rice and Caniato (2003); (18) Kristianto et al. (2014); (19) Scholten et al. (2014); (20) Johnson et al. (2013); (21) Klibi and Martel (2012); (22) Boekholt et al. (1999); (23) Green (2015); (24) Scholten and Schilder (2015); (25) Stevenson and Busby (2015); (26) van der Vaart and van Donk (2008); (27) Supply Chain Resilience Report (2016); (28) Turker and Altuntas (2014); (29) Li et al. (2014); (30) Macchion et al. (2015); (31) Mehrjoo and Pasek (2014); (32) Venkatesh et al. (2015); (33) Čiarnienė et al. 2014); (34) Caniato et al. (2012); (35) Li et al. (2016); (36) Dewi et al. (2015); (37) Vaagen and Wallace (2008); (38) Martino et al. (2016); (39) Martino et al. (2015); (40) Şen (2008); (41) Torstensson and Pal (2013); (42) Wang et al. (2012); (43) Li et al. (2015); (44) Abylaev et al. (2014); (45) Mehrjoo and Pasek (2016); (46) Ait-Alla et al. (2014); (47) Guercini and Runfola (2010); (48) Choy et al. (2009); (49) Marmo (2010); (50) Pal et al. (2014); (51) Escalona Orcao and Ramos-Pérez (2015); (52) Shen et al. (2014)..

3.5.3 III Step: Taxonomy

The literature review generated a massive amount of data, and more than 265 different factors (Table 3.12) are identified. In the "Taxonomy" step, all these factors are clustered into a few concepts. In this research, the taxonomy of factors that affect the SCR is built on extant literature (Pettit, 2008), then refined and validated by a Cognitive Modelling Group following the Delphi method criteria.

In particular, in this work, the group is made up of two academics whose research mainly focuses on SC Management and three managers for every player in the SC examined (14 people for the case study analysed in this paper). Taking into consideration the multidisciplinary competencies required for company managers to develop a cognitive map, the three managers are selected from different company functions: supply chain, marketing and administrative functions. This ad hoc panel is created to encourage communication and meetings, during which the members can contribute their knowledge of the processes.

The first activity of this group is to identify concepts to be included in the cognitive map. The factor list (Table 3.12) is given to the panel of experts. The instructions are to regroup the factors into a few concepts in an efficient way. The optimal breakdown point should be a number high enough to maintain the detail level but low enough to make the analysis simple.

Consensus is reached after three iterations of Delphi analysis with the identification of 29 concepts (Table 3.13). A “top event” is described as a single event that is influenced by all other events. In this case, the top event is the concept “Supply Chain Resilience” (C29).

Code	Concept	Description	Factors involved
C1	Lean Production Characteristics	All practices connected to Lean Production	Lean production practices
C2	External Financial Risk	Risks linked to the financial sector in which the SC operates	Lack of Credit, Economic Crises, Currency exchange rate volatility, weaker cash flow
C3	Internal Financial Risk	Risks linked to the financial situation of the enterprises.	Portfolio diversification, Financial reserves and liquidity, Price margin, Tighter constraints on the capital, insolvency in the SC
C4	Market Volatility	Uncertainties linked to market developments	Demand unpredictability
C5	Market Position	Status of a company or its products in specific markets	Market share, Brand equity, Customer relationships
C6	Risk Management culture	All of the risk management branches: prevention techniques, risk evaluation, reduction of action plans to face sudden disturbances	Risk management culture,Recovery Planning System, Disaster Management, Research Planning and Control, Security people in leadership, BC planning, Intensive training/education in risk management, Sound strategy, Awareness of Disturbances, Assess effect of disruptions, Knowledge assessment
C7	SC Visibility	Knowledge of the state of the operations along the SC	SC Visibility, Collaboration, Collaborative Communication, Long-term Relationship with suppliers, Warning capability, joint goal setting, mutually created knowledge
C8	SC Vertical Integration Degree	A SC is defined as completely vertically integrated when all activities from the raw material to the finished products are carried out by the same company	SC Integration
C9	Deliberate threats	Intentional attacks aimed at disrupting operations or causing human or financial harm	Theft, Terrorism, War, Cyber attack/data breach
C10	Natural phenomena	An environmental danger with which risk of damage to people or things is associated	Natural disasters: earthquakes, flooding, tsunami, adverse weather
C11	Government restrictions	National policies that apply to all sectors of free trade	Measures after terrorist attack, Embargoes, Challenging political context
C12	Loss of infrastructure and/or connection	Physical loss of infrastructures: productive plants, physical connections (roads), telecommunications	Infrastructural Disruptions, IT/Communication outage, Transport/network disruptions,
C13	Materials flow interruption	Interruption of the normal flux of materials or final products	Product recall, Product quality accident
C14	Manpower availability	Availability of human resources to carry on normal activities inside the SC	Workforce availability constraint, Strikes, Loss of talent/skills
C15	Energy sources availability	Availability of energy sources to carry on normal activities within the SC	Energy scarcity
C16	Political Economy	Level of intervention of public bodies on economy with the aim of modifying the macroeconomic system to reach the objectives	Political economy change, State aid
C17	Institutional Policies	Formal restrictions regarding products in the fashion sector	New laws/regulation, environmental protection policies
C18	Negative media and public opinion response towards the SC	Refers to the level of interest of the press regarding events related to the SC	Social media, media influence

C19	Organization	Human resource structures, policies, skills and culture	Cross-training, Substitute leadership/empowerment, Learning/benchmarking, Organizational Capabilities, power and leadership culture, management methods
C20	Connectivity	Degree of dependence on other players	Domino effect
C21	Technology Development	Set of technological know-how and resources	Technological innovation, improved HR capabilities in new technologies
C22	Flexibility in sourcing	Ability to quickly change inputs or the mode of receiving inputs	Flexibility, Modular product design, Multimodal Transportation, Supply Contract Flexibility, Multi-sourcing
C23	Flexibility in order fulfillment	Ability to quickly change outputs or the mode of delivering outputs	Flexibility, Alternate distribution channels, Multimodal Transportation
C24	Redundancy	How much has been invested in resources compared to how much was needed	Redundancy
C25	SC Lenght	Refers to how many players are part of the SC	SC Length
C26	Market Competition	Presence of competitors in the fashion industry market	Highly competitive structure of fashion industry,
C27	Fast Fashion	Capability to adapt quickly to current and emerging trends of the fashion market	Short product life cycles, product variety
C28	Sustainable development	Development that meets the needs of the present without compromising the ability of future generations to meet their own needs	Sustainable development
C29	Counterfeit	Sale of products that imitate the originals at low price and that represent a major risk	Counterfeits
C30	Supply Chain Resilience	The ability of a system to return to its original state or move to a new, more desirable state after being disturbed (Christopher and Peck, Helen, 2004)	Top Event

Table 3.13: Taxonomy analysis: concepts definition

3.5.4 IV Step: FCM Design

As exemplified in the previous section, during this step the analysis of potential conflicts between the various identified concepts and relationships was carried out, by assessing the differences between the different mental models. The result is the FCM shown in Figure 3.7.

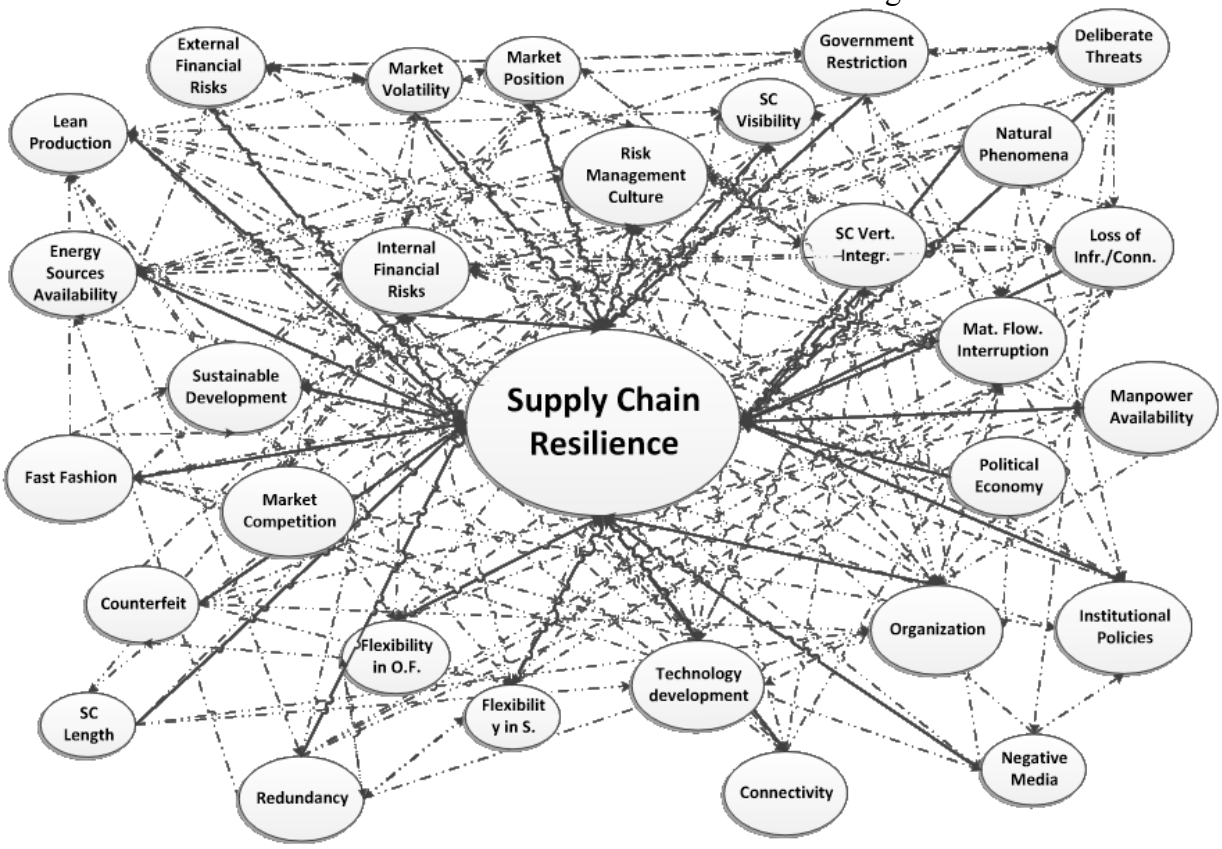

Figure 3.7:Fashion case study FCM

3.5.5 V Step: Refinement Phase

As exemplified in the previous section, during this step the analysis of potential conflicts between the various identified concepts and relationships was carried out, by assessing the differences between the different mental models. The result is the Fuzzy Cognitive Maps, shown in a matrix format in Appendix B.

3.5.6 VI Step: Hidden pattern recognition phase

The most relevant paths of concepts within the route that leads to SCR can be highlighted by sorting the Indirect Effect (IE). In particular, in Table 3.14, principal paths with a indirect effect higher than 0.60 are reported regarding the analysis of the overall SC. Tables 3.15-18 instead list the first 10 paths of each of the players composing the SC analysed in this study to identify an optimal trade-off between comprehensiveness and conciseness of the analysis.

Supply Chain Principal paths						
#path	Starting Node					IE
1	Lean Production Characteristics	SCR				0.74
2	Fast Fashion	Lean Production Characteristics	SCR			0.74
3	Natural phenomena	SCR				-0.72
4	SC Length	SCR				-0.71
5	Sustainable development	SCR				0.70
6	Market Position	SCR				0.68
7	Negative media	Market Position	SCR			0.68
8	Technology Development	Market Position	SCR			0.68
9	Counterfeit	Market Position	SCR			0.68
10	Deliberate threats	Market Volatility	Market Position	SCR		0.66
11	SC Visibility	Flexibility in order fulfilment	Materials flow interruption	SCR		-0.65
12	SC Vertical Integration Degree	Flexibility in order fulfilment	Materials flow interruption	SCR		-0.65
13	Loss of infrastructure	SCR				-0.65
14	Materials flow interruption	SCR				-0.65
15	Manpower availability	SCR				0.65
16	Connectivity	Materials flow interruption	SCR			-0.65
17	Flexibility in sourcing	Redundancy	Materials flow interruption	SCR		-0.65
18	Flexibility in order fulfillment	Materials flow interruption	SCR			-0.65
19	Flexibility in order fulfillment	Redundancy	Materials flow interruption	SCR		-0.65
20	Redundancy	Materials flow interruption	SCR			-0.64
21	Market Competition	Lean Production Characteristics	SCR			0.64
22	Market Competition	Deliberate threats	Loss of infrastructure	SCR		-0.64
23	Market Competition	Deliberate threats	Materials flow interruption	SCR		-0.64
24	Market Competition	Market Volatility	Market Position	SCR		0.64
25	External Financial Risk	Internal Financial Risk	Negative media	Market Position	SCR	0.63
26	Internal Financial Risk	Negative media	Market Position	SCR		0.63
27	Government restrictions	SCR				-0.63
28	Market Volatility	External Financial Risk	Internal Financial Risk	SCR		-0.62
29	Market Volatility	External Financial Risk	Risk Management culture	SCR		0.62
30	Risk Management culture	SCR				0.62

Table 3.14: SC case study principal paths

Tier-One Principal paths					
#path	Starting Node				IE
1	Organization	SCR			0.93
2	Lean Production Characteristics	SCR			0.87
3	Manpower availability	Organization	SCR		0.87
4	Manpower availability	SCR			0.87
5	Fast Fashion	Lean Production Characteristics	SCR		0.87
6	Fast Fashion	Organization	SCR		-0.87
7	Materials Flow Interruption	Organization	SCR		0.73
8	Materials Flow Interruption	SCR			-0,73
9	External Financial Risk	Risk Management Culture	Organization	SCR	0.73
10	External Financial Risk	Risk Management Culture	SCR		0.73

Table 3.15: Tier-one supplier principal paths

	Manufacturer Principal paths				
#path	Starting Node				IE
1	Lean Production Characteristics	SCR			0.87
2	Market Position	SCR			0.87
3	Market Competition	Lean Production Characteristics	SCR		0.87
4	Fast Fashion	External Financial Risk	SCR		0.87
5	SC Vertical Integration Degree	Flexibility in sourcing	Internal Financial Risk	SCR	0.80
6	Market Volatility	External Financial Risk	SCR		0.73
7	Flexibility in order fulfilment	SCR	SCR		0.73
8	Technology Development	Lean Production Characteristics	Flexibility in order fulfillment	SCR	0.73
9	Technology Development	Lean Production Characteristics	SCR		0.73
10	Technology Development	SC Visibility	Flexibility in order fulfilment	SCR	0.73

Table 3.16: Manufacturer Principal Paths

Shipper Principal paths						
#path	Starting Node					IE
1	Redundancy	SCR				0.87
2	Natural phenomena	Materials flow interruption	SCR			0.73
3	Sustainable development	Internal Financial Risk	Risk Management culture	Organization	SCR	0.67
4	Loss of infrastructure and/or connection	Internal Financial Risk	Risk Management culture	SCR		0.67
5	External Financial Risk	Energy sources availability	Risk Management culture	SCR		0.67
6	Internal Financial Risk	Risk Management culture	SCR			0.67
7	Internal Financial Risk	Risk Management culture	Energy sources availability	Risk Management culture	SCR	0.67
8	Internal Financial Risk	Risk Management culture	Organization	Materials flow interruption	SCR	0.67
9	Market Volatility	Risk Management culture	SCR			0.67
10	Market Volatility	Risk Management culture	Energy sources availability	Risk Management culture	SCR	0.67

Table 3.17: Shipper principal paths

Retailer Principal paths							
#path	Starting Node						IE
1	Redundancy	SCR					0.90
2	Lean Production Char.	SCR					0.85
3	Fast Fashion	Lean Production Characteristics	SCR				0.85
4	Manpower availability	SCR					0.70
5	External Financial Risk	Risk Management culture	Manpower availability	SCR			0.70
6	Market Position	SC Vertical Integration Degree	SC Visibility	Flexibility in sourcing	Redund.	SCR	0.70
7	Manpower Availability	SCR					0.70
8	Risk Management Culture	Manpower Availability	SCR				0.70
9	SC Vertical Integration	SC Visibility	Flexibility in Sourcing	Redundancy	SCR		0.70
10	Technology Development	Lean Production Characteristics					0.70

Table 3.18: Retailer principal paths

Analysing Table 3.14, we can observe that the first path (Path 1) is directly linked to the top event "SCR". "Lean production characteristics", with a IE of 0.74, is one of the two most relevant paths for the SC analysed in the case study. Almost all the SC players highlight that adopting lean production techniques is fundamental to maintain a flexible and therefore resilient SC: This can be observed by looking at the tables of the principal paths of the tier-one supplier, manufacturer and retailer actors (respectively, Table 3.15, Table 3.16 and Table 3.18), in which the "Lean Production characteristics" path stands out with a IE of 0.87.

The relationship between Lean Production and SCR has been widely studied in the literature. Our results disagree with those obtained by Soni et al (2014). These authors stated that more lean and just-in-time SC networks have reduced the slack available to handle uncertain events and that doing so reduced SCR.

The path "Fast fashion"-> "Lean Production Characteristics"->"SCR" (Path 2), with a IE of 0.74, is also ranked at the top of the path list in Table 3.14. This result agrees with many authors' research stating that "Fast Fashion" is a key characteristic of the modern fashion industry (Escalona Orcao and Ramos-Pérez, 2015) (Mehrjoo and Pasek, 2016) (Mehrjoo and Pasek, 2014). Moreover, the present result highlights its connection to "Lean Production Characteristics", noting this production philosophy as a solution

to maintain SCR in the modern fashion industry. The production model is at the heart of this sector: The classic assembly line, albeit adapted to the fashion industry, is no longer effective in a rapidly changing world. All the features that make fashion a "fast" sector require not only the least amount of time available to industrialize and produce a product but also the complexity and refinement of the finished product. Direct consequences are always new work cycles, new materials, supply of complex accessories and semi-finished products. Therefore, a flexible production structure is crucial to efficiently and timely address sudden turnarounds of the market. This is also true for the final ring of the SC, in this case the retailer: In fact, the paths “Lean Production Characteristics – SCR” and “Fast Fashion – Lean Production Characteristics – SCR” both have a IE of 0.85.

The “Natural Phenomena” and “SC Length” concepts follow with IEs of -0.72 and -0.71, respectively (Paths 3 and 4, Table 3.15). This result shows that these two concepts contribute negatively to the SCR. A natural catastrophe can seriously damage the everyday activity of the SC. In particular, a tsunami, a flood or even generic adverse weather can affect the regular flow of materials, which in turn can have a negative impact on SCR. Moreover, a significant SC length can increase the probability of such disruptions occurring. Trivially, the more actors compose the SC, the greater probability there is of one or some of them being hit by a disruption.

As seen in Table 3.17, the path “Natural Phenomena – Materials Flow Interruption – SCR” also has an important IE of 0.73: This result shows that the Natural Phenomena concept is a concern to the shipper SC actor, which evidently must keep the Materials Flow running to be resilient in the SC context.

Examining Table 3.14, it can be observed that “Material flow interruption” is directly linked to SCR (path 14) and is the last concept linked to SCR in another 8 paths (11, 12, 16, 17, 18, 19, 20 and 23). This confirms that in this industry sector, it is critical for all actors to contribute to timely deliver products to keep pace with the current fashion trends.

Moving forward in Table 3.14, “Sustainable development” and “Market Position” are found to have, respectively, IEs of 0.70 and 0.68, therefore contributing positively to SCR. Sustainable development in fact represents an increasing issue that must be addressed by fashion industry actors due to the current market trends and consumer behaviour (Macchion et al., 2015) (Şen, 2008) (Mehrjoo and Pasek, 2016). The market position of a company is also fundamental: Brand attractiveness and internationalization are at the core of the fashion industry, and the brand of a company can increase and maintain high SCR. This result agrees with many studies affirming the importance of this factor for the fashion industry (Martino et al., 2015).

This result is also aligned with paths 7-10, where “Negative media”, “Technology development”, “Counterfeit” and “Deliberate threats” along with “Market Volatility” are all linked to “Market Position”, before connecting to “SCR”.

Observing the results shown in Table 3.16, it can be noted that the concept of “Market Position” is crucial even from the point of view of the manufacturer: In fact, it is directly linked to SCR, with a IE of 0.87.

Another interesting aspect can be observed analysing paths 21, 22, 23, and 24: in each one, “Market Competition” is the driver of many concepts that form the paths connecting to SCR.

This result confirms that the factor of competition is preponderant in the fashion industry (Dewi et al., 2015; Vaagen and Wallace, 2008; Wang et al., 2012) and highlights that market competition can strongly influence the SCR of a fashion company.

4 Supply Chain Resilience Triangle

According to various definitions listed in the first chapter, SCR can be linked to the development of readiness to an unexpected event, and into providing an effective and efficient response that supports fast recovery to the desired state of the system.

This behavior can be illustrated with the "Resilience Triangle" (see Fig. 4.1), a plotting tool first introduced by Bruneau et al (2003).

Figure 4.1: The Resilience Triangle

The Resilience Triangle, according to Tierney and Bruneau (2007), can represent "the loss of functionality from harm and discomfort". The Resilience Triangle helps in fact visualizing the magnitude of the disorder and the negative impact on system performance. It is useful to assess the resilience of a system after an unexpected disorder. It represents a measure of both the loss of functionality of a system after a disaster and the amount of time it takes for the system to return to normal performance levels.

Resilience enhancement measures are designed to reduce the Resilience Triangle size by improving performance (vertical axis) strategies and reducing recovery time (horizontal axis).

This figurative tool can be applied in various fields, but it is born primarily because of the need to measure the resilience of infrastructures in case of natural disasters.

Still according to Bruneau et al (2003), considering for example the happening of an earthquake, the "loss of resilience", R_1, with respect to that specific event, can be measured by the size of the expected degradation in quality, over time (that is, time to recovery). Mathematically, it can be defined by the equation 4.1:

$$R_1 = \int_{t_o}^{t_1} [100 - Q_t]\, dt$$

Eq. 4.1 Loss of resilience equation

Yu et al. (2014) exemplify these concepts applied to one of the most frequent catastrophes in the world, the earthquake. In their research the Resilience Triangle was hence used in order to compare services performance after an earthquake in Chile and Japan with Oregon's.

The Resilience Triangle showed in Fig. 4.2 indicates in fact that Chile and Japan have high levels of resilience to earthquakes while, at the time of the study, Oregon had almost none.

Figure 4.2: Resilience Triangle according to Yu et al. (2014) analysis

4.1 Resilience Triangle within the SC performance profile

To our knowledge, in the extant literature there are only few examples of Resilience Triangle applications into the SC field of study.

One example can be found in the study of Carvalho (2012), who applied the Resilience Triangle to SC, providing hence a comprehensive study framework.

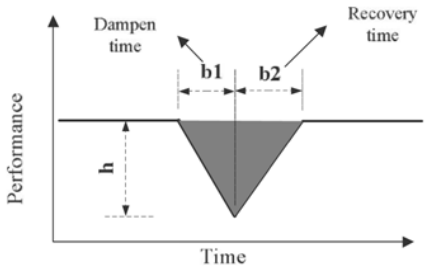

Figure 4.3: Resilience Triangle with dampen time

As can be seen from figure 4.3, the depth of the triangle (h) shows the severity and extent of the damage, i.e. the severity of the disturbance, and the length of the triangle (b) shows the damping time (b1) and the recovery time

(b2). The smaller the triangle, and the more the system or the SC is resilient to unexpected disturbances. Therefore, the Resilience Triangle should be minimized. Actions, behaviors and property of companies should be aimed at reducing the area of the triangle.

To extend this research, this paper aims to combine the Resilience Triangle by plotting within the tool the profile of a disturbance proposed by Sheffi and Rice (2005) in their SCR analysis, in which they exemplified the profile that a significant disruption can have over a company performances.

As can be seen from fig. 4.4, Sheffi and Rice broke the performance

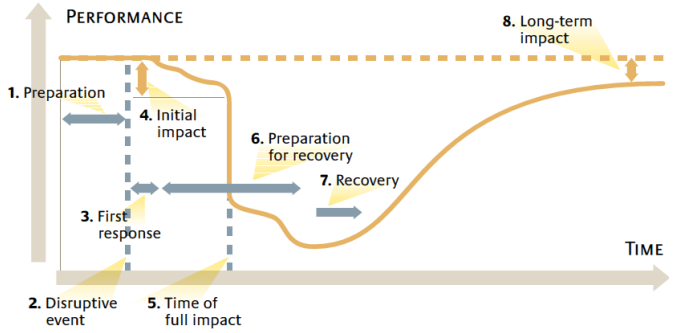

Figure 4.4: The disruption profile plotted by Sheffi and Rice (2005)

profile down into eight different phases:

1. Preparation: the activities of companies with goal of preventing a given disorder, decreasing, when possible, both the likelihood and the impact of a risk;
2. Disruptive Event: the moment in which the disruptive event takes place;

3. First response: the initial response to the event, where a "workaround" solution to the problem is preferred: the aim at this stage is to control the situation and preventing further damage;
4. Initial Impact: This is the first nature that the effect of disruption on company performance can have two natures.
5. Time of full impact: if the disruption is not instantaneous (such as an earthquake or an explosion), it takes time to the event to fully take place;
6. Preparation for recovery: first companies action aimed to resume activities after the destructive event took place;
7. Recovery: all the actions required to bring back company performance to the previous levels as soon as possible;
8. Long term impact: The second nature that a disorder can have. Do not let companies return to the same level of previous performance

Taking this profile analysis to a next step, these phases can be divided into two categories, as Table 4.1 shows:

#	Fase	SC Management	Disruption
1	Preparation	X	
2	Disruptive event		X
3	First response	X	
4	Initial impact		X
5	Time of full impact		X
6	Preparation for recovery	X	
7	Recovery	X	
8	Long term impact	X	

Table 4.1: Disruption profile analysis

In order to combine the Bruneau Resilience Triangle with the disturbance profile plotted by Sheffi and Rice, the elements from the column "SC Management" are placed into the Resilience Triangle according to their afference.

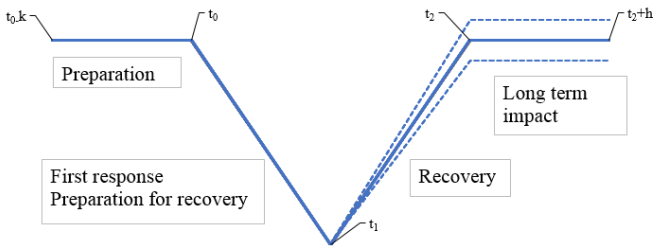

Figure 4.5: The Resilience Triangle of a SC plotted according to Sheffi and Rice (2005)

According to the plotting illustrated in fig. 4.5:

- t_0-k is the beginning of the preparation activities;
- t_0 is the moment in which the disruption takes place;
- t_1 is the time of full impact;
- t_2 is the moment in which the company consider itself recovered from the event;

- t_2+h is the time horizon in which is analysed the long term impact of the disruption.

The preparation phase is associated with all the activities envisaged before the happening of a disruptive event, from t_0-k to t_0.

The "first response" and "preparation for recovery" phases are then associated with the second segment, from t_0 to t_1.

The "recovery" phase is then associated to the third segment, from t_1 to t_2.

The last phase, "long-term impact", refers to the final status of the SC, from t_2 to t_2+k: whether the disturbance causes irreparable damage and therefore long-term effects or, on the contrary, leads the firm to obtaining a competitive advantage over other companies.

4.2 Resilience Triangle Taxonomy

In order to enhance the study of this framework, a taxonomy analysis was conducted.

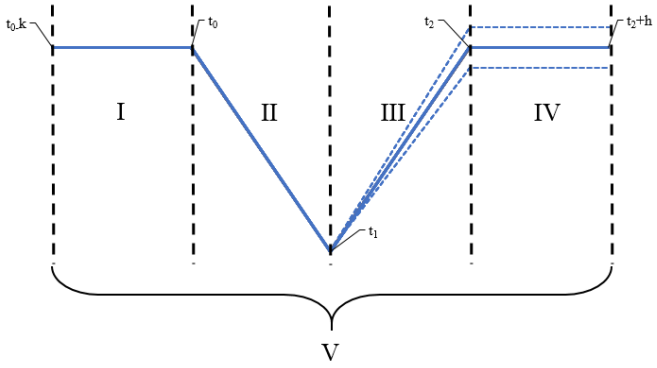

Figure 4.6: Resilience Triangle sectors

All SCR definitions listed in the second chapter (Table 2.1) were then studied in order to assign each of the characteristics exemplified by the definitions, to one of the sectors of the Resilience Triangle, as shown in fig. 4.6:

I. Prevention;

II. Mitigation;

III. Recovery;

IV. Long term impact;

V. Time: despite Sheffi and Rice (2005) didn't explicitly mentioned the component of time in their analysis, many researchers mention it as a critical measure of the resilience performance of a SC (Carvalho et al., 2012; Brandon-Jones et al., 2014; Falasca et al., 2008; Longo, F. and T. Oren, 2008; Shuai et al., 2011; Ambulkar et al., 2015; Hohenstein et al., 2015; Blackhurst et al., 2011)

This step was necessary in order to group the factors exemplified in the five cluster of the Resilience Triangle.

This taxonomy step has been performed following the Delphi method criteria: in order to increase the relevance of this study in fact, experiences and knowledge contributions from both the academic world and from SC management were considered to be fundamental. To this purpose, two academics whose main research field was SC management and two SC managers participated to this classification.

Their task consisted of analyzing Table 2.1 and then associate the SCR characteristic exemplified by each definition to one of the 5 groups. The complete results of this taxonomy are listed in Appendix C.

The results of this step are summarized in Fig.4.7:

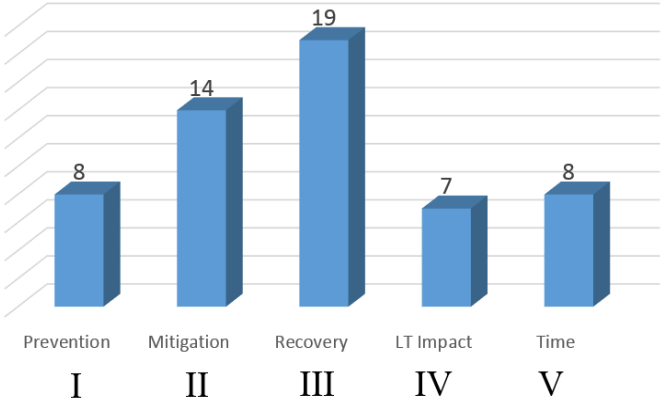

Figure 4.7: Characteristics gathered in the 25 SCR definitions

According to the classification listed in Appendix C, as Fig. 4.7 shows, a number of 19 definitions refers to the recovery phase, 14 times mitigation phase, 8 times prevention and time, and 7 times long term impact.

According to the analyzes carried out, 19 out of 25 definitions taken into account explicitly mention the recovery phase. This result is in line with the definition of resilience according to the Oxford Advanced Learners Dictionary.

Moreover, in one of the first definitions, which dates back to 2004, Christopher and Peck (2004) define SCR as "the ability of a system to return to its original state or move to a new, more desirable state after being disturbed". This definition is perhaps the most faithful to the original definition of resilience, and it only concerned that phase that is called recovery. Over the course of the years however, research has expanded to addressing other phases of resilience: preparation, mitigation, long-term impact as the result achieved by the ability to be resilient. This is because they are all linked with the goal of maximizing company performance, as shown in Fig. 4.8.

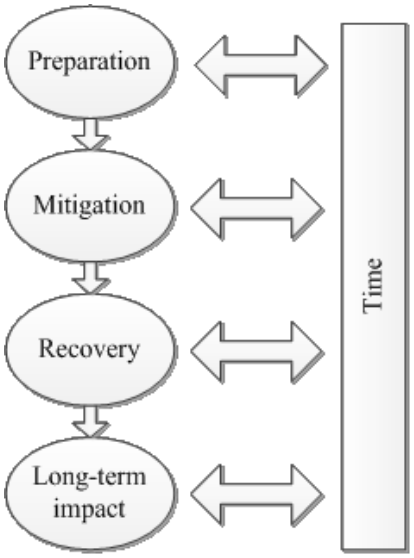

Figure 4.8: Connections among the various sectors of the Supply Chain Resilience Triangle

4.3 Supply Chain Resilience Triangle Modular Analysis

In order to further explore the concept of SCR, this study aims to develop a modular structure of its components. A modular structure can be metaphorically represented as a system in which each piece is independent but functional to everything. Each unit is original but responds to a completed and defined project. Consequently, each module can be characterized as autonomous and can be associated with objectives, results, causes and associations to factors of any nature. The "modules" identified by the SCRT, in fact, represent the total path meaningfully, but independently.

In order to offer a stepping stone for this modular research path, the work methodology has been divided into two parts. The first part consists in

researching the factors that, according to literature, constitute capabilities and vulnerabilities of a resilient SC. This distinction is suggested by the work of Pettit (2008) who, through his research, have constructed a conceptual framework to better understand what influences a resilient SC. The second phase consisted in assigning the various factors to the four categories of SCRT mentioned earlier (prevention, mitigation, recovery, long-term impact).

4.3.1 Literature review: factor Research

To identify the main factors affecting SCR, a literature review was conducted. The literature search was carried out in relevant literature databases, including Emerald, Metapress, Science Direct, Scopus, and Web of Science, using one set of keywords. In order to find cross-sectorial research studies, the set included keywords regarding: “Supply Chain”, “Resilience”, “Risk”, “Disruptions”, “Sustainable” and “Supply Uncertainties”. Subsequently, different filters were applied to select relevant studies constituting the core set of articles for selecting the main factors to include into the study. The filters were defined as follows:

- Ensure substantive relevance, defined as adequacy of the articles in addressing and capturing the investigated phenomenon, by requiring that they contain a keyword in their title, abstract or keywords;
- Consider only English-language articles;

- Read remaining abstracts for substantive relevance;
- Read remaining full articles for substantive relevance.
- No time limit or limit on publication type was adopted in these searches

No time limit or limit on publication type was adopted in these searches. Through the application of the first two filters, 95 papers were identified, of which 27 were defined as relevant. The factors which have been identified were then divided into two categories: capabilities and vulnerabilities.

In this study, capabilities are defined as the methodologies, technologies, and skills a company needs to perform the core functions in the SC context. Consequently, they are understood as endogenous factors in the supply chain.

On the contrary, vulnerabilities are understood as the possible interferences that from outside the context of the SC can prevent companies from carrying out their everyday activities. The result of this research is shown in Table 4.2. Analysing the results, it can be noted that the literature review has allowed some interesting factors to be identified: for example, SC Visibility has been cited several times as a factor characterizing a resilient SC. Risk Management Culture is also a key factor: many studies have characterized it as a crucial basis for building a resilient SC.

Among the vulnerabilities, terrorism and natural disasters were quoted 7 times each. This demonstrates that in recent years such disruption dramatically affected business performance around the world.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Lean Production Practices	C	C		C																							
Portfolio Diversification	C																										
Financial Reserves and Liquidity	C																										
Market Share	C													C													
Brand Equity	C											C															
Customer Relationships	C														C												
SC Visibility	C			C	C			C	C		C								C	C							
Collaboration	C			C				C			C						C			C							
Theft	V																										
Terrorism	V		V					V						V	V	V											V
Political Economy Change	V																										
Cross-Training	C																										
Learning	C																										
Technological Innovation	C																										
Modular Product Design	C																										
Supplier Contract Flexibility	C																										
Alternate Distribution Channels	C																										
Multi-Sourcing	C																										
Credit reserves		C																									C
Natural Disaster		V			V	V									V	V							V				V
Adverse weather																											V
Economic Crises		V	V											V	V	V											
Risk Management Culture	C			C	C			C						C	C				C				C				
War								V						V													
Flexibility				C				C			C		C				C			C							
Redundancy								C									C		C								
Planning and Control									C																		
Power and Leadership Culture									C																		
Product Recall												V															
Negative media												V															
Recovery Planning System														C													
Measures Applied after Terrorist Attack														V													
Workforce Availability Constraint														V		V											V
Multimodal Transportation														C													
Challenging Political Context															V												
Infrastructural Disruptions																V											
Media Negative Influence																V											
BC Planning						C											C										
Intensive Training in Risk Management																	C										
Organizational Capabilities																	C										
Assess Effect of Disruptions																		C									
Knowledge Assessment																			C								
Strikes	V																		V								
Cyber-Attack/Data Breach																							V				V
Embargoes																							V				
It/Communication Outage																							V				V
Transport/Network Disruptions																							V				V
Product Quality Accident																							V				V
Loss of Talent/Skills																							V				V
Energy Scarcity																							V				V
New Laws/Regulation	V																						V				
Collaborative Communication																								C			
Currency Exchange Rate Volatility																											V
Insolvency in the supply chain																											V
Counterfeits																									V		
HR Capabilities in New Technologies																								C			
Closer Relationship with Partners	C																										

Table 4.2: Factor research result. C=Capability, V=Vulnerability

(1) Pettit (2008); (2) Mensah and Merkuryev (2014); (3) Annarelli and Nonino (2016); (4) Soni et al. (2014); (5) Bruno and Clegg (2015); (6) Stolker et al. (2008); (7) Scheffer et al. (2012); (8) Christopher and Peck Helen (2004); (9) Cooper et al. (1997); (10) Craighead et al. (2007); (11) Jüttner and Maklan (2011); (12) Hsu and Lawrence (2016); (13) Lengnick-Hall et al. (2011); (14) Tang (2006); (15) Bueno-Solano and Cedillo-Campos (2014); (16) Boin et al. (2010); (17) Rice and Caniato (2003); (18) Kristianto et al. (2014); (19) Scholten et al. (2014); (20) Johnson et al. (2013); (21) Klibi and Martel (2012); (22) Boekholt et al. (1999); (23) Green (2015); (24) Scholten and Schilder (2015); (25) Stevenson and Busby (2015); (26) van der Vaart and van Donk (2008); (27) Supply Chain Resilience Report (2016)

4.4 Factor categorization

A focus group was created to complete this task. The group was composed of two academics and three managers working in different industry sectors. The task assigned to the group can be described as follows: each of the participants has been delivered the two lists of factors found. After explaining and clarifying the doubts of each of the group members, a card with 4 questions for each factor. Each card was meant to assign capabilities and vulnerabilities factor to one or more sectors of the SCRT. The card illustrated the above represented SCRT and provided the definitions of each sector and required to assign each factor to one of the sectors. Consensus has been reached after three iterations of Delphi analysis, and the results can be seen in Table 3.3 and Table 3.4

Looking the results enlisted by the vulnerabilities table (Table 3.3), the "natural disasters" and "adverse weather" factors classification, according to the results obtained, are both associated with the second and third sector, respectively mitigation and recovery. Only the factor “natural disaster”, though, influence the long-term impact of the disruption on SC. This is in fact witnessed by the disastrous and longstanding consequences of tsunamis, earthquakes and floods for global SC around the world. The second factor, however, has no influence on the third and final stages. Probably, this is

because the consequences of common adverse weather conditions are often contained in a short time. Another interesting observation can be elaborated by analyzing factors such as "new laws and regulation" and "measures applied after terrorist attacks". Both factors, besides affecting mitigation and recovery, affect also long-term impact. Probably because the drafting of new laws or regulations - and in particular those that are applied after an event such as a terrorist attack - are long-term measures that affect companies and society for many years to come. Among vulnerabilities, the only factors influencing the prevention phase are "Workforce Availability Constraint", "Strikes" and "Loss of Talent / Skills". Most likely because this phase is closely associated with the availability of manpower and specific know-how to implement such measures. The “human factor” is confirmed to have a strategic importance for a business and into the entire SC, as other studied pointed out too (Bevilacqua and Ciarapica, 2018).

Examining Table 4.4, we can observe the results of the capabilities analysis. One interesting result is the presence of many transversal factors in all four phases: "SC Visibility", "Collaboration", "Technological Innovation", "Risk" Management Culture", “Collaborative Communication” and "Closer Relationship with Partners" are all crucial factors, at all stages of SCRT, according to this study. Many studies agree with this result. Bevilacqua et al. (2015), for example, pointed out the importance of a SC of an accurate and

self-consistent information flow. "Market Share," "Brand Equity," and "Customer Relationships" are also important factors that are positively influencing the long-term impact that a disruption might have on a SC. "Multimodal transport" is another interesting factor. In fact, according to these results, it only affects the mitigation phase: this is probably because it is an excellent workaround solution in the event of a failure of the SC distribution network.

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Vulnerabilities	Prevention	Mitigation	Recovery	Long Term Impact
Theft		x	x	x
Terrorism		x	x	x
Political Economy Change			x	x
Natural Disaster		x	x	x
Adverse weather		x		
Economic Crises		x	x	x
War		x	x	x
Product Recall				
Negative media			x	x
Measures after Terrorist Attack			x	x
Workforce Availability Constr.	x	x	x	
Challenging Political Context			x	
Infrastructural Disruptions		x	x	
Strikes	x	x		
Cyber-Attack/Data Breach		x	x	
Embargoes		x		
It/Communication Outage		x		
Transport/Network Disruptions		x		
Product Quality Accident		x	x	
Loss of Talent/Skills	x	x		
Energy Scarcity		x		
New Laws/Regulation		x	x	x
Currency Exchange Rate Volatility		x	x	
Counterfeits		x	x	x

Table 4.3: Vulnerabilities analysis results

Capabilities	Prevention	Mitigation	Recovery	Long Term Impact
Lean Production Practices		x	x	
Portfolio Diversification			x	
Financial Reserves and Liquidity	x	x	x	x
Market Share			x	x
Brand Equity		x	x	x
Customer Relationships		x	x	x
SC Visibility	x	x	x	x
Collaboration	x	x	x	x
Cross-Training	x	x	x	
Learning	x	x	x	
Technological Innovation	x	x	x	x
Modular Product Design		x	x	
Supplier Contract Flexibility		x	x	
Alternate Distrib. Channels		x	x	
Multi-Sourcing		x		
Credit reserves	x	x	x	
Risk Management Culture	x	x	x	x
Flexibility		x		
Redundancy		x	x	
Planning and Control	x	x	x	
Power and Leadership Culture	x	x	x	
Recovery Planning System		x	x	
Multimodal Transportation		x		
BC Planning		x	x	
Organizational Capabilities		x	x	
Assess Effect of Disruptions	x			
Knowledge Assessment	x			
Collaborative Communication	x	x	x	x
HR Capabilities in New Tech		x	x	
Closer Relationship with Partners	x	x	x	x

Table 4.4: Vulnerabilities analysis results

An interesting conclusion can be reached by observing the SCRT and the capabilities that lead the performance, plotted by the instrument, to improve over time. In fact, the capabilities pertaining to the third and fourth sectors (respectively Recovery and Long-term Impact) are the factors that, directly, allow the company to return as effectively and efficiently as possible to the initial situation. However, if these capabilities are sufficiently developed within the SC, and if the companies involved in these operations are able to exploit these skills and methodologies acquired at their best, it is possible to obtain a "better" recovery state compared to the pre-disruption one. Moreover, if this "leap" is maintained in the "long-term", it can represent a better state of equilibrium. In fact, if we consider "resilience" as the return to a state of equilibrium after a disturbance, the achievement of a better state can be called "II Level Resilience".

The achieving of such II level Resilience can be crucial: it could mean for example a competitive advantage, especially towards the competitors that may have suffered the same disruption.

5 Conclusions and further research

This research work further contributes to the investigation of resilience in the Supply Chain, by providing a conceptual basis on the subject, and two study approaches.

- The first approach shows the connection among the various factor mentioned in the literature: with this knowledge, the ripple effect is unveiled, allowing decision makers to surgically intervein in order to stop the path of events that can lead to a disruption. Further study of this approach could be the research of cycles among those paths, and how these cycles are connected to each other. The presence of a cycle indicates a recursive ripple effect which can bring positive or negative effect to the Supply Chain. Moreover, these cycles can be connected to each other. The result analysis from this research can bring to the examination of the link within and among those cycles, in order to break the negative ones or to enforce the positive ones. Moreover, the results discussed in chapter 3 highlight how the expertise area of each member of the panel affects the concepts and relationships strength identification. Thus, it will be crucial to provide a mechanism to evaluate properly the experts' knowledge effects on the Fuzzy

Cognitive Map realisation giving different credibility values to each expert judgement according to their expertise area and each specific Fuzzy Cognitive Map relationships.

- The second approach of this research consists in the modular Supply Chain Resilience analysis offered by the Supply Chain Resilience Triangle modelling instrument. The potential of this instrument is its intuition: it is possible to associate each step in a separate and independent way with the various factors involved. Through this, it would also be possible to associate quantitative analysis with each of the proposed phases: for example, it could model a company's or Supply Chain's performance with respect to each phase. Another interesting aspect emerged during this study is the particular contribution that the different factors can offer to each stage of a Supply Chain's performance evolution during a disruption. The SCRT can indeed be a useful tool in order to assess company performances. In fact, a similar benchmark can be conducted by comparing different KPIs internally to a company or to a SC. Comparing the various Triangles can be indeed useful to verify differences at various critical points when dealing with a disorder: preparation, mitigation, recovery, long term impact and time. The

further development of this study regards the use of this research approach to Supply Chains operating in different industrial sectors to provide additional useful insights.

6 Appendix A – Weighted Matrix, Home Appliance case study

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29
C1	0,00	0,00	0,00	0,00	0,00	0,00	0,39	0,41	0,00	0,00	0,00	0,00	-0,36	0,00	0,00	0,00	0,00	0,00	0,66	0,61	0,00	0,64	0,77	-0,46	-0,17	0,00	0,00	0,00	0,67
C2	0,00	0,00	0,60	0,61	0,00	0,54	0,00	0,00	0,00	0,00	0,30	0,00	0,00	0,00	-0,34	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,39
C3	0,59	0,00	0,00	0,00	0,00	0,64	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,30	0,00	0,54	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,56
C4	0,56	0,63	0,64	0,00	0,34	0,63	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,23	0,47	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,20
C5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,24	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,36
C6	0,00	0,00	0,00	0,00	0,00	0,00	0,30	0,16	0,00	0,00	0,00	0,00	0,00	0,13	0,17	0,00	0,00	0,00	0,51	0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,61
C7	0,00	0,00	-0,26	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,31	0,13	0,00	-0,01	0,00	0,00	0,00	0,64
C8	0,00	0,00	0,00	0,00	0,46	0,00	0,57	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,34	0,27	0,46	0,00	0,00	0,00	0,00	0,00	0,37
C9	0,00	0,66	0,36	0,36	0,00	0,00	0,00	0,00	0,00	0,00	0,56	0,51	0,50	0,00	-0,37	0,00	0,00	-0,40	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,60
C10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,63	0,69	0,00	-0,54	0,00	-0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,71	-0,43
C11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,51	0,00	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,41
C12	0,00	0,00	0,56	0,00	0,00	0,47	0,00	-0,47	0,00	0,00	0,00	0,00	0,00	0,00	-0,49	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,26	0,00	-0,59
C13	0,00	0,00	0,67	0,00	0,00	0,56	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,63
C14	0,00	0,00	0,00	0,00	0,00	0,33	0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,40	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,37
C15	0,00	0,00	0,00	0,00	0,00	0,09	0,00	0,00	0,00	0,00	0,19	-0,07	0,00	0,00	0,00	0,00	0,16	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,56
C16	0,00	0,36	0,21	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,26	0,00	-0,31	0,00	0,04	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,11
C17	0,00	0,00	0,11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,36	-0,26
C18	0,00	0,00	0,00	0,60	0,00	0,00	0,00	0,00	0,00	0,00	0,40	0,00	0,00	0,00	0,00	0,00	0,39	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,40
C19	0,00	0,00	0,00	0,00	0,00	0,07	0,39	0,39	0,00	0,00	0,00	0,00	-0,31	0,33	0,00	0,00	0,00	0,00	0,00	0,00	0,16	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,61
C20	0,00	0,00	-0,09	0,00	0,00	0,00	0,00	0,49	0,00	0,00	0,00	0,00	-0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,24
C21	0,26	0,00	0,03	0,00	0,00	0,26	0,49	0,00	0,00	0,00	0,00	0,07	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,06	0,00	0,07
C22	0,00	0,00	-0,47	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,54	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,30	0,00	-0,01	0,00	0,00	0,73
C23	0,00	0,00	-0,40	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,36	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,27	0,00	0,03	0,00	0,00	0,59
C24	0,00	0,00	0,31	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,03	0,20	0,19	0,03	0,00	0,00	0,00	0,04	0,00	0,00	-0,06	0,47	0,00	0,00	0,00	0,00	0,00	-0,27
C25	-0,06	0,00	0,56	0,00	0,00	0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,14	0,00	0,61	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,53
C26	0,00	0,00	0,04	0,00	0,00	0,00	0,00	0,59	0,00	0,00	0,00	-0,01	-0,04	-0,04	0,00	0,00	0,00	0,00	0,07	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01
C27	0,00	0,00	0,64	0,00	-0,07	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,57	-0,54	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,30
C28	0,00	0,00	0,50	0,00	0,71	0,00	0,00	0,00	-0,43	0,00	0,00	0,00	0,00	0,00	0,24	0,00	0,00	-0,64	0,00	0,64	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,06
C29	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

7 Appendix B - Weighted Matrix, Fashion sector case study

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30
C1	0,00	0,00	0,00	0,00	0,00	0,00	0,60	0,32	0,00	0,00	0,00	0,00	-0,22	0,00	0,00	0,00	0,00	0,00	0,57	0,49	0,00	0,49	0,74	-0,46	-0,49	0,00	0,00	0,00	0,00	0,74
C2	0,00	0,00	0,65	0,51	0,00	0,69	0,00	0,00	0,00	0,00	0,43	0,00	0,00	0,00	-0,65	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,58
C3	0,28	0,00	0,00	0,00	0,00	0,57	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,63	0,00	0,26	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,62
C4	0,43	0,63	0,64	0,00	-0,36	0,54	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,55	0,36	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,48
C5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,22	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,68
C6	0,00	0,00	0,00	0,00	0,00	0,00	0,58	0,32	0,00	0,00	0,00	0,00	0,00	0,58	0,65	0,00	0,00	0,00	0,62	0,52	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,62
C7	0,00	0,00	-0,74	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,58	0,66	0,00	0,00	0,00	0,00	0,00	0,00	0,54
C8	0,00	0,00	0,00	0,00	0,55	0,00	0,66	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,68	0,72	0,00	0,00	0,00	0,00	0,00	0,00	0,57
C9	0,00	0,65	0,57	0,37	0,00	0,00	0,00	0,00	0,00	0,00	0,63	0,71	0,66	0,00	-0,68	0,00	0,00	0,65	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,54
C10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,52	0,75	0,00	-0,65	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,48	0,00	-0,72
C11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,58	0,00	0,00	0,00	0,60	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,63
C12	0,00	0,00	0,68	0,00	0,00	0,57	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,41	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,65
C13	0,00	0,00	0,62	0,00	0,00	0,62	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,62	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,65
C14	0,00	0,00	0,00	0,00	0,00	0,46	0,63	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,68	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,65
C15	0,00	0,00	0,00	0,00	0,00	0,57	0,00	0,00	0,00	0,00	0,52	-0,42	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,55
C16	0,00	0,28	0,24	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,66	0,00	0,68	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,62
C17	0,00	0,00	0,55	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,57	0,00	-0,51
C18	0,00	0,00	0,00	0,65	-0,75	0,00	0,00	0,00	0,00	0,00	0,58	0,00	0,00	0,00	0,00	0,00	0,49	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,45
C19	0,00	0,00	0,00	0,00	0,00	0,45	0,65	0,51	0,00	0,00	0,00	0,00	-0,60	0,49	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,58
C20	0,00	0,00	-0,60	0,00	0,00	0,00	0,00	0,68	0,00	0,00	0,00	0,00	-0,71	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,55
C21	0,65	0,00	-0,46	0,00	0,68	0,65	0,60	0,00	0,00	0,00	0,00	0,00	-0,55	0,66	0,65	0,00	0,00	0,00	0,57	0,48	0,00	0,62	0,55	0,54	0,00	0,00	0,00	0,49	0,00	0,48
C22	0,00	0,00	-0,69	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,62	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,75	0,00	0,00	0,00	0,00	0,00	0,49
C23	0,00	0,00	-0,54	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,68	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,65	0,00	0,00	0,00	0,00	0,00	0,55
C24	0,00	0,00	0,57	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,46	-0,71	0,54	0,48	0,00	0,00	0,00	0,00	0,00	0,00	-0,58	0,60	0,00	0,00	0,00	0,00	0,00	0,00	0,62
C25	0,00	0,00	0,58	0,00	0,00	0,55	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,60	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,71
C26	0,65	0,00	0,60	0,65	-0,52	0,00	0,00	0,62	0,69	0,00	0,00	0,00	0,00	-0,57	0,00	0,63	0,00	0,00	0,00	0,69	0,62	0,65	0,54	0,63	0,00	0,00	0,54	0,60	0,54	-0,63
C27	0,88	0,69	0,62	0,72	-0,57	0,72	0,51	0,60	0,55	0,00	0,00	0,00	0,60	0,00	0,00	0,00	0,00	0,00	-0,52	0,00	0,63	0,62	0,55	0,57	0,00	0,65	0,00	0,60	0,00	-0,58
C28	0,00	0,00	0,58	0,00	0,46	0,00	0,00	0,00	-0,74	0,00	0,00	0,00	0,00	0,00	0,46	0,00	0,00	-0,55	0,00	0,72	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,60
C29	0,00	0,00	0,49	0,62	-0,69	0,60	0,00	0,00	0,77	0,00	0,74	0,00	0,60	0,00	0,00	0,00	0,62	0,52	0,00	0,00	0,54	0,00	0,00	0,00	0,00	0,72	0,57	-0,62	0,00	-0,54
C30	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

8 Appendix C - SCR Definitions Taxonomy Results

Preparation	#	**Mitigation**	#	**Recovery**	#	**Long Term Impact**	#	**Time**	#
Prevent	5	React to an unforeseen disturbance	1	Return quickly to their original state	1	Move to a new, more advantageous	1	Quickly	1, 12, 19, 20, 23
Reduce the probabilities of a disruption	9	Withstand and respond	5	Return to its original state	2, 3, 4, 11	A new more desirable	3	Within an acceptable period of time	2
Proactively plan and design the SC network for anticipating disruptive events	13	Maintain control over performance variability in the face of disturbance	6	Recover from an incident, respond and rebuild alternative means of operations when the subject of an incident	5	Move to a new, more desirable state	4	Reduce the time to recover normal performance	9
Prepare for unexpected events	14	Response to unexpected or unforeseen changes and disturbances	8	Adapt and respond to such changes	8	Ideal status	11, 17	Rapidly, use the recovery time to measure the ability	16
Reducing the likelihood of a disruption	15	Reduce the consequences of those disruptions when they occur	9	Resume and restore operations	10	If possible a more favourable one than that prior to the event, thus gaining a competitive advantage	13		
To be alert	19		10	Recovering an equilibrium state	12	A new stable situation is achieved	22		
Avoid/reduce the probability of disruptions	20	React to internal/external risks and vulnerabilities	12	Transcending to a post robust state of operations	13				
Increases a firm's readiness in dealing with risks	21	Respond adaptively to disruptions while maintaining control over structure and function	13	Recover from them	14				
		Respond to disruptions	14	Bounce back from disruptions	15, 18				
		Respond to changes brought	19	Recovery ability to equilibrium	16				
		Recover	20	Returning to the original	17				
		Its original stable situation is sustained	22	Adapt	19				
		Absorb such shocks	24	Respond	20				
		Maintain continuity in the face of vulnerability or interruption of operations	25	Efficiently recover	23				
				Ability to cope and recover	25				

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