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MILANO 1863

SCUOLA DI INGEGNERIA INDUSTRIALE
E DELL'INFORMAZIONE

A questionnaire for the maturity assessment of direct suppliers risk management capabilities

TESI DI LAUREA MAGISTRALE IN MANAGEMENT ENGINEERING
INGEGNERIA GESTIONALE

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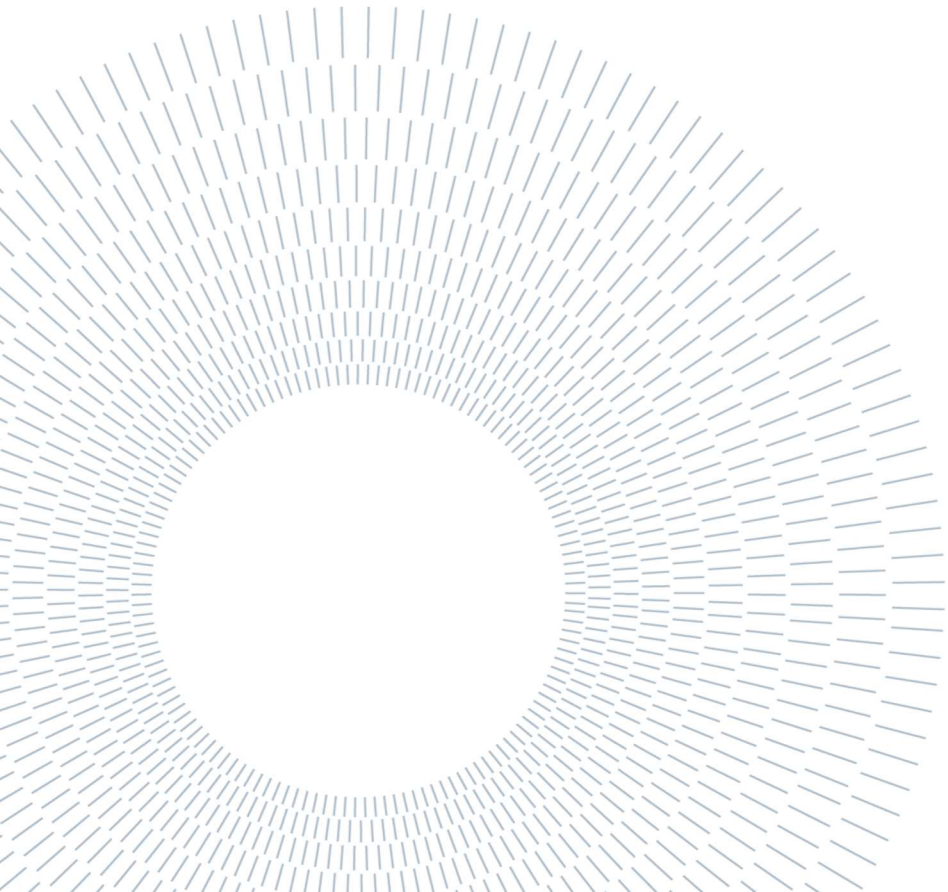
Academic Year:	2020-21

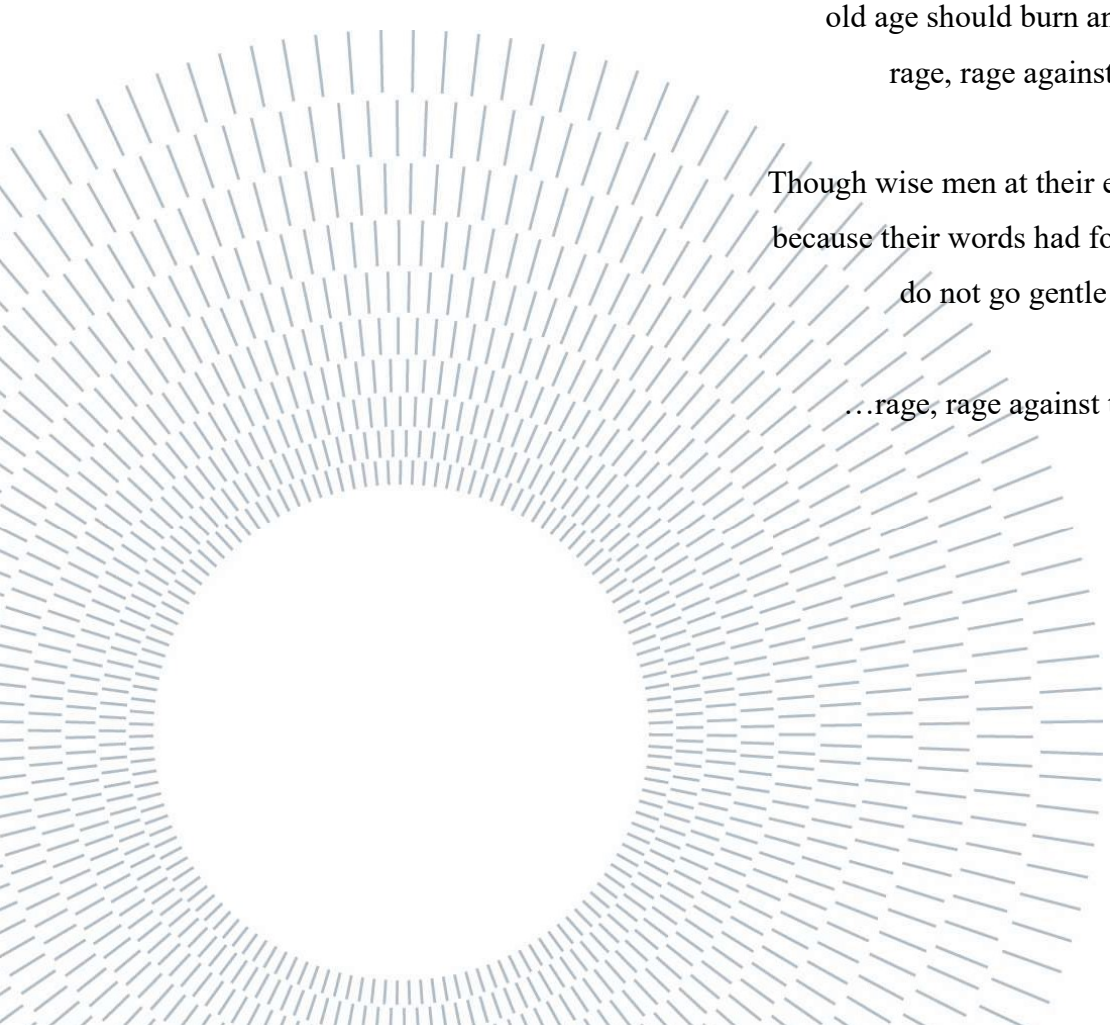


“Do not go gentle into that good night,
old age should burn and rave at close of day;
rage, rage against the dying of the light.

Though wise men at their end know dark is right,
because their words had forked no lightning they
do not go gentle into that good night…

…rage, rage against the dying of the light.”

Dylan Thomas, 1947



POLITECNICO DI MILANO

Abstract

Management Engineering
Dipartimento Di Ingegneria Gestionale
Laurea Magistrale in Management Engineering

A questionnaire for the maturity assessment of direct suppliers risk management capabilities

by Giulio Gambino 925708

Over the past years, the increased level of complexity of actor's interconnections and the increasing amount of data being generated and collected along the supply chain have led to a growing interest of companies in Supply Chain Risk Management and, as a port of it, in sub-supplier management.
Not always, indeed, the same level of attention paid to direct suppliers has been devoted also to sub-suppliers.
Nevertheless, different kind of risks may arise, such as sub-suppliers' disruption, financial instability, etc.
All of this may cause a negative impact on the profitability and performances of the focal company.
On the other end, monitoring and management of sub-suppliers is not that simple: lack of visibility and transparency, issues related to accountability and responsibility may take place.
In recent literature it has been explored the concept of indirect risk mitigation and risk delegation to direct suppliers. Nevertheless, it is missing a practical and easily applicable tool to assess direct suppliers maturity in managing their own supply risk.

This thesis proposes a questionnaire meant to assess exactly these practices and capabilities, by exploring the broad field of risk mitigation strategies and approaches. The questionnaire has been developed with an iterative approach based on the feedbacks obtained through interviews to Hilti Risk expertise and Supply Managers. The reliability, reproducibility and applicability of the model in Hilti processes, enable it to be a valid supporting tool in further industrial and academic applications.

POLITECNICO DI MILANO

Abstract

Management Engineering
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Laurea Magistrale in Management Engineering

Un questionario per la valutazione della maturità delle capacità di gestione del rischio dei fornitori diretti

by Giulio Gambino 925708

Negli ultimi anni, il livello crescente di complessità nelle interconnessioni fra i nodi delle Supply Chain e il crescente quantitativo di dati generati e raccolti lungo la stessa, hanno portato le aziende ad avere un maggiore interesse nella Gestione del rischio della Supply Chain e, come parte di essa, nella gestione del rischio dei sub-fornitori.
Non sempre, infatti, lo stesso livello di attenzione dato ai fornitori diretti è stato dato anche ai sub-fornitori.
Nondimeno, diversi tipologie di rischio possono sorgere, come interruzione della produzione dei sub-fornitori, instabilità finanziaria degli stessi, etc.
Tutto ciò potrebbe causare un impatto negativo sulla profittabilità e le performance aziendali.
D'altro canto, monitorare e gestire i sub-fornitori non è semplice: mancanza di visibilità e trasparenza e problematiche legate alla responsabilità e accountability possono avere luogo.

Nella recente letteratura è stato esplorato il concetto di mitigazione del rischio indiretto e delegazione del rischio ai fornitori diretti. Tuttavia, manca uno strumento pratico e di facile applicazione per valutare la maturità dei fornitori diretti nel gestire il proprio rischio di fornitura.
Questa tesi propone un questionario atto a valutare proprio queste pratiche e capacità, esplorando il vasto campo delle strategie e approcci di mitigazione del rischio.
Il questionario è stato sviluppato con un approccio iterativo basato sui feedback ottenuti internamente da esperti di rischio e Supply Managers di Hilti.
L'affidabilità, riproducibilità e applicabilità del modello nei processi di Hilti, lo rende un valido strumento di supporto per applicazioni industriali e accademiche future.

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List of Abbreviations

AVO	Avoidance strategy
BI	Business Interruption
BM	Bonus/Malus
BN	Bayesian Network
BNT	Bayesian network theory
CON	Control strategy
CPT	Conditional Probability Table
CSR	Corporate Social Responsibility
D&B	Dun & Bradstreet
DBN	Dynamic Bayesian Network
DRR	Disaster Risk Reduction
DTMC	Discrete-Time Markov Chain
FMEA	Failure Mode Effect Analysis
GDP	Gross Domestic Product
GS	Geographical segregation
HED	Hedging strategy
ICT	Information and Communication technologies
INFORM	Index for Risk Management
MM	Manufacturer mitigation
MSC	Multi-tier Supply Chain
OEM	Original Equipment Manufacturer
PVO	Purchasing Volume
RMI	Raw Material Inventory
RQ	Research Question
SC	Supply Chain
SCM	Supply Chain Management

SCRM	Supply Chain Risk Management
SCRM	Supply Chain Risk Management Maturity Model
SM	Supplier mitigation
SPE	Speculation strategy
TC	Total cost
TCO	Total cost of ownership
TDC	Total cost of a disruption
TSR	Transfer and share strategy
TTR	Time To Recover
TTS	Time To Survive
WIP	Work In Process

1 Introduction

1.1.Introduction

Business organizations have always been exposed to the risk of a supplier to fail in delivering the required amount, with the agreed price, quality and lead time. Consequently, organizations have developed strategies to manage such risks to control and minimize the effect of suppliers' failure into the company aggregated performance (Ritchie and Brindley, 2007).

In the last years, the level of attention given to manage these risks in supply chains has become bigger and bigger, until questioning the effective applicability of traditional supply chain risk management approaches in current global scenario. Among the others, particular attention should be devolved to the fact that strategies and structures of supply chains are evolving more rapidly and changing shape to search for competitive advantage, resulting in amorphous supply chains. Technological change provides the opportunities to alter the shape and the relationships within supply chains, but at the same time may pose a threat to established supply chain arrangements.

ICT development added a new dimension of risk by increasing the level exposure of global competitiveness.

Interdependency within supply chain is increasing creating inter-locking of interest among supply chain members.

The result of all of this is a greater complexity, making the impact of risk arising within the supply chain more severe on consequences.

These characteristics lead to a contingency vision of each supply chain to be unique and, thus, requiring unique approaches to the management of the risks involved. However, a significant value might lay in seeking to map the common or shared characteristics and to employ common approaches for decision making to manage the risks faced.

Flow of material, information and cash can be severely disrupted along an organization's supply chain, because of disruptive events. The origin of these disasters might be environmental (such as hurricanes, earthquake or floods), human (such as strikes or terrorism), or, as contemporary history taught us, a virus pandemic.
How well a company copes with such threats will depend on its level of preparedness, and the type of disruption. Each supply chain risk has its own drivers and effective mitigation strategies. To avoid lost sales or increasing costs, managers need to tailor risk-reduction strategies to their organizations (Chopra and Shodi, 2004).

Nowadays, it is more and more important for companies to recognize Supply Chain risks and act promptly on them. That is why, in literature, risk is a popular word when talking about Supply chain management, and risk mitigation strategies are widely and practically applied in sever industrial application (BCI, 2018).
Nevertheless, it is not easy to find exhaustive models for the management of sub-suppliers for the aim of a comprehensive risk evaluation of the upstream supply chain risk of a company.

1.2.Problem Statement

Risk management, in companies, is about understanding whether it is economically more convenient running a risk or avoiding that risk or mitigating its consequences. The spectrum of application of risk model in operations is, then, considerably broad, going from finance, to operating and sales risks.
Also, the suppliers' and supply chain management can benefit of rich literature of risk models and analysis. Nevertheless, not exhaustive contribution has been devolved so far to risk models applied to sub-suppliers relationship management.

Reiterating the philosophy on supplier's risk management, it may be investigated how much the risk evaluation of a direct supplier is influenced by their own suppliers, so tier-2 suppliers. Furthermore, it is interesting to assess the mitigation capabilities of direct suppliers with respect to potential supply disruption of sub-suppliers.

Sub-suppliers' management literature, nowadays, is quite narrow, and particularly limited to Sustainability evaluation of sub-suppliers which can impact the Sustainability performance of the focal company.
Very poor contribution is present about sub-suppliers' risk management and assessment of direct suppliers' risk mitigation approaches.
Considering these gaps in the existing literature, and the high practical value that sub-supplier risk management model might have on manufacturing industries, the model that this thesis work proposes will represent a contribution in this field of research.

1.3. Industrial relevance

The importance of a higher visibility along the entire supply chain is demonstrated by the study of Business Continuity Institute. With a sample of 301 respondent, only 44% answered that, the predominant source of disruption in supply chain incidents in the last 12 months, was with their immediate supplier (Tier 1). 24% with supplier's supplier (Tier 2) and 10% originated lower down the supply chain. The remaining 22% stated not to analyze the full supply chain to identify the original source of disruption, which is an indicator of the poor visibility that many companies manage to have along their supply chain (BCI 2017).

In the same report, an analysis has been conducted on 408 respondents from 64 different countries. In 65% of the case companies experienced at least one supply chain disruption, but still 69% of the total case state not to have full visibility of their supply chain.

In companies there is a general perception that their supply management practices are only somewhat effective or not effective at all. According to a recent Deloitte study of 600 Supply Chain and C-Level executives 45% felt this lack of effectiveness in their supply chain risk management programs and just 33% used risk management approaches to proactively and strategically manage supply chain risk based on conditions in their operating environment.

The consequences of disruption have impact of productivity and costs in almost 50% of the cases. More than 40% of times a complaint by customers is received, and finally almost 30% of the case experiences considerable loss in revenues and damage to the brand image and reputation.

Over the last 10 years, earthquakes, economic crises, SARS, strikes, terrorist attacks have disrupted supply chain operations repeatedly (Tang, C.S.). Supply chain disruptions can have significant impact on a firm's short-term performance, as seen in the example of Ericsson losing 400 million Euros after their supplier's semiconductor plant caught on fire in 2000. Supply chain disruptions can have long-term negative effects on a firm's financial performance as well as loss on the demand side, like Apple losing many customer orders during a supply shortage of DRAM chips after an earthquake hit Taiwan in 1999.

A link does exist also between supply chain glitches and operating performance (Hendricks, K.B., Singhal, V.R., 2005). Firms that experience glitches report on average 6.92% lower sales growth, 10.66% higher growth in cost, and 13.88% higher growth in inventories. Moreover, firms do not quickly recover from the negative economic consequences of glitches. During the two-year time period after the glitch announcement, operating income, sales, total costs, and inventories do not improve. It

has also been found that it does not matter who caused the glitch, what the reason was for the glitch, or what industry a firm belongs to, glitches are associated with negative operating performance across the board.

Recent history is a dramatic proof of the enormous economic impact that a massive un-forecasted disruption might have on manufacturing companies. In March 2020, due to the Covid-19 rapid spread in in Italy, a nationwide lockdown imposed from 10 March and all non-essential production being shut down since 22 March. The industrial production of the country dropped by 28.4 per cent. The fall was the steepest on record and worse than any of the 18 forecasts collected by Reuters and Italy's GDP contracted 4.7 per cent in the first quarter of the year (Independent).

As already mentioned, the following step for a company, after having a solid supplier risk management, is to have a broad and comprehensive supply chain risk management. Due to the difficulties in having control on sub-suppliers' practices, it is important for organizations to ensure that their direct suppliers have in place supplier risk management themselves. Another survey conducted by BCI on 285 respondents, asking whether the organization asks key suppliers (new and existing) if they have a Business Continuity Plan in place. In 16% of the cases the answer is negative and in 10% was not even able to provide an answer.

Apart from the increasing number of disruptions, also the nature and consequently the entire risk landscape is evolving continuously. The world economic environment is always more turbulent because of the rapid obsolescence of technologies and the increasing level of globalization and internationalization.

These elements proof the presence of an inadequate gap in companies supply chain risk management practices, from which there is a need to create a stronger support methodology.

1.4.Objectives and Structure

The scope of this thesis is to develop a model for the evaluation of suppliers' capabilities in managing their own supply risk.

The final objective is to obtain an applicable and comprehensive model whose output might serve for future different purposes inside the company, such as being integrated into the calculation of Business Interruption Risk Parameters or in the Bonus/Malus system for comparison price used in tactical supplier selection. Further details on these practices will be treated in Chapter 4.

The development of this model for sub suppliers risk management will address the above-mentioned literature gaps and the practical relevance of its industrial application.

Hence, the study aims at answering the following research question:

RQ: How can sub-suppliers risk be addressed by investigating direct suppliers' risk mitigation maturity?

For this thesis, the following structure has been followed based on the methodology research proposed by Ulrich, 2001. His proposed structure has been adapted as in the figure below:

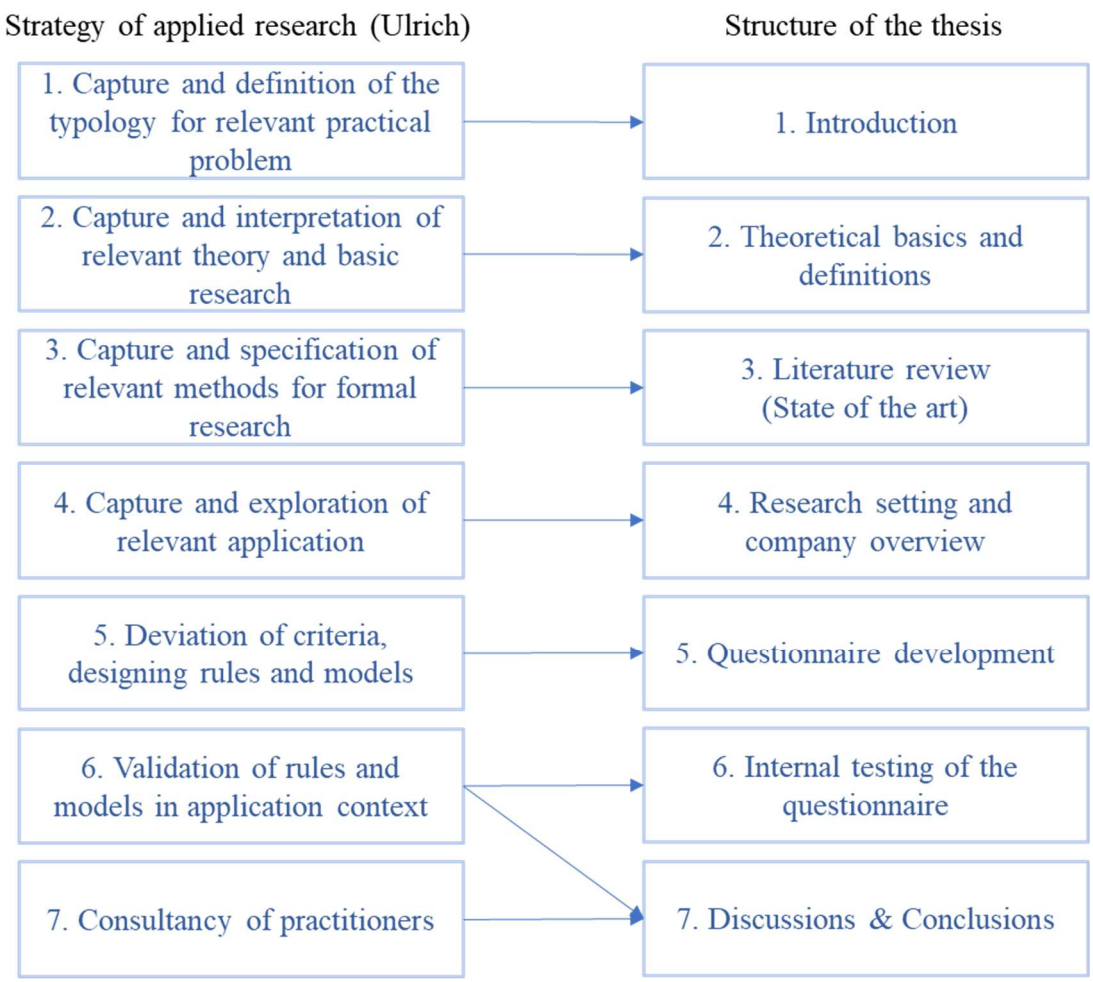

Figure 1 Thesis structure (Ulrich, 2001)

Chapter 1 aims at identifying the need of introducing a model for the integration of sub-suppliers risks into supplier risk assessment. The context and the problem addressed are identified, as well as the relevance of the issue from an industrial perspective. The objectives and the base structure of the work are declared.

Chapter 2 provides a theoretical basics of literature on Risk, Supply Chain Risk Management, Sourcing and Sub-suppliers' risk management.

Chapter 3 explores the state of the art by analyzing the most recent theories and methodologies which address Risk mitigation approaches and Sub-suppliers' risk managements models. Existing models' are deeply explored, and literature gaps are explicated in order to frame the contribution.

Chapter 4 frames the research settings and processes followed by the author. Besides that, an overview of Hilti organization is depicted.

Chapter 5 illustrates how the development of the questionnaire has been conducted. Concretely, what comes from Hilt's questionnaire experience and a first version of the questionnaire.

Chapter 6 depicts the questionnaire results and analysis conducted on the results and the feedback received. Here the final version of the questionnaire is proposed.

Chapter 7 concludes the research summarizing the results achieved, comparing the proposed model with respect to others discussed in the literature and highlighting the practical implications and benefits for the company. The novelty and transferability of the work is evaluated, its limitations and possible future developments are identified.

2 Theoretical basics and definitions

This chapter gives the basic theoretical approach that is relevant for the purpose of this research.

2.1 What is risk

The concept of risk

The concept of Risk has received bigger and bigger importance for organizations in last decades. The estimation and monitoring of risk related parameters can have considerable impact of business performance in the long run.
Hereafter, it will be analyzed and explored the broad spectrum of risk proposed by literature, with particular focusing on supply chain and supplier risk related variables.

Risk definition

The first question we want to provide an answer to is "What is risk?".
According to (Knight, 1921) Risk is any event which is subject to a known or knowable probability. It is distinguished from uncertainty which indicates an event for which it is not possible to specify a quantitative probability.
Thus, a subject playing a lottery with a 50% of probability to lose his money and 50% of doubling his win, is taking a risk.
The author makes a further classification of probabilities distinguishing:

- A priori probabilities, whose outcome is derived deductively.
- Statistical probability, whose outcome is generated as an empirical evaluation of frequencies.
- Estimates, when there is no valid basis for classifying instances.

To comprehensively define risk, (Kaplan, 1997) suggests posing three questions:

- What can happen?
- How likely is it to happen?
- If it does happen, what are the consequences?

The last two questions investigate two parameter that are often used in describing risks as a couple of coordinates in a plan of two axis: Likelihood and Consequence. The matrix individuated by the two axis is the so called “Risk Matrix” as shown in th figure below:

			Impact			
			0 Acceptable	1 Tolerable	2 Unacceptable	3 Intolerable
			Little or No Effect	Effects are Felt but Not Critical	Serious Impact to Course of Action and Outcome	Could Result in Disasters
Likelihood	Improbable	Risk Unlikely to Occur				
	Possible	Risk Will Likely Occur				
	Probable	Risk Will Occur				

Figure 2 Risk Matrix (Li and Hong, 2007)

Thus, a quantification of the risk (Li and Hong, 2007) can be expressed as the product:

$$Risk = Likelihood\ of\ the\ risk\ \times Impact\ of\ the\ risk \quad (1)$$

More recently, (Hubbard, 2009) provides a definition of risk as a state of uncertainty where some of the possibilities involve a loss or any other undesirable outcome. In this case, risk starts having a meaning of impact/effect that uncertainty may have of on objectives.

The same perspective is stated according to (ISO GUIDE 73:2009), but with no limitation of the negative aspect of risk, rather on the concept of uncertainty on objective, either it is positive or negative from the subject point of view.

Risk factors and classifications

Once stated what risk is and how it can be defined, in literature, there have been many attempts of classifying risks according to their nature, sources of origin and characteristics.
In the broad area of Enterprise Risk Management (Clark C.J. and Varma S., 1999) suggest considering four major areas of risk:

- Operational risk
- Event risk
- Market risk
- Counter party risk

Operational risk has been widely investigated in literature to try to define the most common typologies natures of risk affecting company operations. (Chapman, 2012) suggests a common classification of operational risks into:

- Technology risk
- Information risk
- Supply chain risk
- Occupational risk
- Environmental risk
- Organization risk
- Production risk

For the scope of this thesis also Event risk deserves particular attention. In this category are considered mainly external risks, such as Regulatory risk, Political risk or Disaster risk.
This last one, is what from now on we will refer to as Disruption risk: a risk which arise from natural disaster, such as weather disruption, or man-made ones, such as economic crises, that can severely affect supply chain performances.

Risk management

Since risk is inherent in all aspects of a quality management system. There are risks in all systems, processes and functions. Risk-based thinking ensures these risks are identified, considered and controlled including the systematic application of management policies, procedures and practices to the activities of communicating, consulting, establishing the context, and identifying, analyzing, evaluating, treating, monitoring and reviewing risk (IS73:2009 & ISO9001: 2015).
The following Risk management framework has been formulated by the International Organization for Standardization in Geneva for the first time in 2008 (ISO 31000:2009).

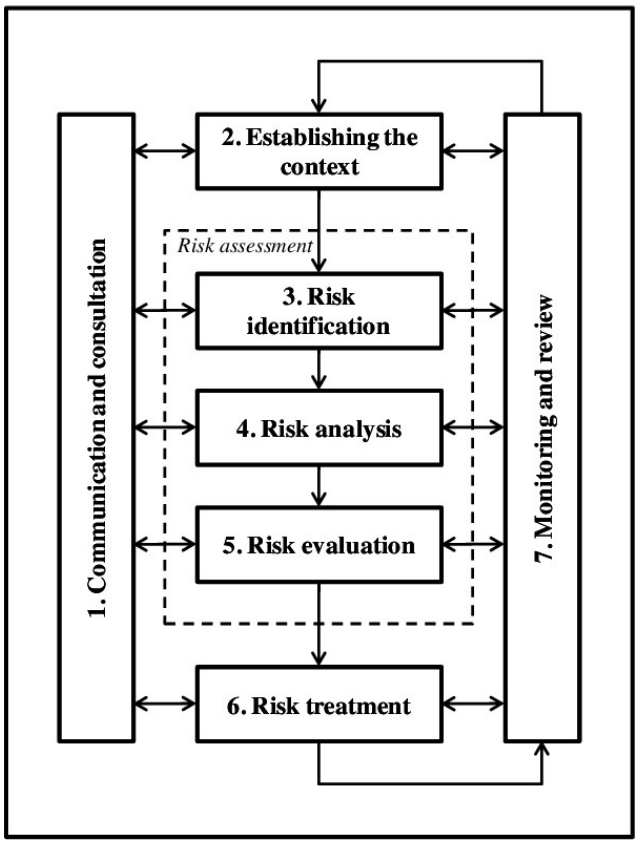

Figure 3 Risk Management Framework (ISO 31000:2009)

So, according to this model, risk management process consists of the following steps (ISO 31000:2009):

1. Communication and Consultation: It should take place during all stages of the risk management process, addressing issues relating to the risk itself, its causes, its consequences, and the measures being taken to treat it. Effective communication and consultation should take place to ensure that those accountable for implementing the risk management process and stakeholders understand the basis on which decisions are made, and the reasons why particular actions are required. Communication and consultation with stakeholders are important as they make judgements about risk based on their

perceptions of risk. These perceptions can vary due to differences in values, needs, assumptions, concepts and concerns of stakeholders. Communication and consultation should facilitate truthful, relevant, accurate and understandable exchanges of information, taking into account confidential and personal integrity aspects.

2. Establishing the Context: The objectives, strategies, scope and parameters of the activities of the organization, or those parts of the organization where the risk management process is being applied, should be established. Both internal and external context should be addressed. The management of risk should be undertaken with full consideration of the need to justify the resources used in carrying out risk management. The resources required, responsibilities and authorities, and the records to be kept should also be specified. The context of the risk management process will vary according to the needs of an organization.

3. Risk Identification: The organization should identify sources of risk, areas of impacts, events and their causes and their potential consequences. The aim of this step is to generate a comprehensive list of risks based on those events that might create, enhance, accelerate or delay the achievement of objectives. It is also important to identify the risks associated with not pursuing an opportunity. The organization should apply risk identification tools and techniques that are suited to its objectives and capabilities, and to the risks faced. Relevant and up-to-date information is important in identifying risks. This should include appropriate background information where possible.

4. Risk Analysis: It involves developing an understanding of the risk to provide an input to risk evaluation and to decisions on whether risks need to be

treated, and on the most appropriate risk treatment strategies and methods. Risk analysis involves consideration of the causes and sources of risk, their positive and negative consequences, and the likelihood that those consequences can occur. Risk is analyzed by determining consequences and their likelihood, and other attributes of the risk.

5. Risk Evaluation: The purpose of risk evaluation is to assist in making decisions, based on the outcomes of risk analysis, about which risks need treatment and the priority for treatment implementation. It involves comparing the level of risk found during the analysis process with risk criteria established when the context was considered. Based on this comparison, the need for treatment can be considered.

6. Risk Treatment: Risk treatment involves selecting one or more options for modifying risks and implementing those options. Once implemented, treatments provide or modify the controls. The options can include: avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk; taking or increasing the risk in order to pursue an opportunity; removing the risk source; changing the likelihood; changing the consequences; sharing the risk with another party or parties and retaining the risk by informed decision.

7. Monitoring and Review: Both should be a planned part of the risk management process and involve regular checking or surveillance. The organization's monitoring and review processes should encompass all aspects of the risk management process for the purposes of ensuring that controls are effective and efficient in both design and operation, obtaining further information to improve risk assessment, detecting changes in the external and

internal context, including changes to risk criteria and the risk itself which can require revision of risk treatments and priorities and identifying emerging risks. Progress in implementing risk treatment plans provides a performance measure. The results can be incorporated into the organization's overall performance management, measurement and external and internal reporting activities.

2.2 Supply Chain Risk Management

Supply Chain Management

According to (Forrester, 1958), management is on the verge of a major breakthrough in understanding how industrial company success depends on the interactions between the flows of information, materials, money, manpower, and capital equipment. The way these five-flow systems interlock to amplify one another and to cause change and fluctuation will form the basis for anticipating the effects of decisions, policies, organizational forms, and investment choices.

The term supply chain management has risen to prominence over the past ten years. For example, at the 1995 Annual Conference of the Council of Logistics Management, 13.5% of the concurrent session titles contained the words “supply chain”.

The definition of “supply chain” seems to be more common across authors than the definition of “supply chain management”. For the purposes of this paper, a “supply chain” is defined as a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer (Mentzer, J.T., DeWitt, W., Keebler, J.S., (...), Smith, C.D., Zacharia, Z.G., 2001).

Although, historically, the term supply chain management had several definitions, a single, encompassing definition of SCM can be developed. Supply chain management involves multiple firms, multiple business activities, and the coordination of those activities across functions and across firms in the supply chain. Pulling together these disparate aspects of supply chain management, it can be defined as the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole (Mentzer, J.T., DeWitt, W., Keebler, J.S., (...), Smith, C.D., Zacharia, Z.G., 2001).

Supply Chain Risk Management

Risks in Supply chain may arise from any uncertainty that would cause a variation in the capabilities of the company, quantifiable in terms of value variation.
Risk in the supply chain centers around the disruption of "flows" between organizations. These flows can relate to information, materials/products and money (Jüttner, 2005).

The categories of risk affecting supply chain according to (Kleindorfer, P.R., Saad, G.H., 2005) are:

1. The ones arising from the problems of coordinating supply and demand.
2. The ones arising from disruptions to normal activities.

Looking at the category (1), a risk model can be exploited depending on the context in which the company operates, thus, meaning also, that different supply chains can be subjected to different kind of risks. According to (Lee, 2002), it is possible to distinguish four different strategies that should be implemented in managing the supply chain of a company, depending on the characteristics of the supply chain's

environment itself, since different environments will expose the organization to different types of risks. Two main variables are taken into account:

- Demand Side Uncertainty, which includes all the uncertainties coming from the market (product variety, demand uncertainties, obsolescence risk, etc...).
- Supply Side Uncertainty (number of supply sources, suppliers' reliability, capacity constraints, possibility to change over, etc...).

Given the definition of risk as the effect of uncertainty on reaching companies objectives, it could be possible to interpret the four strategies proposed as risk mitigation strategies:

		Demand uncertainty	
		Low (Functional Products)	**High (Innovative Products)**
Supply uncertainty	**Low (Stable process)**	Grocery, basic apparel, food, oil and gas **Efficient supply chains** Scale economies, best capacity utilisation, information linkages via the Internet	Fashion apparel, computers, pop music **Responsive supply chains** Mass customisation and build-to-order, order accuracy using the Internet
	High (Evolving process)	Hydro-electric power, some food produce **Risk-hedging supply chains** Sharing resources, safety stock, Internet for real-time information	Telecom, high-end computers, semiconductor **Agile supply chains** Pooling resources and inventory

Figure 4 Supply Chain Risk: Demand and Supply uncertainty (Lee, 2002)

Looking at the category (2) proposed by (Kleindorfer, P.R., Saad, G.H., 2005) we enter the realm of risks arising from disruptions. This kind of risk is characterized by

very low probability but extremely high impact of performances. So, looking back at the framework of (Lee, 2002) Supply Chain Risk Management needs to be considered as a general need and disruption risks must be managed by all the supply chains independently from the adopted strategy.
To arrive to a comprehensive view of Supply Chain Risk Management we can recall the definition of (Tang, 2006) that the current scope of management of supply chain risks takes place through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity.

Supply Chain Risk Management Frameworks

Along the time different authors in literature have stressed the importance of Supply Chain Risk Management implementation. Different frameworks which enable SCRM processes have been proposed, debated and deeply studied in literature. Starting from Lee general framework, different literature contributions have been developed in order to adapt it to supply chain risk management needs.

A great contribution has been proposed by (Tummala and Schoenherr, 2011), who provided a process view of Supply Chain Risk Management which can support supply chain managers' strategic thinking and strategic decision making for evaluating options to improve supply chain performance. The framework consists of a structured approach developed along 6 phases, similarly to the risk management framework proposed in the ISO 31000 together with some tools and guidelines on how to apply this framework to a supply chain risk management context.

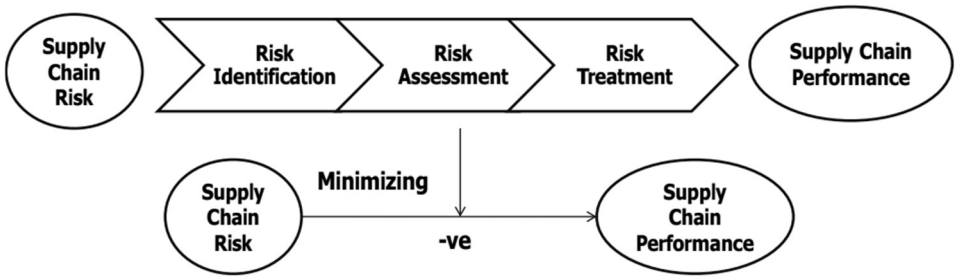

Figure 5 Process view of SCRM (Tummala and Schoenherr, 2011)

1. Risk Identification: enumerate all the possible threats which can affect the supply chain performance. Possible tools are:
    a. Supply chain mapping,
    b. Checklists,
    c. Failure Mode and Effect Analysis (FMEA),
    d. Ishikawa diagram.

2. Risk Assessment: determine and quantify consequences of all potential Supply Chain risks, as well as the likelihood of each risk factor. Possible tools are:
    a. Delphi method,
    b. Focus group,
    c. Montecarlo simulation.

    After that, all risks can be ranked based on the SC risk exposure calculated based on the:

$$Risk = Likelihood\ of\ the\ risk\ \times Impact\ of\ the\ risk \quad (1)$$

Risks can be clustered in order to understand the most critical and the negligible areas. Possible tools here are the risk matrix or the Pareto analysis approach.

3. Risk Treatment: Risk Mitigation action plans are developed to contain and control the risk by selecting which are the most appropriate mitigation strategies to deal with a certain risk. After this, all the risks can be ranked with their respective probability of occurrence, severity and risk mitigation costs. Finally Risk Control and Risk Monitoring are applied to the processes, in the implemented risk response action plans, to take corrective actions to achieve the desired performance, and report, when needed, any deviation or Supply Chain disruption. Risk related information are stored and updated in order to actively support risk assessment and risk management continuous improvement.

Suppliers' risk categories

As already mentioned for the scope of this thesis also Event risk deserves particular attention. In this category are considered mainly external risks, such as Regulatory risk, Financial risk, Political risk or Disaster risk.
This last one, is what from now on we will call also Disruption risk.
We will dedicate particular attention to this last-mentioned category, together with Financial risk, being them very common risk sources that may lead to a supplier business interruption.

Disruption risk

Disruption risks refer to events caused by nature, man-made or technology, characterized by low probability to happen but high impact on company performances.

One of the variables affecting the intrinsic Disruption risk level of a company is the country it is located in. Some countries are surely more critical than others regarding political instability, natural disasters or social security. All these factors can play a role in the likelihood and the severity of disruption risks in a country.

The Country Disruption Risk can be estimated through the consultation of INFORM (Index for Risk Management).
INFORM is a partnership of a group of United Nation agencies, donors, Non-Governmental Organizations and research institutions that developed a comprehensive, widely accepted, open and continuously updated, transparent and evidence-based multi-hazard humanitarian risk index with global coverage and regional/sub-national scale and seasonal variation.
The aim of the group is to incorporate risk indexes in internal decision-making processes. It can be considered a reliable source for the measurement of the risk originating because of crises and disasters, supporting the identification of where and why crises and disasters are likely to occur.
The dimensions used in the INFORM index are shown below.

In details:

- The Hazard & Exposure Dimension reflects the probability of physical exposure associated with specific natural and human hazards. The metric for the natural hazard risk in INFORM is the annual average exposed population and this category includes five components aggregated with a geometric average:
    - Earthquake,
    - Tsunami,
    - Flood,
    - Tropical cyclone

- Drought.
- Epidemic

Human-made hazards are either technological (industrial accidents) or sociological (civil wars, crime, terrorism) in nature and they are included in the indicator by considering the national and sub-national power conflicts and the probability of violent conflicts.

- The second dimension is Vulnerability. It is made up by two components. The first is Socio-economic and it takes into account:
  - The development of the country.
  - The social inequality.
  - The dependence from external aid.

  The second one is Vulnerable groups, considering the level of unprotected people and other vulnerable groups in the country.

- The third general dimension used for the estimation of the Disruption Risk indicator is the Lack of Coping Capacity.

  It is meant to give relevance to the capability the country and the society have to cope with a disruptive event. In analyzing this, it is important to understand which issues the government has addressed to increase resilience of the society and how successful their implementation is. The Lack of Coping Capacity Dimension measures the ability of a Country to cope with disasters in terms of formal, organized activities and the effort of the Country's government as well as the existing infrastructure, which contribute to the reduction of disaster risk.

Credit Risk

Credit risk is a variable to estimate the risk of financial default of an entity which does not fulfil its financial obligations in a timely manner.

In a lot of companies (Hilti included), a constant monitoring of the credit risk of its supply base takes place, based on financial figures provided by the company Dun & Bradstreet (D&B).

D&B defines its calculation of credit risk using publicly available financial information, by measuring the probability of default in the upcoming 12 months.

The first part of the D&B, the Tangible Net Worth rating, gives an indication on the size of the company, using a codification based on letters and numbers.

In the table below is represented the complete scale of financial strength.

Financial Strength Indicator	**Tangible Net Worth (in £)**	
Net Worth	From	To
5A	35.000.000	And Above
4A	15.000.000	34.999.999
3A	7.000.000	14.999.999
2A	1.500.000	6.999.999
1A	700.000	1.499.999
A	350.000	699.999
B	200.000	349.999
C	100.000	199.999
D	70.000	99.999
E	35.000	69.999
F	20.000	34.999
G	8.000	19.999
H	0	7999
Alternate Symbols Used		
N	Negative net worth (negative balance of equity after deduction of intangibles)	

O	Net worth undetermined (accounts unavailable or older than 2 years)
NB	New Business (less than 12 months old)
NQ	Out of Business: Business has ceased to trade

Table 1 Financial strength indicator (D&B)

The second part is specifically related to a risk level indication (in a range from 1 to 5, with 1 minimal level of risk, 4 significant level of risk and 5 insufficient information to assign a risk indicator).

In the table below are depicted the different risk classes.

Risk Indicator	Meaning	Probability of failure
1	Minimal Risk	Proceed with transaction - offer extended terms if required
2	Low Risk	Proceed with transaction
3	Slightly greater than average risk	Proceed with transaction but monitor closely
4	Significant level of risk	Take suitable assurances before extending credit - e.g. personal guarantees
-	Insufficient information to assign a risk indicator	No public information or D&B proprietary information available to assign a valid risk

Table 2 Risk indicator (D&B)

To identify in advance the most critical situations, a constant monitoring of supplier riskiness has to be provided. Due to the lack of transparency or available information, the monitoring is not possible for all the countries but the most of European and US countries are included in D&B analysis.

2.3 Sourcing

Sourcing, Outsourcing and Crowdsourcing

Sourcing, also known as procurement, is the practice of locating and selecting businesses or individuals based on a set of criteria. Sourcing is carried out in business in many different areas and for different reasons. One of the most common uses of sourcing is in supply chain management. Businesses that can find the most appropriate suppliers at the lowest cost can lead to a competitive advantage.

Outsourcing is a common technique where businesses contract out a business function, typically something non-critical such as payroll, to a third-party supplier. As part of the outsourcing process, businesses will draw up a list of potential third parties and choose the most appropriate for their needs.

Crowdsourcing is a relatively new technique that aims to use the power of groups to efficiently perform a set task, such as brainstorming or recruitment. (https://www.hrzone.com/hr-glossary/what-does-sourcing-mean)

Strategic and Tactical sourcing

Some scholars consider the most popular definition of sourcing is Strategic Sourcing (https://www.purchasing-procurement-center.com/definition-of-sourcing.html). This is the process of taking advantage of purchasing opportunities by continually reviewing current needs against purchasing opportunities.
Strategic sourcing was first established by General Motors in the 1980's and is now a common business purchasing tool. The rise of China and its manufacturing capabilities has opened up numerous strategic purchasing opportunities.
There are several processes within the strategic sourcing process, these are:

- Evaluation of the company's current purchasing cycles.
- Evaluation of what is currently available in the supply market.

- A review of the cost benefit analysis of using other suppliers.
- A review of potential vendors.
- An update of the current procurement strategy.
- Negotiations with potential vendors to ensure that they meet the new procurement strategy and cost benefit analysis.
- Implementation of the new vendor relationship.
- On a continuous process, review and update the strategic sourcing.

So, Strategic sourcing, is a comprehensive and long-term system of processes to support current and future business objectives. It is focused on combining enterprise-wide ambitions with procurement-specific continuous process improvement, by making sure selected suppliers perfectly fit the strategic needs of the company in all its details.

On the other hand, we have Tactical sourcing: a more short-term, transactional approach to procurement. Here procurement decisions are based on fewer criteria, typically on price and available delivery dates, it ensures that purchases are made at optimal price and that supply is available when needed. Then, tactical processes take place in order to select from the existing base the right supply for each part in line with quality price, delivery and environmental requirements.

The previous considerations regarding supply chain risk impact on company performance and the currently stated importance covered by sourcing along the supply processes merged with the increasing attention of risk implication already in supplier selection. Supply chain operations fluctuations and disruptions which may have huge business implication on company market performance and business interruptions, but also risk management and mitigation strategies may imply relevant

costs for the company in order to secure its business. Thus, purchasing can take a strategic role in mitigating the negative effects of supply chain risk.

2.4 Sub-suppliers' management

Sub-suppliers, sub-suppliers management and sub-suppliers risk management

The term "sub-suppliers", is defined in this work, as the suppliers of the direct supplier of the focal company.
The focal company is the organization that, ultimately, we are interested in building the model for.

Direct suppliers will be here also called as Tier-1 suppliers, and sub-suppliers as Tier-2 suppliers.
Tier-3, Tier-4…Tier-N suppliers are defined accordingly, even though rarely mentioned in the work.

As a consequence of this, sub-suppliers management can be defined as a set of practice, tools, methods and models the focal company may apply in order to increase its visibility and control on sub-suppliers and on the way direct suppliers manage their supplier base.

Sub-suppliers risk management is, thus, integrating the risk dimension applied to supplier in the upper tiers of the supply chain, with the aim for the focal company to reduce the risk of increasing its costs, reducing sales or losing value in a broad perspective.
The performance of the focal company can, indeed, be influenced by subs-suppliers' risks. In particular, disruptions events at sub-suppliers level can cause business interruption downstream the whole supply chain. Beside this, also sustainability

impact and score may have a strong influence on the footprint of the entire supply chain compromising sustainability performance of the focal company or even jeopardizing its reputation.

Ripple effect

Disruption events at any node in the higher tiers of the supply chain may lead to business interruption on the lower tiers.

If not adequately managed, the negative impact on economics parameters caused by the disruption might become bigger and bigger going downstream along the supply chain.

This is what is commonly called as “ripple effect”. It occurs when a disruption, rather than remaining localized or being contained to one part of the SC, propagates downstream and affect performance of the downstream supply chain with an ongoing increasing effect.

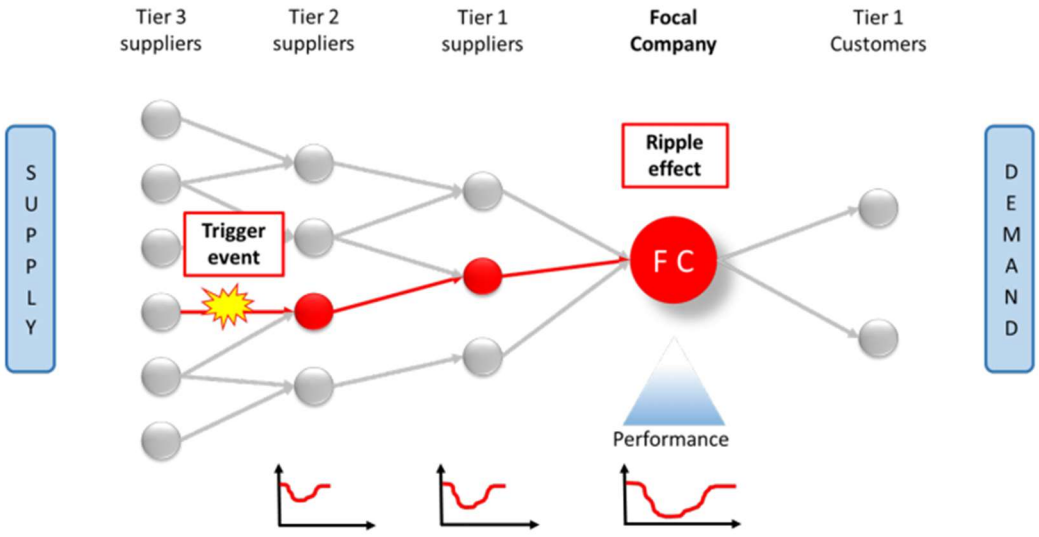

Figure 6 Ripple effect on a Supply Chain

3 Literature review (state of the art)

3.1 Literature Research Methodology

In the previous chapter some concepts around the topic of Supply Chain Risk Management have been analyzed in order to set the basis for the development of this work.
In this chapter, instead, recent literature is thoroughly investigated in order to catch the last improvements, questions and theories developed around the discussed topics.

Scopus has been the tool of choice in the literature analysis, which has been developed using a logical combination of relevant keywords in article title, abstract and topic.

3.2 State of the art on Supply Risk Mitigation

In the first part of the analysis, papers published from 2008 on have been collected; to consider the most recent trends of the last years.
The subject areas have been limited to the ones related to the industrial application of the contribution, therefore only literature related to “Business, management and accounting”, has been initially considered.

The document type has been filtered for “Article”, “Book” or “Book chapter” and Source type has been limited to “Journal”, “Book series” and “Book” and results have been limited to English language.
Only articles with a number of citations on Scopus higher than 30 have been considered; this characteristic has been considered as a threshold for the identification of the irrelevancy of a paper contribution in this study area.

A two-level search has been run on the database considering the combinations of the keywords “Risk mitigation” AND “Supplier”.

The total number of 65 documents (after the application of the filters previously mentioned) has been furtherly streamlined by a qualitative evaluation of the relevance of the topic by reading the abstract.

In this way a total number of 10 papers was eventually selected as their content contributed to risk mitigation related topics.
Further articles of particular relevance on the topic have been reviewed when encountered as reference in the articles selected.

Contingency Theory

In supply chain risk management the appropriateness and effectiveness of risk mitigation strategies are contingent on the internal and external environments and there is no one-size-fits-all strategy (Talluri, S., Kull, T.J., Yildiz, H., Yoon, J. 2013). Nevertheless, literature on risk management has proposed a variety of tools and strategies for effectively evaluating and mitigating supply chain risk. The review of the literature on supply risk mitigation will help us in identifying which strategies should be adopted by companies to mitigate their supply risk, thus, which ones to consider for building the model that will be proposed.

Supply Risk Management Maturity Model

The need of a tool for the assessment of the risk management capabilities of companies has been acknowledged by the Supply Chain Leadership Council, a cross-industry council comprised of world class manufacturing & services supply chain firms that work together to develop and share supply chain risk management best practices. In this regard, the “Supply Chain Risk Management Maturity Model” was

designed to help managers assessing their organization's capabilities with respect to managing supply chain risk. The maturity model allows a self-assessment of supply chain risk management (SCRM) capabilities across five categories (Leadership, Planning, Implementation, Evaluation, and Improvement), scoring each section on a five-stage rating scale (Reactive, Aware, Proactive, Integrated, Resilient). The model is easy to use and produces three output charts that highlight the overall capability of an organization to manage supply chain risks (The SCRLC Maturity Model Team, 2013).

Risk mitigation strategies

We have seen that according to (Tummala and Schoenherr, 2011) the third phase of Supply chain risk management is Risk Treatment, a broad field of this is about reducing and mitigating risks.

Over the years, a wide range of mitigation strategies have been identified in order to reduce risk probability, amount loss, speed of losses, time for detection of the events, frequency or exposures, etc. Different contributions have been found in literature regarding the identification and classification of mitigation strategies.

Even tough has been posited by (Srinivas Talluri, Thomas J. Kull, Hakan Yildiz, Jiho Yoon, 2013) that the appropriateness and effectiveness of risk mitigation strategies are contingent on the internal and external environments and that there is no one-size-fits-all strategy, in the contribution of (Manuj and Mentzer, 2008) we find a list of risk mitigation strategies related to the main risk covered with each strategy.

- Avoidance: This strategy applies above all, but not only, to supply side risk. It consists in avoiding doing business with a supplier because it is considered too risky. For example, the financial stability of that supplier in particularly in danger or it is located in a country considered highly risky (e.g. for political instability reasons).

- Postponement: This strategy applies to demand side. It consists in delaying the processing or commitment of resources in order to delay the incurrence of some costs. Usually, it relates to cost such as labeling, packaging, assembly, and manufacturing after customer order has taken place.
- Speculation: This strategy applies to demand side and is, basically, the opposite of postponement strategy. In this case, the company takes the risk, it bets and takes decisions before customer demand.
- Hedging: This strategy applies both to supply and demand side. It consists in differentiating the risk by dispersed portfolio of suppliers, customers or facilities, so that, a single event does not affect all the entities ate the same time, reducing the relative impact of the disruption. Increasing the level of Safety stock for some raw materials, WIP or finished products is one of the most common and diffused examples of pursuing a hedging strategy.
- Control: This strategy applies both to supply side. In this case the company follows a vertical integration approach by acquiring the supplier. This way capacity constraints, asset specificity and bargaining power dynamics risks can be controlled and reduced.
- Transferring/Sharing Risk: This strategy applies both to supply and demand side. It can be achieved through outsourcing, offshoring, and contracting. Global supply chain outsourcing can take the form of domestic or international sourcing of services and products.
- Security: This strategy applies more to external related risks. In shipments, security measure may take place, thanks to sensors to identify nuclear, chemical or biological elements that can be a source of risk.

Geographical segregation of suppliers.

Another risk mitigation strategy suggested by (Hosseini, S., Morshedlou, N., Ivanov, D., (...), Barker, K., Khaled, A.A., 2019) to start a resilient supplier selection process is "Geographical segregation of suppliers".

It is an important proactive resilience strategy that helps to reduce the risk of a geographically induced supply chain disruption. To model this resilience strategy, an objective function represents the maximization of the sum of the distance between selected suppliers, thus the segregation of suppliers:

$$\mathrm{GS} = \max \sum_{i-1}^{n} \sum_{j-i+1}^{n} \mathrm{zi\ zj\ dij} \qquad (2)$$

Where:

- zi is equal to 1 if supplier i is assigned to the firm, 0 otherwise.
- dij is the shortest distance between locations of suppliers i and j

Back-up supplier and protected supplier

A risk mitigation strategy may also consist in having a back-up supplier. It is a secondary supplier that is used only when a primary supplier is disrupted. Contracting with a backup supplier ensures that the flow of material is maintained if disruption happens in other sources (Tomlin, 2006, Sodhi and Lee, 2007). Since the firm makes the contract prior to any disruption, this strategy is classified as a mitigation tactic.

Protecting suppliers, instead, is a strategy to fortify suppliers in order to strengthen their reliability and resiliency during disruptions and in turbulent environments (Sawik, 2013). The issue of linking risk assessment with risk mitigation for low-probability high-consequence events such as disruptions of supplies is discussed by (Kleindorfer and Saad, 2005) and (Cohen and Kunreuther, 2007) and the need to build resiliency to disruption events in supply chains is discussed by (Knemeyer et al., 2009), who considered a proactive planning, based on methodology used by the

insurance industry. They quantify the risk of multiple types of catastrophic events on key supply chain locations. The proposed proactive planning process involves four critical steps: identification of key supply chain locations and threats, estimation of probabilities and loss for each location, evaluation of alternative countermeasures for each location, and selection of countermeasures that may prevent or mitigate disruption risks. Examples of such countermeasures include relocation of facility away from high risk location (e.g., moving a warehouse to a hurricane-free area), redesign of facility to increase storm preparedness, building storm walls to help protect against flooding, maintaining excess inventory, etc. In practice, the fortification of suppliers to protect them against disruptions is recently observed. For example, to prevent flooding during monsoons, a flood wall has been under construction around the perimeter of an industrial zone, in which over 200 factories of electronics and computer components suppliers were located (Sawik, 2013).

This strategy is concerned with identifying optimal sourcing policies for supplier selection and resource allocation, based on protected suppliers. Sawik examined the selection of suppliers to be protected against disruption, and developed mechanisms for the allocation of emergency inventory of parts to be pre-positioned at the protected suppliers. He determined the optimal selection and allocation of protected and unprotected suppliers in order to minimize the total cost.

Finally, (Torabi et al. 2015) extended the Sawik paper by assuming that the fortification of a supplier decreases the impact of disruptions on that supplier, based on the level of protection and the disruption event. They developed a model allowing a mixture of protected suppliers and backup suppliers and solved it using a 5-step process.

Raw Material Inventory and Reserve capacity.

(Lücker, F., Seifert, R.W., Biçer, I., 2019) present a model for investigating the role of inventory and reserve capacity in mitigating supply chain disruption risk, it is based on a stylized mathematical model on a single product and a single location subject to supply chain disruptions.

In the event of a supply chain disruption, the firm can instantaneously use the available Raw Material Inventory (RMI) and the reserve capacity to meet customer demand.

The problem is to find the optimal combination of RMI and reserve capacity production rate under stochastic demand.

RMI levels are decided before a disruption has occurred, and the costs are the RMI holding costs h, which are incurred as long as no disruption takes place.

In the event of a supply chain disruption, only excess inventory is charged with the holding cost h during the disruption time τ.

The reserve capacity production rate a is decided before a disruption has occurred. The actual production volumes given a specific reserve capacity, however, are only decided after a disruption has occurred, and hence this mitigation strategy provides more flexibility. In particular, there is no risk of overproduction and hence no overage cost due to using the reserve capacity.

The reserve capacity is associated with:

- an upfront fixed component for reserving the capacity: $\hat{c}_A$,
- a variable production cost: c_A, incurred based on actual production volumes.

The underage costs for unmet demand during the disruption time τ are the penalty costs p.

The firm minimizes its expected costs by deciding:

- RMI levels I
- Reserve capacity production rate a.

As a simplification, it is assumed that only one disruption of the length τ occurs at a given point in time with probability ω_τ.
Demand during the disruption time τ is characterized as a non-negative, continuous random variable X with the distribution $F_\tau(\cdot)$ and the probability density $f_\tau(\cdot)$.

The optimization problem can be written as follows:

$$\begin{aligned}\min_{I\geq 0, a\geq 0} L(I,a) = \omega_\tau (p \int_{I+a_\tau}^{\infty} (x - I - a_\tau) f_\tau(x) dx \\ + h \int_0^I (I - x) f_\tau(x) dx \\ + c_A \int_I^{I+a_\tau} (x - I) f_\tau(x) dx + c_A a_\tau (1 \\ - F_\tau(I + a_\tau))) + (1 - \omega_\tau) hI + \hat{c}_A a\end{aligned} \tag{3}$$

Where:

p: penalty cost

h: inventory holding cost

The first term represents the penalty, inventory holding and reserve capacity production costs in case a disruption occurs:

- Penalty costs are only incurred for demand larger than $I+a_\tau$.
- Holding costs are incurred if the demand is smaller than *I*.
- Costs for emergency production are incurred if demand is larger than *I*.

The second term $((1-\omega_\tau)hI)$ gives the inventory holding costs in cases no disruption occurs.

The reservation costs for the reserve capacity $\hat{c}_A$ incur for all time, independently of the occurrence of disruptions.

The choice of the strategy to follow, now, depends on the value of the parameters of the model:

1) If the fixed cost of reserve capacity and the penalty costs are high compared to inventory holding costs, quantitatively if both:
   - $\hat{c}_A \geq \Delta_1$ where $\Delta_1 \triangleq \tau\,(h/(p+h))\,(p-c_A)$
   - $p > \hat{h} / \omega_\tau$ where $\hat{h} \triangleq (1-\omega_\tau)h$

   then the optimal RMI can be found mathematically according to the previously defined parameters and the optimal Reserve capacity is equal to zero.
   This is called "Inventory Strategy".
2) If the fixed cost of reserve capacity $\hat{c}_A$ is lower than Δ_1 but higher than another threshold Δ_2 defined as $\Delta 2 \triangleq \tau(\hat{h}-\omega_\tau c_A)$, then the optimal RMI and the optimal Reserve capacity are not null and can be found mathematically according to the parameters.
   This is called "Mixed Strategy".
3) If the fixed cost of reserve capacity $\hat{c}_A$ is lower Δ_2 and even lower than a threshold defined as $\hat{c}_A < (p-c_A)\omega_\tau$, then the optimal reserve capacity can be found mathematically according to the previously defined parameters and, instead, the optimal RMI is equal to zero.
   This is called "Process flexibility strategy".
4) If the penalty costs p is lower than the threshold $p < \hat{h} / \omega_\tau$, and the fixed cost of reserve capacity $\hat{c}_A$ is either too high or too low ($\hat{c}_A \geq \Delta_1$ or $\hat{c}_A < \Delta_2$), then both the optimal RMI and the optimal reserve capacity are equal to zero.
   This last is called "Passive acceptance".

So, the final objective of this model is determining which risk mitigation strategy is optimal for which products, and second, what are the optimal RMI and reserve capacity levels?

We could identify high inventory holding costs with functional products and low inventory holding costs with innovative products.

Again, high fixed cost for the reserve capacity with an efficient supply chain and low fixed cost for the reserve capacity with an agile supply chain.

From the intersection of these two variables and the mitigation considerations we made before regarding the cost parameters, a four boxes table can be framed.

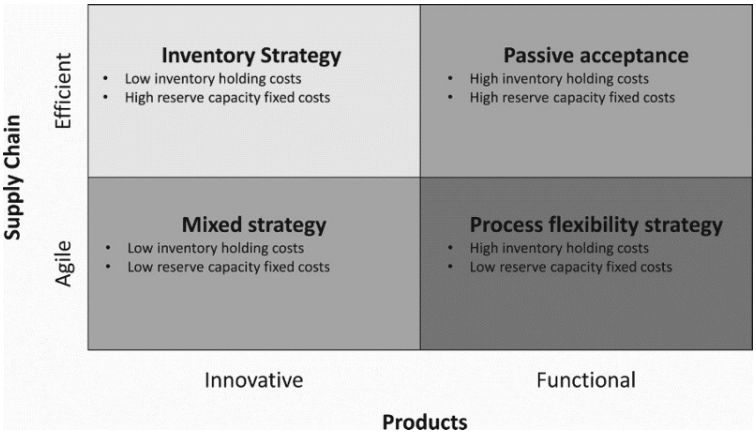

Figure 7 Supply chain/Products strategy matrix (Lücker, F., Seifert, R.W., Biçer, I., 2019)

3.3 State of the art on sub-suppliers' risk

In the first part of the analysis, papers published from 2004 on have been collected; to consider the recent knowledge on the topic.

The subject areas have been limited to the ones related to the industrial application of the contribution, therefore only literature related to "Business, management and accounting", has been initially considered.

The document type has been filtered for “Article”, “Book” or “Book chapter”, Source type has been limited to “Journal”, “Book series” and “Book” and results have been limited to English language.
Only articles with a number of citations on Scopus higher than 30 have been considered; this characteristic has been considered as threshold for the identification of the irrelevancy of a paper contribution in this study area.

A two-level search has been run on the database considering the combinations of the keywords “Sub-suppliers” OR (“Multi-tier supply chain” AND “Supplier”).

The total number of 77 documents (after the application of the filters previously mentioned) has been furtherly streamlined by a qualitative evaluation of the relevance of the topic by reading the abstract.

In this way a total number of 11 papers was eventually selected as their content contributed to the mentioned sub-suppliers risk management related topics.

Further articles of particular relevance on the topic have been reviewed when encountered as reference in the articles selected.

Ericsson case: a disaster as a trigger to establish a new SCRM approach
A good example in the literature of Sub-suppliers management came from the company Ericsson (Norrman, A., Jansson, U., 2004).
Ericsson is one of the largest suppliers of mobile telecom systems in the world, active worldwide since 1876.
They set a proactive supply chain risk management approach after facing a serious sub-supplier accident.

We will shortly describe the accident that can be seen as the major trigger for Ericsson to improve its supply chain risk management.

On 18 March 2000 in a very small production cell at a sub-supplier's plant in Albuquerque, New Mexico (USA), a ten-minute fire caused by a lightning bolt hitting an electric line in New Mexico, causing power fluctuations throughout the state. When the power was out, there was no spare diesel motor to supply the fans with power, so the fans stopped. From a plant perspective, the resulting fire was almost negligible, but for Ericsson, the impact was huge. In the spring of 2001, when the annual report from Ericsson was announced, a major loss of about $400 million was indicated. The reason was that the fire occurred in one of the plant's "clean rooms", where absolutely no dust is tolerated, took almost three weeks until the production was up and running, and it would take years to get new equipment delivered and installed. As this plant was Ericsson's only source for this chip, Ericsson was not able to sell and deliver one of its key consumer products during its booming "market window". The company lost many months of mobile phone production, and the accident finally had a great impact on Ericsson's decision to withdraw from the mobile phone terminal business.
Later, Ericsson's business interruption costs were calculated as approximately $200 Million. The accident made Ericsson realize the importance of better analyzing, assessing and managing risk along the supply chain and to take immediate action when incidents are indicated. Ericsson did not act quickly and powerfully enough after the "Albuquerque accident", and it took too long before higher management was aware of the incident. Furtherly, Ericsson neither had alternative sources nor was prepared for this kind of accident. Now, actions have been taken: during the last few years, a formal SCRM organization has been put in place, and many SCRM processes and tools have been developed and implemented. Today's philosophy at Ericsson is that "everyone is a risk manager".

After this interesting, though catastrophic, example, we can have a look at the SCRM process adopted by Ericsson afterwards. The company has now developed and implemented improved organization, processes and tools for supply chain risk management. It tries to identify, analyze and manage both internal and external risk sources, related to the company as well as its suppliers and sub-suppliers. According to Ericsson, an important success factor, to make SCRM work, is having an open discussion with the suppliers, both during risk analysis and assessment, but particularly when handling incidents. Many ideas and tools have been taken from normal risk management practice, but have been applied with a supply chain perspective, focusing not only on Ericsson's own activities. As a result, risk consequences have been reduced.

Supply chain principles have been influenced in the last decades, by the attempts to reduce costs, time and quality, and have focused on concepts of responsiveness, agility and leanness. Those principles might lead to lean but very vulnerable supply chains, and, consequently, the interest in SCRM has increased simultaneously. It might be that the best approach to be pursued is a balanced one, where SCRM is one part of the equation. This could be done by trying to relate risk consequences to time and money parameters, such as Ericsson is now doing.

Moreover, it is possible to expand the risk management focus from focal companies' perspective to suppliers and sub-suppliers – by working together in risk identification and assessment but also by investigating how suppliers are working with those issues on their side.

Critical factors for sub-supplier management

In a study of (Grimm, J.H., Hofstetter, J.S., Sarkis, J., 2014), by means of interviews with representatives of food supply chains, they identified 14 critical success factors for managing sub-suppliers. Among this, particularly the critical success factors number 9,10,11 and 12 had not been extensively considered in previous Sustainable Supply Chain Management research due to the preponderance of research focusing on dyadic direct supplier relationships.

1. “Trust between focal firm and direct supplier”
2. “Trust between direct supplier and sub-supplier”
3. “Focal firm's buyer-power (over direct supplier)”
4. “Direct supplier's buyer-power (over sub-supplier)”
5. “Committed long-term relationship between direct supplier and sub-supplier”
6. “Supply-know-how of focal firm”
7. “Direct supplier's willingness to disclose sub-suppliers”
8. “Involvement of direct supplier”
9. “Perceived value for direct supplier”
10. “Perceived value for sub-supplier”
11. “Low risk of supplier-by-passing”
12. “Sub-supplier's capability to comply with requested sustainability standards”
13. “Geographical distance between supply-chain-partners”
14. “Cultural distance between supply-chain-partners”

Strategies and contingencies in managing sub-suppliers

(Wilhelm, M., Blome, C., Wieck, E., Xiao, C.Y., 2016) investigated, in their research, which contingent strategy should be adopted to better manage sub-suppliers. Considering the impact that these strategies have on performances and sustainability of the entire multi-tier supply chain (MSC).

The finding show that institutional distance between the buying firm and its supply base mattered for the selection of an MSC strategy: a low level of horizontal complexity at the Tier-1 level, those cases where the buying firm is sourcing from suppliers that operate in a tightly regulated environment (Europe and North America in our cases), facilitates the delegation of sub-supplier sustainability management tasks, leading to an open MSC.
Moreover, the higher the level of horizontal complexity at the sub-supplier level, the more is likely to have the involvement of additional (external) parties, leading to a "work with third parties" MSC, particularly when institutional distance is high.

The higher the horizontal complexity at the Tier-2 level, the higher the dependency of the buyer on a particular Tier-1 supplier to disseminate sustainability upstream leading to a delegating strategy.
Strong T1 supplier sustainability management capabilities facilitate the delegation of authority for managing sub-suppliers' sustainability and lead to an open MSC.
On the other end, Less developed Tier-1 supplier sustainability management capabilities increase the risk of a "don't bother" MSC, even though the buyer intends to manage the MSC.

Supply chain leadership for multi-tier sustainable supply chain management
(Jia, F., Gong, Y., Brown, S., 2019) explored, in their research, the concept of supply chain leadership, investigating which role supply chain leadership plays for multinational companies in multi-tier supply chains.
Findings of the research show that, what they refer as "Proactive focal companies" tend to apply a transformational leadership style (inspiration, intellectual stimulation and individualized consideration) on Tier-1 suppliers in implementing proactive sustainability initiatives in a multi-tier supply.

While they intend to achieve sustainability by applying a transactional leadership style (contingent reward and management by exception) and at the same time using one or more mechanisms of the three approaches on the middle tier suppliers: "Direct", "Indirect", or "Work with third-party".
Applying a transformational leadership combined with "direct" alone or "direct" together with "work with third party" approaches to extreme upstream suppliers can lead to the creation of an overall closed supply chain structure and help its multiple-tier supply chain to learn the proactive sustainability initiatives.
Thus, proactive focal companies need to apply different leadership styles together with different governance mechanisms along the supply chain learning stages towards different tiers of suppliers to facilitate their multi-tier supply chains learn sustainability.

Ford model: a quantitative approach from automotive industry

An interesting example of lower-tier supply chain management come from automotive industry (Simchi-Levi, 2015).
Ford, second-largest U.S.-based automaker and the fifth-largest in the world, like many others OEM has typically a good information on Tier 1 suppliers but it is way more complicated to have the same information also on lower-tier suppliers in the supply chain.
As we mentioned more than once so far, disruptive events, so events characterized by low probability to happen but high impact on performance, can originate in a point of a supply chain and propagate their negative effect downstream with increasing magnitude. Clearly, in a long and complex supply chain, with a multitude of sub-suppliers, the focal company should consider a huge number of possible disruption scenarios.

So, for a company such as Ford, it is barely impossible to conduct a traditional risk analysis for the more than 4.000 Tier 1 suppliers: the time to conduct the analysis would make the analysis itself obsolete.

Starting from this consideration Ford developed a TTR (Time To Recover) - TTS (Time To Survive) model.
Namely:

- TTR is defined as the time that a node in the supply chain needs to fully recover after a supply chain disruption.
- TTS is defined as the time the supply chain can continue working without evident performance loss after a node of the supply chain is disrupted.

The multi-tier TTR model is based on an optimization problem.
The objective is to minimize the profit margin loss due to loss of production:

$$\min \sum_{j \in v} f_j l_j \qquad (4)$$

Where:

- j: vehicles
- v: set of all final vehicles j
- f_j: performance impact of one unit of product j [$/unit]
- l_j: lost production volume of vehicle type j [units]

Considering the following assumptions and sets of constraints:

1. Processing lead time are neglected, since very short compared to TTR.

2. Rerouting materials and changeover costs are neglected, since very low compared to the cost impact of the lost in sales due to the disruption.
3. Set of Bill of materials constraints, basically the downstream node cannot produce more units than the amount allowed by the materials supply of the upstream node, applied to all the nodes:

$$u_j \leq \sum_{i \in P_{jk}} \frac{y_{ij}}{r_{kj}} \qquad \forall k \in N^{-}(j), \qquad \forall j \in D \qquad (5)$$

Where:

- i: nodes
- k: parts type
- D: Set of all nodes, except the first one
- $N^{-}(j)$: Set of parts required to produce node j
- u_j: Total production quantity of node j during time TTR
- P_{jk}: Set of all nodes in the upstream of node j and part type k
- y_{ij}: allocation of upstream node i to downstream node j during TTR
- r_{jk}: number of parts k required to make one unit of vehicle j

4. Material flow balance, basically what the upstream node produces plus the stock it has, must be able to satisfy the demand of all the downstream nodes:

$$\sum_{j \in N^{+}(i)} y_{ij} \leq u_i + s_i \qquad \forall i \in U \qquad (6)$$

Where:

- U: set of all nodes (vehicle), except the last one

- $N^+(i)$: set of nodes that require node i
- s_i: finished goods inventory of node i

5. Disruption scenario, basically the disrupted node does not produce during TTR:

$$u_j = 0 \qquad \forall j \in S \tag{7}$$

Where:

- Set of all nodes disrupted by disruption the scenario

6. Demand side balance, basically for every component, the demand is theoretically satisfied by the upstream production, either it is actually produced, or it is the volume lost because of the disruption:

$$l_j + \sum_{k \in V_j} u_k \geq d_j \times TTR \qquad \forall j \in \nu \tag{8}$$

Where:

- V_j: set of all final nodes (vehicles) that are of the same type j
- d_j: demand for j per time unit

7. Set of production capacity constraints, basically the production capacity of upstream suppliers during TTR must be equal or higher than the total production capacity of all the downstream nodes:

$$\sum_{k \in A_\alpha} u_k \leq c_\alpha \times TTR \qquad \forall \alpha \in A \tag{9}$$

Where:

- A_α: set of all nodes produced at supplier and/or plant α
- A: set of all suppliers' plants
- c_α: production capacity of node α per unit of time

8. Physical constraints:

$$l_j, u_j, y_{ij} \geq 0 \quad (10)$$

The TTS model applies the same criteria and structure of the TTR.
In this second case the objective is to maximize the TTS.
Thus, the hypothesis is that no loss is considered.

Thanks to this model, Ford was able to identify risk exposure associated with some parts and/or suppliers. Indeed, the company managed to identify several supply chain nodes that would have a huge impact of their performance if that node operations faced a disruption. The following steps for the focal company are allocating resources and develop mitigation strategies to be able to survive to that disruption with no severe losses.
Simply speaking, for all the nodes of the considered supply chain it should apply the following law: Time To Survive of focal company must be higher than Time To Repair of the disrupted company, plus, eventually, a Safety Margin.

In the following steps of the study the company found out also that the suppliers whose disruption would lead to the most severe profit impact were those from which Ford's annual spend was relatively small. That means, there were some critical suppliers that, when disrupted were leading to considerable profit losses, being they difficult to be replaced quickly.

Disruption Risk and Optimal Sourcing in Multi-tier Supply Networks

Another model was developed by (Ang, E., Iancu, D.A., Swinney, R., 2017) based on a supply chain consisting of three tiers: Tier 0, Tier 1 and Tier 2.

Tier 0 contains a single firm, the "manufacturer", that assembles finished goods and sells to a consumer market.

The manufacturer sources a critical component from Tier 1, which consists of two identical suppliers, A and B, that provide fully substitutable products.

Each Tier 1 supplier, in turn, sources a critical intermediate component from Tier 2.

Disruptions in the supply chain originates in Tier 2: we assume all suppliers in Tier 2 are prone to disruption, and with some probability will be unable to deliver the production order placed by Tier 1 suppliers. We assume a Bernoulli disruption distribution with disruption probability λ and we assume there are two "classes" of Tier 2 suppliers:

- reliable (denoted by the subscript r), less prone to disruption but more expensive, and
- unreliable (denoted u).

Mathematically, this implies $\lambda u > \lambda r$.

The Tier 2 sourcing cost is exogenous and the per unit sourcing cost is, then, $c_r > c_u$.

Aside from their reliability and their sourcing cost, the Tier 2 suppliers are identical, and all Tier 2 suppliers have sufficient capacity to fulfill any downstream order.

Disruption of an individual Tier 2 supplier occurs independently of other Tier 2 suppliers.

Suppliers in Tier 1, after receiving a contract from the manufacturer select which Tier 2 suppliers to use with the goal of maximizing their expected profit.

If a Tier 1 supplier selects a Tier 2 supplier that disrupts, then all parts from that supplier are lost and the Tier 1 supplier potentially faces a shortage of components, which may in turn lead to a failure to deliver product to the manufacturer.
We assume that both Tier 1 suppliers have access to one reliable and one unreliable Tier 2 supplier.
Tier 1 suppliers may choose to single source from any type of supplier or may choose to dual source from a combination of reliable and unreliable suppliers.
So, four possible supply chain structures are assumed:

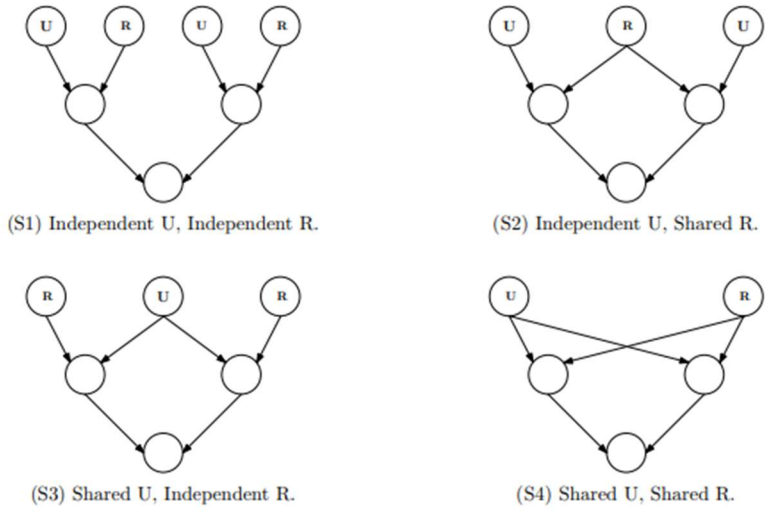

Figure 10 - Four supply chain structures (Ang, E., Iancu, D.A., Swinney, R., 2017)

There is no possibility of disruption considered originating in Tiers 0 or 1.

The manufacturer faces deterministic market demand D and makes fixed per unit revenue of π for every unit it sells up to D.
We assume that $\pi \geq c_u$, so that it is possible for the supply chain to profitably sell the product; moreover, all manufacturer costs outside of procurement costs from Tier 1 suppliers are normalized to zero.
The sequence of events is as follows:

- In the first period, the manufacturer offers its Tier 1 suppliers A and B a price and quantity contract of the form (p, Q). We denote the contracts offered to suppliers A and B by (p_A, Q_A) and (p_B, Q_B), respectively.
- After receiving the manufacturer's contract, each Tier 1 supplier then places orders (c_u, q_u) and (c_r, q_r) with its Tier 2 unreliable and reliable suppliers. The ordering quantities q_u and q_r are chosen by the Tier 1 suppliers to maximize expected profit.
- In the second period, the Tier 2 suppliers either disrupt or fulfill their deliveries to the Tier 1 suppliers.
- After collecting all deliveries from Tier 2 suppliers, Tier 1 suppliers then attempt to fulfill the order submitted by the manufacturer. Any excess inventory delivered by Tier 2 suppliers to Tier 1 suppliers has zero value.
- In turn, after collecting deliveries from Tier 1 suppliers, the manufacturer attempts to fulfill consumer demand D. Any excess components delivered by Tier 1 suppliers to the manufacturer has zero value.
- The manufacturer seeks to maximize its expected profit from the consumer market at the end of the second period and its decision variables are the price and quantity in the contracts it gives to its Tier 1 suppliers, (p_A, Q_A) and (p_B, Q_B); hence, we define the sourcing strategy of the manufacturer to be {(p_A, Q_A),(p_B, Q_B)}, the pair of contract offers to its two Tier 1 suppliers.

It is assumed that the disruption probabilities and sourcing costs are known to all parties in the supply chain.

It is also assumed that the structure of the supply network is known to the manufacturer.

To define the optimal sourcing strategy for a Tier 1 supplier, recalling that each Tier 1 supplier can source from two Tier 2 suppliers, one reliable and one unreliable, let

denote as q_u and q_r denote the amounts ordered by a Tier 1 supplier from its unreliable and reliable Tier 2 suppliers, respectively.

The Tier 1 supplier's profit is then:

$$\Pi^{(S)}(q_u, q_r) = (1 - \lambda_u)\,\lambda_r\,[\mathrm{p}\min\{\mathrm{q}_u, \mathrm{Q}\} - \mathrm{c}_u \mathrm{q}_u] + \lambda_u(1 - \lambda_r)[\mathrm{p}\min\{\mathrm{q}_r, \mathrm{Q}\} - \mathrm{c}_r \mathrm{q}_r] + (1 - \lambda_u)(1 - \lambda_r)\,[\mathrm{p}\min\{\mathrm{q}_u + \mathrm{q}_r, \mathrm{Q}\} - \mathrm{c}_u \mathrm{q}_u - \mathrm{c}_r \mathrm{q}_r]$$

The manufacturer also has a profit function that is of a very similar form to the one above.

For any contract offered by the manufacturer, an optimal sourcing strategy for a Tier 1 supplier can be found in the set $\{(0, Q), (Q, 0), (Q, Q)\}$. In the latter strategy, the quantity sourced is twice the contracted quantity Q, which corresponds to the supplier adopting two forms of disruption risk mitigation: dual sourcing and inventory mitigation.

Observe that it is never optimal to adopt dual sourcing without inventory mitigation, so to source from two Tier 2 suppliers with a total quantity equal to the manufacturer's contracted quantity Q.

Consequently, using the terminology of (Tomlin, 2006), the supplier's optimal strategy is one of passive acceptance (sourcing from the unreliable Tier 2 supplier), sourcing mitigation (sourcing from the reliable Tier 2 supplier), or dual sourcing and inventory mitigation (sourcing from both Tier 2 suppliers, and sourcing more than the requested quantity).

The optimal strategy depends critically on whether the inequality $c_r/c_u > \lambda_u/\lambda_r$ holds:

- When $c_r/c_u > \lambda_u\,\lambda_r$ sourcing from the reliable supplier increases cost more than it reduces risk.
- When $c_r/c_u < \lambda_u/\lambda_r$ sourcing from the reliable supplier increases cost less than it reduces risk.

So, when the reliable supplier is costly, it is less effective than the unreliable supplier in a cost-risk sense, thus, the Tier 1 supplier never sources exclusively from the reliable supplier.

However, for high enough per unit revenue p, the Tier 1 supplier will use the reliable supplier, since the cost of extra sourcing is made up by the risk reduction due to diversification.

When the reliable supplier is cheap it may be optimal to use the reliable supplier in isolation. This gives rise to an intermediate regime where a Tier 1 supplier strictly prefers to single source sourcing from the reliable supplier, followed by the dual sourcing and inventory mitigation regime.

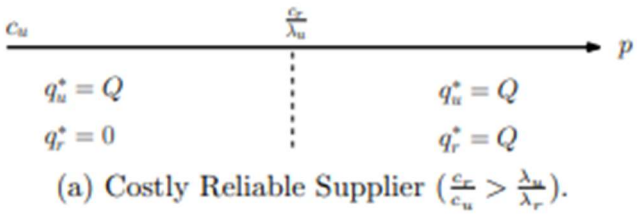

Figure 8 Costly Reliable Supplier (Ang, E., Iancu, D.A., Swinney, R., 2017)

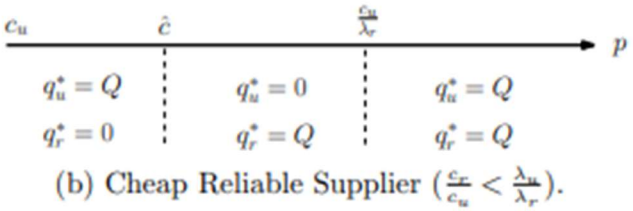

Figure 9 Cheap Reliable Supplier (Ang, E., Iancu, D.A., Swinney, R., 2017)

Having derived the optimal sourcing strategy of a Tier 1 supplier in response to a contract (p, Q) from the manufacturer, we may now determine the optimal contracts offered by the manufacturer to the two Tier 1 suppliers.

The manufacturer offers contracts of the form {(pA, QA), (pB, QB)} to the Tier 1 suppliers. As such, the manufacturer's expected profit function is:

$$f_1(p_A, p_B)[\pi \min\{Q_A, D\} - p_A q_A] + f_2(p_A, p_B)[\pi \min\{Q_B, D\} - p_B q_B] + (1 - f_1(p_A, p_B) - f_2(p_A, p_B) - f_3(p_A, p_B))\ [\pi \min\{Q_A + Q_B, D\} - p_A q_A - p_B q_B]$$

Where:

- $f1(p_A, p_B)$ is the probability supplier A delivers and supplier B does not;
- $f2(p_A, p_B)$ is the probability supplier B delivers and supplier A does not;
- $f3(p_A, p_B)$ is the probability that no Tier 1 supplier delivers.

These probabilities depend on two key elements: the prices p_A, p_B offered by the manufacturer and the degree of concentration in the Tier 2 supplier base.
The manufacturer may employ different risk mitigation strategies:

- Passive acceptance (ordering inventory equal to the total demand from a single Tier 1 supplier);
- Direct inventory mitigation (ordering more inventory from Tier 1 than the total demand);
- Direct dual sourcing (ordering from both Tier 1 suppliers).

The manufacturer may use multiple direct strategies simultaneously and may induce different strategies at each Tier 1 supplier.
For low revenues, the manufacturer prefers to induce both Tier 1 suppliers to single source from unreliable Tier 2 suppliers. The total quantity sourced by the manufacturer is D (no direct inventory mitigation). In addition, the manufacturer is indifferent between single sourcing and dual sourcing; hence, an optimal strategy is passive acceptance.

For higher revenues, the manufacturer switches to direct dual sourcing and inventory mitigation while still inducing Tier 1 suppliers to follow a passive acceptance strategy by paying a low unit price; in this regime the manufacturer gets all surplus from its Tier 1 suppliers and directly pursues all disruption risk mitigation efforts.
This strategy can be defined: manufacturer mitigation (MM).
For the highest revenues, the manufacturer induces both Tier 1 suppliers to dual source by paying both a high price, relinquishing significant supply chain profit to its Tier 1 suppliers, but incentivizing suppliers to manage disruption risk.
This strategy can be defined: manufacturer mitigation + full supplier mitigation (MM + SM).
So, the authors want to prove that with a fully independent Tier 2, the manufacturer's optimal sourcing strategy builds risk mitigation from the bottom of the supply chain up.
As revenue increases, it's optimal to first add manufacturer mitigation, then partial supplier mitigation, and finally full supplier mitigation.
Notably, it's never optimal with a fully independent Tier 2 for the manufacturer to induce any supplier mitigation without first engaging in its own mitigation efforts.

When any Tier 2 reliable supplier is shared, the optimal strategy of the manufacturer changes. Anyway, the study shows that a shared reliable supplier base only impacts the manufacturer's optimal sourcing strategy at very high unit revenues and the manufacturer pursues MM + SM. This strategy is never optimal when Tier 1 suppliers share a reliable supplier, since inducing both Tier 1 suppliers to source from the (shared) reliable supplier would never provide any diversification benefits.
When sharing any Tier 2 unreliable supplier, the optimal strategy of the manufacturer changes too. Indeed, a shared unreliable Tier 2 supplier reduces the manufacturer's reliance on direct mitigation: because of the correlation introduced to the disruption

risk of the Tier 1 suppliers by sharing an unreliable Tier 2 supplier, manufacturer mitigation is less valuable than in the fully independent structure.
So, the manufacturer should rely less on direct inventory mitigation and dual sourcing, instead focusing on offering its suppliers a higher price and allowing them to mitigate disruption risk.
Differently from the independent Tier 2 supplier case, now, the manufacturer's optimal strategy builds risk mitigation from the top of the supply chain down, first inducing Tier 1 suppliers to mitigate risk and then adding manufacturer mitigation only for high unit revenues.
Last case, in a fully shared supply chain, manufacturer mitigation has no value because Tier 1 suppliers have access to identical Tier 2 suppliers.
Dual sourcing is one optimal solution, but it is never strictly preferred to single sourcing. Direct inventory mitigation, thus, sourcing more from Tier 1 than total demand D, is not valuable either, since this strategy is only beneficial if used in conjunction with dual sourcing.
So, even more in this fully shared supply chain structure, the manufacturer never adopts direct disruption mitigation efforts, but it could raise the price offered to Tier 1 suppliers, inducing its suppliers to use dual sourcing and inventory mitigation strategy.

3.4 Conclusions and literature gaps

In this section the literature research has been discussed and the related findings described. This analysis led to the identification of some gaps in the current literature. The screening of the existing contributes related to risk mitigation and sub-suppliers risk management has shown a well-established knowledge of the topic growing over the years, resulting in a stable and broad basis for further developments.

As shown and discussed in this chapter, some models identified, from a general and broad perspective, which are the success factors in a buyer-supplier-subsupplier relationship.
In other models it has been explored the risk mitigation delegation approach, identifying for which supply chain configurations and morphologies it is more recommended for the buyer to act “directly” on sub-suppliers risk mitigation, or delegating this task to tier-1 suppliers.
In this regard, also the concept of supply chain leadership has been explored. Identifying which leadership approach the focal company should adopt depending on the tier level of the supplier to incentivize proactive sustainability initiatives along the entire supply chain.
The indirect mitigation approaches have been discussed also in quantitative models, identifying links between risk mitigation strategies parameters like buyers margins or supplier reliability.
Thus, the idea of mitigating sub-suppliers risk by acting on supplier risk mitigation capabilities or delegating supply chain risk management task to tier-1 supplier which have been considered reliable, is well established in recent literature.
Beside this, they also have been presented models helping companies in identifying which node of the supply chain would be more economically critical in case of a business interruption.

What has been considered missing is a practical and easily implementable model to help industrial companies in assessing how much the tier-1 suppliers are mature in their supply risk management practices and capabilities.
In this regard, the SCRMMM introduced in this chapter is a valid tool to take inspiration from, but, two limits have been identified for the usage of this model for supplier risk mitigation maturity assessment.

Firstly, the aim of the SCRMMM is to support companies in performing a self-assessment of their risk management maturity to identify possible areas of improvement. The objective of this research is, instead, providing the focal company with a tool to assess how good are they supplier in managing their supply risks, so that, eventually, the focal company is protected from those risks.
In this research, the company supposed to be benefiting from the questionnaire is not the one performing the questionnaire but its customer.
Because of this, it is considered necessary to have a questionnaire where questions are easy to read, understand and answer, so that the willingness of supplier to respond is likely to be higher.

To conclude, the aim of this thesis is to contribute to the current literature filling the research gaps highlighted. This objective is reached through the development of a model for sub-suppliers disruption risk management.
Concretely the aim is to provide a practical tool, easily adoptable in different industries, that allows supply managers to assess the risk profile of the sub-suppliers base, to eventually englobe this estimations in suppliers' risk assessments, to obtain at the end, more comprehensive and farsighted supply risk management processes.

4 Research setting and company overview

4.1 Research setting

The work here proposed has been carried out over a period of ten months, by one researcher working on site at the Headquarter of Hilti Corporation, Schaan, Liechtenstein. Support has been provided by the team the researcher was working in: Sourcing Excellence Team (XLSE). XLSE operates in the company in order to offer supply management tools and improve supply processes to all the Business Units (BU). Each of Hilti's Business Units has indeed its own independent Supply Team and Supply Managers which dedicate themselves to the BU's success. Besides that, an alignment between the BUs and joint efforts is necessary in order to allow Supply Teams to further improve Hilti cost situation and the overall supply efficiency: in this regard XLSE plays a coordination role. The author has been working in XLSE for the whole research period by mainly covering Sourcing Management, Suppliers Compliance management and Suppliers Onboarding on the e-Sourcing platform adopted in Hilti. Next to the support provided by the XLSE Team, a fundamental contribute for model development has been provided by other employees among Hilti, mostly Supply Managers, when supporting the researcher in testing the questionnaire developed. Details on how this research methodology has been conducted presented in chapter 6.

4.2 Company Overview

Hilti Corporate was founded in Shaan, Liechtenstein, in 1941 by the engineer Martin Hilti (1915-1997) and his brother Eugen (1911-1964). Today Hilti Corporation is World market leader in fastening and demolition technology for construction professionals and offers a broad range of products and services with a total sale of CHF 5.6 billion (2018). Its size reaches around 30'000 employee who work in 120 different countries. Despite the growth that has interested the Company both in terms of geographical expansion and increase volumes sold, Hilti is still today a family

business: all the shares are owned by the Martin Hilti Family Trust, which ensures its long-term continuity. The Hilti Group's strategic orientation is based on a caring and performance-oriented culture summarized by the mission statement "We passionately create enthusiastic customers and build a better future". In order to do so, Hilti runs a direct sales model, with no third-parties retailers' involvement, with around 15'000 of Hilti team members working directly with customers, worldwide. Field engineers and sales representatives go daily onsite, with roughly 250'000 customer contacts per day, and they help to find solutions, getting back insights to Hilti design labs to create better projects starting from customers' needs. Overall, 10 Business Units are presents, each of them autonomous and responsible for its own results.

Supply Chain at Hilti

The direct sales approach and the multitude of market organizations lead to a complex supply chain set up. The nodes in the supply chain are plants, local, regional and central warehouses, transshipment points, stores and moving warehouses on construction sites. Materials can follow different flows: raw materials and components from suppliers can move directly to one of the company's production facility where they are stocked, or they can pass through some central or regional warehouses.

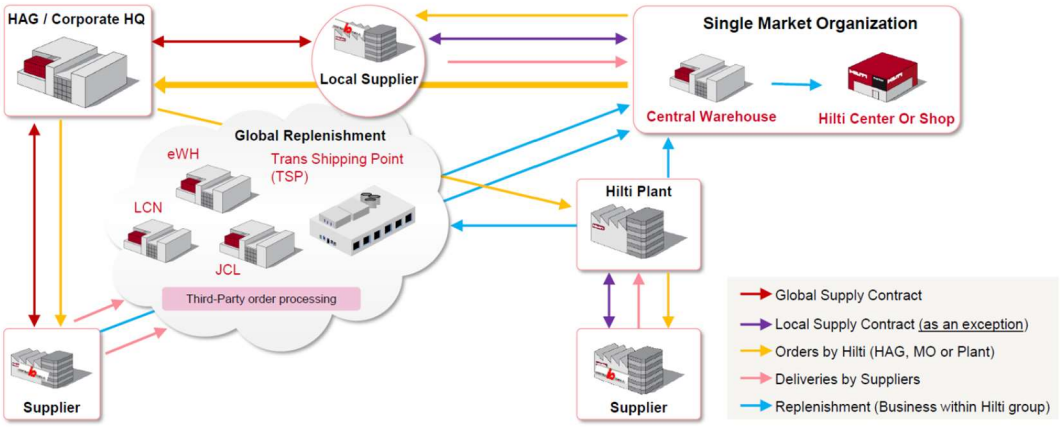

Figure 10 Supply chain flows in Hilti.

Risk Management at Hilti

The main strength of Hilti Risk Management is given by fact that it distinguishes between strategy and market risks, and financial and occurrence-oriented risks, differently from the common practice of several companies. While at Business Unit (BU) level decisions about BU specific strategy are taken, Corporate Development develops long-term and mid-term strategy and Group Controlling manages the information flow with the Executive Board.

Part of the risk management process is the internal audit, that aims at checking risk management processes and includes independent checks on selected corporate risk topics.

Considered the importance of tracking strategic and non-strategic suppliers, since 2006, Hilti applies Consequence Based Risk Management focused on the concept of Business Interruption Risk. Using this approach, starting from the Business Interruption estimation, the most risk critical suppliers from sales perspective are identified and accordingly, mitigation measures are proactively introduced in order to reduce the eventual impact of a supply chain disruption.

The main tasks of Supply Managers in the process are:

- The identification of risky suppliers which can cause a business interruption;
- The active and periodical monitoring of the suppliers' risk;
- The establishment of risk mitigation measures to minimize the probability and impact of business interruption;
- The predefinition of a Business Continuity Plan that will be applied in case of supplier disruption to have the minimum impact on Hilti;

Twice a year an appointed controller at Hilti performs the computation of the BI12 for each and every supplier. This figure represents the loss the company will have from sales perspective in case the supplier interrupts the supply. It is computed indeed

once all the components provided from the given supplier, and all the finished items in which these components end have been identified. These are the prerequisites to compute the sum of the profit for the last twelve months of each item and fixed costs, which correspond to the figure of BI12.

Given the values of BI12, the Supply Managers can easily identify which are the most risk critical suppliers, based on the relevance of the impact on sales in case of their interruption. The suppliers with a BI12 higher than the threshold value of 10 million CHF are picked and inserted among the ones to be actively monitored due to their risk relevance.

To understand the effective impact of the interruption on the business, Supply Managers estimate the Mean Time To Recover necessary to ensure an equivalent material flow of the relevant items after a supplier disruption, taking all existing risk mitigation measures into account.

Finally, the BI effective is computed according to the following formula:

$$BI_{effective} = MTTR[months] \times BI_{12}[12\ months] \qquad (11)$$

This value represents the effective loss of sales the company will suffer of if the supplier stops its deliveries.

The main benefit brought by the Consequence Based Risk Management is the possibility of identifying very risky suppliers which would have not been spotted otherwise.

Supply Chain Management and Suppliers selection at Hilti

The supply base is defined for each material group according to the different strategies, then tactical selection processes are put in place in order to establish the best supplier/item combinations. In parallel to these processes, the supply contract is negotiated and once it is established the relation, it can proceed and can be developed both tactically and strategically; purchasing processes can be carried on depending on

the company needs. These activities cannot be performed unless the suppliers have been subjected to the qualification and the audit process which ensure that the supplier is able to supply the required component fulfilling the company quality and quantity requirements (supplier/item combination).
Risk management module is activated after supplier selections, with the consequence-based evaluation previously mentioned.
In parallel to the phase described in the proposed process runs the Time To Market (TTM), a process that describes all the activities necessary to bring new products and services to market, from the start with a business opportunity description until the completion of the launch of the new offering into the markets. In the large majority of cases, tactical supply decisions are taken in TTM.

The aim of this process is to select, establish and maintain proactively the optimal supply base for each material group. The supply base is the result of full understanding of the global industry for each material group, the definition of a material group strategy aligned with Hilti strategic direction, and the supplier identification and selection process that aims to contract the perfect supplier(s) according to the strategy. Once the supply base is created, suppliers' relation is maintained along the time through the process of Supplier relationship Management by rewarding the best suppliers, developing the ones which show potential for benefits and improvements, and phasing out redundant or under-performing suppliers.

The tactical processes aim to select the right supplier / item combination for each part. This process is carried on with the following sub-processes developed on the SAP Ariba platform:

- Identification of the most suitable candidates to supply the specific required component;
- Request For Information (RFI): generic business information is gathered if needed;

- Request For Proposal (RFP): suitable suppliers are asked for a quotation for the needed component. Suppliers are informed of the company requirements and needs and are able to submit their quotes together with all the other additional information directly on the SAP Ariba platform;
- Auction: auction processes can be carried on sequentially to an RFP according to Game Theory principles;
- Awarding: quotations are compared and the sourcing strategy is established by awarding the chosen suppliers with the respective agreed quantity. This phase, when after an auction, is always supported by the application of the Bonus/Malus transformation. The result of the whole process is the selection of the supplier/suppliers offering the lowest price (or the lowest comparison price after the application of the Bonus/Malus).

Bonus/Malus system

Hilti developed a quite comprehensive Bonus/Malus system, a solution to achieve the comparability and equivalency of alternative prices in a transparent way. This methodology is always applied in order to compare prices at the end of auction processes and it is recommended to be included in the awarding process also after a Request for Proposal.

The first step is the determination of criteria of interest for the company. Different functions are examined and a total of 30 criteria can be activated depending on the relevance of the different cost items in the different application cases. The application of the Bonus system in negotiations transforms the quoted price into the comparison price which is then used in order to finally select suppliers.

The final evaluation and supplier selection are done on comparison prices that better reflects the real cost perception the company has of the suppliers. All the quotes are collected and the direct (or quoted) prices are then adjusted by the absolute or relative

bonus depending on the degree of variance of the individual quote with respect to a neutral threshold a priory estimated.

A Bonus/Malus system has the potential of improving quality of internal decision making of purchasers.

Bonus/Malus system is built on the basis of the Total Cost of Ownership or the Total Value of Ownership which are standard concepts in purchasing since the 1980s.

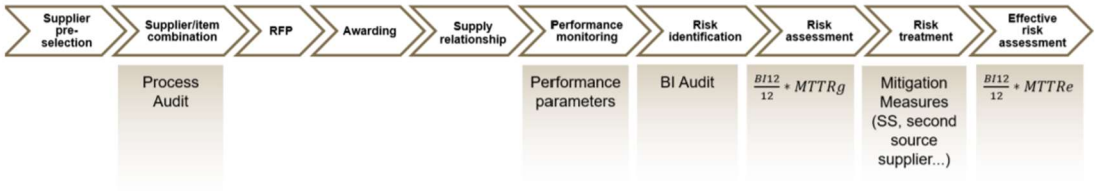

Figure 11 Hilti Processes

5 Questionnaire development

So far it has been discussed the need of providing a tool for sub-suppliers risk management.
Recent experiences, such as the Ericsson case (Norrman, A., Jansson, U., 2004), shows us how a business interruption taking place in any point of the upstream supply chain can “ripple” downstream leading to huge losses in sales for the focal company.

To forecast a business interruption at sub-suppliers level, or to have clear transparency on who the sub-suppliers are and how risky they are, is anything but an easy task. As already discussed, gathering data and information about the suppliers of suppliers, for a company, is a lot of the times: simply not possible.

Nevertheless, we have seen how tier-2 suppliers’ risk can be mitigated by a focal company manufacturer by mitigating the tier-2 indirectly by inducing tier-1 suppliers to activate mitigation measures with respect to their suppliers. From (Ang, E., Iancu, D.A., Swinney, R., 2017) model we have seen that as revenues increases, the focal company manufacturer may rationally even decide to relinquish supply chain profit to incentive suppliers to manage their supply disruption risk. In other words, the focal company manufacturer builds risk mitigation from the bottom to the top of the supply chain up.
Stated that we can englobe the sub-suppliers’ dimension of risk not acting directly on sub-suppliers, but rather trying to assess the tier-1 suppliers capabilities in manage their supply risk.

The aim is, thus, to develop something that can allow Hilti to assess the level of maturity of the tier-1 suppliers in managing their suppliers’ risks.

All of this has, finally, led the researcher to the decision to develop a questionnaire for the "Maturity assessment of the supply risk management capabilities".
The questionnaire, comprehensive of risk identification, assessment and mitigation approaches, is meant to be proposed to direct suppliers for the assessment of the maturity of their risk management practices in place.

The ultimate purpose of the questionnaire is not meant to be assessing which strategies is more convenient for the supplier, such as evaluating if it is more convenient for the supplier to take risk or take money or evaluating if risk or risk practices have impact on supplier profit. But, instead, the questionnaire is meant to be estimating how much the focal company (i.e., Hilti) is protected from sub-suppliers risk, thanks to the risk management capabilities of the direct supplier.

The risk management capabilities discussed and analyzed in-depth in the literature review will be therefore addressed in the questionnaire. Nevertheless, it has to be reminded and considered that usually the appropriateness and effectiveness of risk mitigation strategies are contingent on the internal and external environments and that there is no one-size-fits-all strategy (Talluri, S., Kull, T.J., Yildiz, H., Yoon, J. 2013). Stated that, the questionnaire will be developed with the objective of being:

1. Versatile (adapt to assess companies of different size, age and industry).
2. Clear (each question should be understandable and not ambiguous at a first reading).
3. Comprehensive (the relevant risk management practices and capabilities have to assessed).

To stress the importance of the versatility: it is relevant to mention that the biggest fifteen Hilti suppliers consist of 80% of the overall PVO. For these suppliers, the questionnaire can be considered as a starting point to investigate furtherly and

develop more ideas in a second moment. The rest of the supply base is made of company mostly relying on small and local supply chain. Therefore, the objective is to obtain a simple but effective questionnaire to target both groups of suppliers in the first place, with the possibility, if needed, to dive deep with the first group.

Being a common practice in the company to submit questionnaires to suppliers, by means of digital platform, other features of the questionnaires have been decided based on the experience gathered recently from submitting questionnaires to suppliers through these platforms.

5.1 IntegrityNext experience

IntegrityNext is a cloud-based platform that covers all major aspects of CSR and sustainability requirements, allowing companies to monitor thousands of suppliers with minimal administration.

IntegrityNext platform is part of Hilti supply daily activities. More than 20 questionnaires are offered by the platform and the experience of Hilti employees with the usage of these questionnaires, suggests that a list of 10 to 15 Yes/No questions, are an effective tradeoff between completeness of results of the questionnaire and high level of attention by the respondents.

Starting from this experience, it has been decided to build the first version of the questionnaire with a number of Yes/No question ranging from 15 to 20.

5.2 Questionnaire development

The questionnaire has been built, thus, based on the current practices adopted by Hilti and the finding of the reviewed literature.

To start the concrete development of the questionnaire, it has been decided to start investigating separately the 3 phases of the process view of Supply Chain Risk Management by (Tummala and Schoenherr, 2011), thus having three sections of questions:

1. Risk Identification.
2. Risk Assessment.
3. Risk Mitigation.

The Supply Chain Risk Management Maturity Model in its structure, is also divided into section, and beside the three dimensions of Planning, Implementation and Evaluation which typically resemble the Plan-Do-Check-Act cycle, we find other two dimensions: Leadership and Improvement. Starting from this hint, it has been considered relevant to include, next to the three above-mentioned phases of the Supply Chain Risk Management, two additional section regarding how pervasively and structurally the Risk Management practices are spread within the company and how much effort the company is employing its existing risk management knowledge and practices. In this regard, two sections have been considered:

4. Risk Management Governance
5. Risk Management Continuous Improvement

Risk Identification

In this section we want to identify the sources of risk, thus, questioning whether the company is considering that risk adequately.

In Hilti the risks are categories considered are:

- Risk of insolvency,
- Risk of elementary loss (e.g. fire, including also earthquake and floods)

- Risk of termination of contract (in case the supplier does not want to continue the relationship)
- Risk of forced disruption (any facility of the supplier is not allowed to operate anymore), (e.g. epidemic, child work…).

However, it has been decided to consider the two categories distinction in-depth discussed in the previous chapters: Financial Risk and Disruption Risk.
We want to know whether the company knows the financial and country situation of its suppliers.
This has been boiled down into the question number 1) and 2).

Beyond questioning what type of risks does the company collect information on, we should also ask if they know where their biggest supply risks hide. In the Ford case (Simchi-Levi, 2015) we have seen how the company found out also that the suppliers whose disruption would lead to the most severe profit impact were those from which Ford's annual spend was relatively small. These "critical suppliers" when disrupted were leading to considerable profit losses, being they difficult to be replaced quickly. Thus, it has been considered necessary to question whether also Hilti suppliers have precise criteria and method to identify critical suppliers.
This constitutes question number 3).

In the last two years researchers in Hilti have developed models to include risk considerations in strategic and tactical sourcing decisions. A Bonus/Malus system has also been developed to ponder supplier selection decision not only on price but on others risk factors that can lead a certain supplier to be economically inconvenient even if cheaper. In this regard, it has been considered relevant to question whether the company include risk considerations in the supplier selection process.
This constitutes question number 4).

Beside the Bonus/Malus, twice a year a supplier audit process is performed to check the riskiness of a supplier. The active monitoring of the supplier representing a relevant risk implies the identification and introduction of mitigation strategies, the definition and continuous update of the Business Continuity Plan and the monitoring of the financial situation. In this regard, it has been considered relevant to question whether also Hilti suppliers perform a suppliers' audit process on a yearly basis.
This constitutes question number 5).

Risk Assessment

In the above-mentioned audit process an appointed controller at Hilti performs the computation of the BI12 for each and every supplier. This figure represents the loss the company would incur from sales perspective in case the supplier interrupts the supply. Given the values of BI12, the Supply Managers can easily identify which are the most risk critical suppliers, based on the relevance of the impact on sales in case of their interruption. The suppliers with a BI12 higher than a certain threshold, are picked and inserted among the ones to be actively monitored due to their risk relevance.
To understand the effective impact of the interruption on the business, Supply Managers estimate also the Mean Time To Recover necessary to ensure an equivalent material flow of the relevant items after a supplier disruption, taking all existing risk mitigation measures into account.
Finally, the BI effective is computed as shown in chapter 4.
In this regard, it has been considered relevant to question whether also Hilti suppliers conduct quantitative Business Interruption analysis and evaluation of the expected impacts of BI if mitigation actions are present.
This has been boiled down into the question number 6) and 7).

Risk Mitigation

A wide range of mitigation strategies has been discussed in previous chapters, starting from the different contributions found in literature regarding the identification and classification of mitigation strategies.

In the list of risk mitigation strategies of (Manuj and Mentzer, 2008) we met the so called risk-hedging strategies.

These consist in differentiating the risk by a dispersed portfolio of suppliers, customers or facilities, so that, a single event does not affect all the entities at the same time, reducing the relative impact of the disruption. Increasing the level of Safety stock for some raw materials, WIP or finished products is one of the most common and diffused examples of pursuing a hedging strategy.

In this regard, it has been considered relevant to question whether Hilti suppliers increase their level of Safety Stock to hedge supplier business interruption risk.

This constitutes question number 8).

In (Lücker, F., Seifert, R.W., Biçer, I., 2019) contribution, we have also seen the role of reserve capacity, together with raw material inventory, in mitigating supply chain disruption risk.

The study determined which RMI and reserve capacity levels are optimal to mitigate risk depending on type of products and supply chain (agile or efficient).

In this regard, it has been considered relevant to question whether Hilti suppliers increase also their level of Reserve Capacity to hedge supplier business interruption risk.

This constitutes question number 9).

Dual sourcing strategy has been extensively discussed both in (Manuj and Mentzer, 2008) risk-hedging strategies and optimal sourcing decision in multi-tier supply network of (Ang, E., Iancu, D.A., Swinney, R., 2017). Beside buffering inventories

and production capacity, the possibility of a company to hedge their supply risk encompass also increasing the number of suppliers from which the focal company buys a certain product.
In this regard, it has been considered relevant to question whether Hilti suppliers adopt the strategy to source certain products to more than one supplier to mitigate supplier business interruption risk.
This constitutes question number 10).

Beside buying the same product from two different suppliers. A company may decide to have a secondary supplier to be used only when a primary supplier is disrupted. This is called back-up supplier (Tomlin, 2006, Sodhi and Lee, 2007). Since the firm makes the contract prior to any disruption, this strategy is classified as a supplier business interruption mitigation tactic relevant to be questioned to Hilti suppliers.
This constitutes question number 11).

Another possible strategy is to fortify suppliers in order to strengthen their reliability and resiliency during disruptions and in turbulent environments (Sawik, 2013). (Torabi et al. 2015) paper assumed that the fortification of a supplier decreases the impact of disruptions on that supplier, based on the level of protection and the disruption event. These practiced will be hereafter indicated as supplier development program and protection measures. And it has been considered relevant to question whether Hilti suppliers have any of these virtuous approaches in place.
This constitutes question number 12).

Another risk mitigation strategy suggested by (Hosseini, S., Morshedlou, N., Ivanov, D., (...), Barker, K., Khaled, A.A., 2019) aims to maximize the distance between suppliers in the supplier selection process. This strategy helps to reduce the risk of a

geographically induced supply chain disruption and is called “Geographical segregation of suppliers”.
This constitutes question number 13).

Risk Management Governance and Risk Management Continuous Improvements

We already mentioned that starting from the structure of the section of (The SCRLC Maturity Model Team, 2013) two additional section have been added in the questionnaire.

One section concerns how pervasively and structurally the Risk Management practices are spread within the company: Risk Management Governance.
The SCRMMM defines the executive leadership of a resilient enterprise such as “a SCRM that has a senior management defined leadership role and active engagement of management is enterprise-wide” and the governance such as a company where “Supply chain risk management framework is well defined across the enterprise including multi-tier critical supply chain partners”
In this regard, it has been considered relevant to question whether Hilti suppliers have a defined senior management leadership role regarding supply risk management and defined supply chain risk management framework.
This has been boiled down into the question number 14) and 15).

Beside this, stakeholders and external partners identification, consultation and communication are more than once considered in the SCRMMM as enabler of a supply chain resilient enterprise. In the same way, it has been considered worthy to question whether Hilti suppliers involve stakeholder and external partners in the supply risk management processes.
This constitutes question number 16).

The other section concerns how much effort the company is employing in improving its existing risk management knowledge and practices: Risk Management Continuous Improvement.
In the SCRMMM it is defined a resilient enterprise as “Continually monitoring for opportunities for improvement throughout the enterprise and the supply chain”. The same way, we desire to question whether Hilti suppliers regularly and continuously monitor opportunities for improvements.
This constitutes question number 17).

Finally, it has been considered worthy to be questioned whether also Hilti suppliers perform scanning of good practices and benchmarking to improve supply risk management processed of the company. Somehow in the same Hilti is doing by means of this research.
This constitutes question number 18).

5.3 First version of the Questionnaire

QUESTIONS	
RISK IDENTIFICATION	
1	Does the company systematically map and collect information to measure suppliers' financial risk?
2	Does the company systematically map and collect information to measure suppliers' country risk?
3	Does the company have precise criteria and methods to identify critical suppliers?
4	Does the company include risk considerations in the supplier selection process?
5	Does the company perform suppliers' audit process on a yearly basis?
RISK ASSESSMENT	
6	Does the company conduct a quantitative Business Interruption analysis?
7	Does the company conduct a quantitative evaluation of the expected impacts and mitigation actions (e.g. different Mean Time To Recover)?
RISK MITIGATION	
8	In case a supply Business Interruption takes place, does the company rely on Safety Stock?
9	In case a supply Business Interruption takes place, does the company rely on Spare Production Capacity?
10	Does the company adopt double sourcing strategy (i.e., buying the same item from two different suppliers)?

11	In case one supplier face a Business Interruption, does the company have pre-qualified back-up suppliers (i.e., a secondary supplier that is used only when a primary supplier is disrupted)?
12	Does the company implement supplier development programs or protection measures (i.e., measures to fortify suppliers in order to strengthen their reliability and resilience during disruptions and in turbulent environments)?
13	In the supplier selection process, does the company apply Geographical Segregation strategy (i.e., supplying from companies located among different countries to diversify country risk)?
RISK MANAGEMENT GOVERNANCE	
14	Does the company have a defined Senior management for Supply risk?
15	Does the company have a defined supply risk management framework?
16	In the supply risk management process, does the company have external partners and stakeholders involved?
RISK MANAGEMENT CONTINOUS IMPROVEMENT	
17	In the field of supply risk management, does the company monitor regularly and continuously opportunities for improvements?
18	Does the company regularly perform scanning of good practices and benchmarking?

Table 3 First version of the Questionnaire

6 Internal testing of the questionnaire

Drafted the first version of the questionnaire based on the literature review findings and taking inspiration from existing practices currently adopted by Hilti, the aim is now to start testing the questionnaire.
The objective of the questionnaire is supposed to be a reliable assessment of the risk management capabilities of the supplier, under the hypothesis that the supplier who respond to the questionnaire understand the questions and is able to answer unambiguously and transparently.
To be able to accomplish this, the questionnaire itself, in the first place, needs to satisfy three characteristics mentioned in the last chapter:

- Clarity.
- Versatility.
- Comprehensiveness.

To amend this first version of the questionnaire with the aim of improving the above-mentioned three characteristics, it has been decided to test the questionnaire internally within the company.

6.1 Internal testing methodology

The researcher has conducted interviews with sixteen Supply Managers in Hilti from seven different Business Units (Anchors, Diamond, Direct Fastening, Fire Protection, Installation, Measuring, PT&A) and from the different teams of the Power Tool units, including Managers of the Austrian and Chinese offices.

Beside the supply managers, the researcher has conducted interviews with the Head of Risk & Insurance management and with the Head of Demand and Supply Management IT.

Interview methodology

Each meeting was conducted individually by the researcher and the interviewed employee.

Thirty minutes have been scheduled for each meeting, observing the following process:

- The first minutes of the meeting were dedicated to a presentation by the researcher to the interviewed to illustrate the purpose of this thesis, of the questionnaire, and as a consequence, of the interview itself.
- Then the researcher interviewed the selected employees going through the questions of the questionnaire. The interviewed has been asked to answer regarding Hilti risk management capabilities. For example, the first question was posed like: “Does the company systematically map and collect information to measure suppliers’ financial risk?”.
- The interviewed was suggested to answer the questions openly.
- In case the question was clear, and the answer was clearly yes or clearly no, then the interviewed was asked to enrich the answer with some details or examples.
- If the question was clear, but the answer was not clearly affirmative nor negative (e.g. it depends, partially, yes but not always…), the interviewed was asked for feedback on possible ways to make the question more likely to get a clear affirmative (or negative) answer, less dependent from contingency factors.

- If the question was not immediately clear to the interviewed, then the researcher investigated whether the question was:
    - Syntactically unclear but meaningful, thus, needing to be kept but rephrased.
    - Not meaningful, because not addressing any relevant aspect of risk management or too theoretical to be impossible for respondents to give a concrete answer. In this case it was discussed whether to take the question out of the questionnaire.
- If the question was considered redundant, because the same aspect was already addressed in another question, then it was evaluated whether to delete the question from the questionnaire or to englobe it into another one.
- Finally, after responding and reviewing all the questions, the interviewed was asked for additional feedback of any kind: perception that some questions were missing, that important aspect of supply risk management were addressed deeply enough, or precisely enough, etc.

Second version of the questionnaire

After the first eight interviews, the feedback collected were already notable.
In order to, improve immediately the quality of the following ten interviews, it has been decided to start amending the questionnaire according to the feedbacks.
The questions analysis thanks to the feedback will be deeply and detailly discussed in the chapter 6.3.

Here they are just shorty listed the changes made from the first to the second version of the questionnaire:

- Question 2 is split into questions 1.2 and 1.3
- Question 4 is split into questions 3 and 4.
- Question 8 is split into questions 5 and 6.

- Question 10 and 11 are merged into question 7.
- Question 14 and 15 are merged into question 9.
- Question 5, 6, 7, 9, 13, 17 and 18 are deleted.

The questionnaire results analysis of Chapter 6.2 will be based on the 12 questions of this second version:

QUESTIONS	
RISK IDENTIFICATION	
1	For which of these supplier's risks does the company map and collect information:
1.1	Financial risk?
1.2	Natural risks (e.g. earthquakes, cyclones, epidemic)?
1.3	Social risk (e.g. wars, crime, terrorism)?
2	Does the company quantify/calculate its risk exposure toward a specific supplier?
3	Does the company regularly conduct a business interruption risk audit on existing suppliers?
4	Does the company regularly conduct a business interruption risk audit on new potential suppliers?

RISK MITIGATION	
5	To mitigate supply Business Interruption, does the company rely on its internal Safety Stock?
6	To mitigate supply Business Interruption, does the company rely on supplier's Safety Stock?
7	Does the company either adopt dual sourcing strategy (i.e., buying the same item from two different suppliers) or have pre-qualified back-up suppliers (i.e., a secondary supplier that is used only when a primary supplier is disrupted)?
8	Does the company implement supplier development programs or suppliers' protection measures (i.e., measures to fortify suppliers in order to strengthen their reliability and resilience during disruptions and in turbulent environments)?
RISK MANAGEMENT GOVERNANCE	
9	Does the company have a defined Senior management for Supply risk and a supply risk management framework?
10	In the supply risk management process, does the company have external partners and stakeholders involved?

Table 4 Second version of the Questionnaire

6.2 Questionnaire results

Beside the feedbacks collection, the questionnaire has been tested, as we already explained, by asking the interviewed to answer regarding Hilti risk management capabilities. The final answer considered, for each question, was either a "Yes" or a "No", regardless of the discussion on the clarity, versatility and comprehensiveness of the question.

Since the purpose of the thesis is not investing or assessing Hilti current supply management capabilities, hereafter will not be presented in which questions the answer were affirmative or negative. Instead, the analysis will be concentrated on the validity of the questions themselves; and in the following section, on the assessment of the clarity, versatility and comprehensiveness of the questions.
What has been analyzed is whether a certain question was receiving coherent answers among the interviewed, and, if not, it has been assessed the reason of the incoherence. The reasons of incoherence, together with the feedback collected for each question, will be detailly discussed in the next paragraph.
The 12 questions hereafter considered are the ones of the second version of the questionnaire:

- 7 out of 12 questions received the same response from all the interviewed.

- 2 out of 12 questions received 2 responses discordant from the ones of other 16 interviewed: (Question 8 – Question 10).

- 2 out of 12 questions received 3 responses discordant from the ones of other 16 interviewed: (Question 1.2 – Question 1.3).
- 1 out of 12 questions received 4 responses discordant from the ones of the other 16 interviewed: (Question 7).

Clarity, versatility and comprehensiveness

It has been stated before that being the questionnaire meant to assess the risk management capability of the supplier, the questionnaire needs to satisfy the three characteristics of clarity, versatility and comprehensiveness.

The clarity has been tackled and addressed during the interview by making sure that any question was immediately clear to the interviewed, and asking the interviewed, if according to his experience, he presumed that the supplier he/she works with would understand the question without doubts or ambiguities.

The versatility has been addressed thanks to the diversified teams the interviewed employees belong to. Indeed, among the different teams the employees have experience of suppliers of very different size, industries, material groups, countries and relationships status. Thanks to the feedbacks and judgements received, the researcher has been able to assess whether the questions were broadly applicable to the varied spectrum of Hilti supplier base.

The comprehensiveness has been addressed and enhanced by the request for feedback during and, especially, at the end of the interview. In case the interviewed, based on his/her experience, believed that any kind of risk management practice, factor or detail was missing in the questionnaire. In this regard, the end of the interview was the moment for the researcher to welcome the suggestions of enrichment of the questionnaire.

Additional precious feedbacks

Next to the structured interviewing approach followed by the researcher to get the most clear and valuable feedbacks from the interviewed; the most precious

contribution has been given by the interviewed employees for their spontaneous suggestions.
Beside the willingness to dedicate the time to help the author in his research, every interviewed has shown a sincere commitment to provide the researcher with their experience and valuable feedbacks and recommendations.

6.3 Questions analysis

In this chapter, it will be discussed how the collection of answers and feedbacks during the interviews has driven the iterative process of amendment of the questions, until reaching the final version of the questionnaire.

The first question, meant to investigate whether the company maps and collects information to measure suppliers' financial risk, has collected good feedbacks and has been immediately clear in all the interviews. It has been suggested, to make the question more self-explaining, to mention next to Financial Risk also "Risk of insolvency".

The second question was initially investigating whether the company maps and collects information to measure suppliers' country risk. The concept of country risk has been not immediately clear and subject to many contingencies. Thus, after some interviews, it has been considered more precise to boil down the concept of country risk into the different type of risk. Question 1 and 2 have been englobed in question 1, questioning which types of risk the company map and collect information about:

- Financial risk/risk of insolvency,
- Natural risk (e.g. earthquakes, floods, epidemics),
- Social risk (e.g. wars, crime, terrorism, use of child labor).

The third question was initially investigating whether the company had precise criteria and method to identify critical suppliers. The question has been welcomed as clear and direct. Nevertheless, “precise criteria” entails the problem of establishing at which point you can define criteria as precise. Thus, it was considered more appropriate, after some feedback, to ask whether the company “quantify/calculate risk exposure from a specific supplier”.

The fourth question addressed the fact of including risk considerations in the supplier selection process. In this case, the discussions in the interviews were usually leading to the risk audit process. This is usually done differently on existing suppliers and new potential suppliers. Because of this, it has been decided to split the question into two. Addressing whether the company performs regularly business interruption risk audit on existing supplier and on new potential suppliers.

As just said, the audit process, initially present in the fifth question, has been already addressed by two questions. Specifying the frequency of the process (i.e., yearly basis) is strongly contingent, thus, not included in the questions.

In the sixth question it was asked whether the company conducted a quantitative Business Interruption analysis. While in the seventh whether the company conducted a quantitative evaluation of the expect impact and mitigation actions. After a couple of interviews, it was decided to merge these questions into one, since evaluating the expected impacts somehow entails conducting a Business Interruption analysis. After some other interviews, it has been noticed that the question was addressing the same topic of the one on “quantifying/calculating risk exposure from a specific supplier”. Therefore, the question, and in general, the risk assessment section by itself, has been deleted.

The first question of the risk mitigation section investigated whether the company relied in Safety Stock in case of supply BI. The answer of the interviewed immediately pointed out the distinction between having internal safety stock and safety stock at supplier side. Besides that, it has been discussed the importance to stress out that keeping safety stock is just one of the possible risk mitigation strategies of the supplier. Using the expression “to rely on” on the first question induced more than once the interviewed to think that Safety Stock was meant as the only mitigation strategy in place. To make this all clearer, it will be stressed out that the Risk Mitigation section of the questionnaire is meant to assess whether the supplier has different practices in place at the same time. The expression “rely on stock” is substituted with “keep stock”. The question is subdivided in two, asking both if the company keeps internally safety stock of finished goods and of components. And finally, in the following question it is asked whether the company has an agreement with all the key suppliers about the safety stock held on supplier side.

Initially, a similar question to the one about safety stock was drafted also for Spare Production. After some interviews it has been noticed that it was hardly considered as a supply risk mitigation strategy and also, it was too strongly depending on the product considered. Because of this, it has been chosen to delete it.

Tenth and eleventh question were, respectively, about double sourcing strategy and pre-qualified back-up suppliers. In almost every interview it has been experienced a discussion about how much the use of dual sourcing is depending on the item (e.g. price, volume, criticality, importance of the material group). Besides that, qualifying a supplier is often so expensive that taking the risk of facing a business interruption is economically more convenient than onboarding a new supplier. Same logic applies to back-up supplier, for which it might be very expensive, or even purposeless, to qualify a supplier just to “have it on the bench”.

Despite of the drawbacks and criticalities embedded in these two mitigation strategies, many feedbacks suggested to keep these questions and deepen this topic, because of the great strategic relevance that these strategies might have for same companies, as it commonly happens in automotive industries because of the very high production volumes.
As a result of these discussion, it has been decided to keep these questions and englobe them into one.

Twelfth question addressed the implementation of supplier development programs and protection measures. Even though, the practices here addressed are less common, subject to contingency, and needs a clear self-explaining question. The feedbacks have been positive, so that the question has basically remained unchanged.

On the other end, geographical segregation strategy is both unclear and uncommon to respondents and prone to ambiguity. It has been decided not to include it.

Regarding risk management governance, the two questions about senior management for supply risk and supply risk management framework, have raised no doubt about clarity. Nevertheless, they seemed addressing the same thing, usually one answer of a question was given as a consequence of the other one. Because of this, it has been decided to merge the two question into one, by asking if in the company at least one senior official is in charge of supply risk monitoring and supply risk management framework definition.

The following question addressed external partners and stakeholders involvement in risk management processes. In this case attention should be paid to the fact that the involvement of external parties in the risk management process can sometimes depends directly on the size of the company, not on its risk management maturity.

Effective risk management practices can be perfectly applied also entirely internally. Stated this, the question has still been considered relevant to be included in the questionnaire and didn't get any modification, if not specifying in brackets which kind of risk management topics, a company, could usually benefit of external partners involvement.

Lastly, they were initially proposed two questions about risk management continuous improvement, addressing the regular monitoring of opportunities for improvements and scanning of good practices and benchmarking. These questions appeared multiple time ambiguous and strongly depending on the contingent ways of companies improvement process. Considered the difficulty to boil this down into yes/no questions and the high likelihood for these kinds of questions to be incorrectly interpreted, it has been decided to not include this section in the final questionnaire.

6.4 Final version of the Questionnaire

QUESTIONS	
RISK IDENTIFICATION	
1	For which of these supplier's risks does the company map and collect information:
1.1	Financial risk/risk of insolvency?
1.2	Natural risk (e.g. earthquakes, floods, epidemics)?
1.3	Social risk (e.g. wars, crime, terrorism, use of child labor)?
2	Does the company quantify/calculate its risk exposure from a specific supplier?
3	Does the company regularly conduct a business interruption risk audit on existing suppliers?
4	Does the company regularly conduct a business interruption risk audit on new potential suppliers?
RISK MITIGATION	
5.1	To mitigate supply Business Interruption, does the company keep internal Safety Stock of finished goods?
5.2	To mitigate supply Business Interruption, does the company keep internal Safety Stock of components?
6	To mitigate supply Business Interruption, does the company have Safety Stock agreement in place with all key suppliers (i.e., supplier with a strategic

	relevance for the focal company)?
7	Does the company either adopt dual sourcing strategy (i.e., buying the same item from two different suppliers) or have pre-qualified back-up suppliers (i.e., a secondary supplier that is used only when a primary supplier is disrupted)?
8	Does the company implement supplier development programs or suppliers' protection measures (i.e. identifying key supply chain location and threats, thus evaluating countermeasures for preventing or mitigating disruption risks in those locations)?
RISK MANAGEMENT GOVERNANCE	
9	Does the company have at least one senior official in charge of monitoring supply risk and defining a supply risk management framework?
10	In the supply risk management process, does the company have external partners involved in risk assessment (e.g. product compliance, ethics, labor and environmental standards assessment)?

Table 5 Final version of the Questionnaire

7 Discussions & Conclusions

The purpose of this thesis has been to provide a questionnaire to expand the risk management process of a company by integrating the sub-suppliers risk dimension. This research highlighted interesting risk mitigation practices in the literature that led to the development of the proposed questionnaire enriched by the experience and the feedbacks of the interviewed supply managers and expertise.

The proposal contributes to the current literature landscape by providing a tool for sub-suppliers risk management by means of an assessment of direct supplier risk mitigation capabilities and maturity.

The main outcome of this Research work has been a questionnaire, simple and essential, to address a broad spectrum of companies, in terms of size and products, however comprehensive to give possibility of furtherly deepening the assessment when needed.

This has allowed to answer to the Research Question presented in Section 1.4:

RQ: How can sub-suppliers risk addressed by investigating direct suppliers' risk mitigation maturity?

This chapter provides an overview of the main outcomes brought by this thesis work from an academic perspective. In addition to that, also the main limitation and proposed further developments are discussed here in order to provide the starting point for possible future researches and implementations within Hilti.

7.1 Original contribution of the study.

As discussed in the literature gaps, the models presented in the third chapter of this research address precise needs of organizations in performing sub-suppliers management.
To set up an effective sub-supplier management process it is necessary to understand which success factors are fundamental to build sustainable and well-performing relationships in the supply chain. In this regard, the work of (Grimm, J.H. et al., 2014) provide a clear and exhaustive list of points.

(Wilhelm, M. et al., 2016) instead, explored the approach of indirect sub-suppliers risk mitigation, defining for which supply chain configurations and morphologies it is more recommended for the focal company to act "directly" on sub-suppliers risk mitigation or "indirectly" delegating this task to tier-1 suppliers.
Similarly (Jia, F. et al., 2019) discussed which supply chain leadership approach the focal company should adopt depending on the tier level of the supplier to incentivize proactive sustainability initiative along the entire supply chain.
(Ang, E., Iancu, D.A., Swinney, R., 2017) work included also discussions on the connections existing between risk mitigation strategies and buyers margins or supplier reliability.

The Ford model discussed by (Simchi-Levi, 2015) goes more into a quantitative evaluation of risk of sub-suppliers, by identifying which node of the supply chain would cause a higher revenue loss for the focal company in case of a business interruption of that node.

In this regard, it has been considered relevant to include in sub-suppliers management literature a practical tool for industrial companies willing to manage sub-suppliers

risk by following an indirect approach. The questionnaire proposed in this research, meant to assessing how much the tier-1 suppliers are mature in their supply risk management practices and capabilities, fits this purpose.

Given the existence of the Supply Chain Risk Management Maturity Model, as a tool to support companies in performing a self-assessment of their risk management maturity to identify possible areas of improvement, it is now intention of the author to compare the SCRMMM with the questionnaire proposed in this research.

To perform the comparison of the two questionnaire the author referred to the criteria for comparing models presented in the work "The Guidelines of Modeling - an approach to enhance the quality in information models" by (Schuette R., Rotthowe T., 1998). According to these authors the three basic requirements to frame a model are:

1) Correctness: A model is only correct if it is both syntactically correct, i.e., complete and consistent with regard to the specified modeling method, and semantically correct. The semantic correctness is given if the depicted facts correspond to reality to a large extent.

In this regard, the SCRMMM presents a detailed list of risk management processes and practices adopted by organizations. Each section and each question present five possible answers aiming to cover in an exhaustive way each possible maturity level of a company in that specific risk management area. The reality of companies processes is, thus, extensively covered by the level of detail that this model proposes.
On the other end, the questionnaire proposed in this research has enhanced its correctness in two ways:

- The reality of companies' risk management practices has been covered by including a broad spectrum of risk mitigation practices found in literature through the extensive state of the art research.

- On a semantic level, the interviewing process has been conducted with employees of long-lasting experience, belonging to all the different supply teams of Hilti Corporations. Consequently, exploiting the experience maturated by the interviewed employees in different market, for different material groups and with supplier of different sizes and locations.

Therefore, from the point of view of the author, the correctness of the proposed questionnaire is sufficiently satisfied, even though a narrower degree of details in the risk management processes is provided, if compared with the SCRMMM.

2) Relevance (goal-oriented parsimony): According to this principle, only sections that correspond to the modeling purpose should be shown. The model should therefore not contain more information than absolutely necessary, which is also related to the requirement that a model may only contain as many elements and relationships as is necessary and appropriate for the benefit to be achieved.

In this regard, the SCRMMM presents a degree of information that fits his purpose of supporting companies in performing a self-assessment of their risk management maturity to identify possible areas of improvement.
The objective of the proposed questionnaire is, instead, providing the focal company with a tool to assess how good their supplier are in managing supply risk, so that, eventually, the focal company is protected from that risk.
The narrower degree of details in the proposed questionnaire, thus, is justified by the difference in purpose that this does have with respect to the SCRMMM.
The amount of questions proposed, indeed, has been narrowed down during the interviewing and testing process, by strictly keeping only those questions who served the above-mentioned purpose.

3) Economical allocation: It relates both to the profitability of the model application and the profitability of the model creation and, as a marginal cost-benefit function, often represents a restriction that sets an upper limit on the modeling intensity.

From the point of view of the author, the higher level of complexity of implementation of the SCRMMM, makes it an effective model for the internal usage it is meant for.
The questionnaire here proposed, instead, has been streamlined to a minimum level of complexity to make it externally efficient. Using Yes/No questions makes the questionnaire even more effective to be submitted to supplier, expecting from them a limited level of effort in providing reliable answers in a limited amount of time. Therefore, the implementation of this questionnaire in strategic and tactical sourcing processes of Hilti Corporation (presented in chapter 7.3), is reasonably economically efficient. In the sense of bringing benefits to the Hilti sourcing processes while keeping limited the level of time, effort and resources needed.

Considering also the extended requirements presented in the above-mentioned work of (Schuette R., Rotthowe T., 1998):

4) Clarity: A model must always be readable and usable for all potential model users. To ensure clarity and comprehensibility, on the one hand a breakdown into partial views for different consumers in the sense of a user focus, on the other hand the use of a simple and uniform modeling method to increase clarity and legibility.

Comparing the clarity of two models might be subjective to users' perspective and experience.
Regarding the questionnaire proposed in this research, in Chapter 5 it has been stated by the author that it is developed with the objective of being clear, versatile and comprehensive.
Clarity has been considered as the first criterium to be satisfied to make each question understandable and not ambiguous at a first reading. The whole interviewing process has been based, first of all, by ensuring this characteristic.
As a consequence, with respect to Hilti users and their knowledge of their suppliers, the questionnaire here proposed is considered having, beside a good level of versatility and comprehensiveness, a high level of clarity.

5) Comparability: The comparability of models is closely related to the principle of clarity and aims at the semantic comparison of two models. It can be assessed on the basis of the congruence of the contents described with two models.

This criterium is given by the comparisons here presented between the questionnaire proposed in this research and the SCRMMM.

6) Systematic setup: This principle relates to the integration ability of models that can be developed in different user and usage-dependent perspectives. To fulfill this principle, all partial views must be integrated into an overarching architecture concept and the cross-view referential integrity must be guaranteed.

The proposed questionnaire satisfied this criterium both in the building phase of the questionnaire, when the questions received coherent answers among the interviewed (Chapter 6.2), and in the running phase.
The running phase consists in the proposals of implementation of the questionnaire. In this regard, it will be shown in Chapter 7.3 a systematic integration of the questionnaire in different Hilti processes and in different supplier relationship management applications (i.e. Ariba, IntegrityNext, BIRS tool, Bonus/Malus system).

7.2 Practical implications and transferability

One of the main practical implications of the questionnaire, when applied to Hilti processes, is the possibility to exploit existing digital solutions to reach out to supplier with questionnaire and storing the responses in a structured and accessible way. The questionnaire can be easily adopted by Supply Managers, both in a systematical or occasional way, depending on the need; and working also as an input to deepen furtherly the topic when the situation requires it.

One of the strengths of the proposal is that it does not substitute the current practices and tools available for supplier risk management, but only enriches the current solutions in place at Hilti by integrating sub-suppliers' risk management dimension. Some of the existing tools and solutions currently adopted by Hilti, will be presented in chapter 7.4, together with proposals of integration of the questionnaire here developed with the aim to enhance or broaden their value.

The aim of the researcher is to provide a versatile model that can be easily transferred and adopted by different businesses. Nowadays, since supply chain are getting more and more complex and global, sub-suppliers management is becoming a common process that companies need to perform systematically. The model will provide companies with a support tool easy to apply. The simplicity of application comes

from the basic knowledge required from supply managers in its adoption and, even though the questionnaire has been built up based on the needs and opinion of Hilti employees, it is considered by the author as highly customizable, depending of the specific necessities of the company. For the reasons listed, the author believes the model could represent a supporting tool for other companies as well.

7.3 Limitations and future development

The questionnaire proposed in this research work, does not provide:

- A scoring system based on the responses received,
- The countermeasures that a company should adopt based on the responses received,
- A quantification of the risk exposure toward a certain supplier depending on the responses received.

Consequentially, the model developed leaves room for further improvements and above-mentioned developments.

In this regard, the researcher wants now to present some proposals of integration of the questionnaire into tools and solutions currently adopted by Hilti, to give insights for future researches and implementations within the company.

Implementation of the Questionnaire into SAP Ariba

As introduced in the Chapter 4, in the tactical sourcing process, Hilti can create sourcing event in the digital platform used for supplier relationship management: SAP Ariba. One of these sourcing events is the, so called, Request For Information (RFI).

RFI allows supply managers to request for generic business information from suppliers by means of templates that can be developed for specific purposes.

By the time this research was developed, most of Hilti supplier had been onboarded on Ariba and the author of this research was responsible for the development and support of these sourcing process into SAP Ariba.
Responses provided by supplier by means of an RFI can be stored in a structured way in the system, improving accessibility and classification of information around the company.

In this regard, the author has developed a template proposal for the implementation of the questionnaire into SAP Ariba by means of an RFI.

Here below it is shown a screenshot of what suppliers would see in his Ariba Network, if Hilti reaches out to them with the proposed questionnaire.
As the picture below shows, the supplier has to answer compulsorily all the questions with a Yes/No answer, and has, for each question, the possibility to attach a comment of any type next to the question.

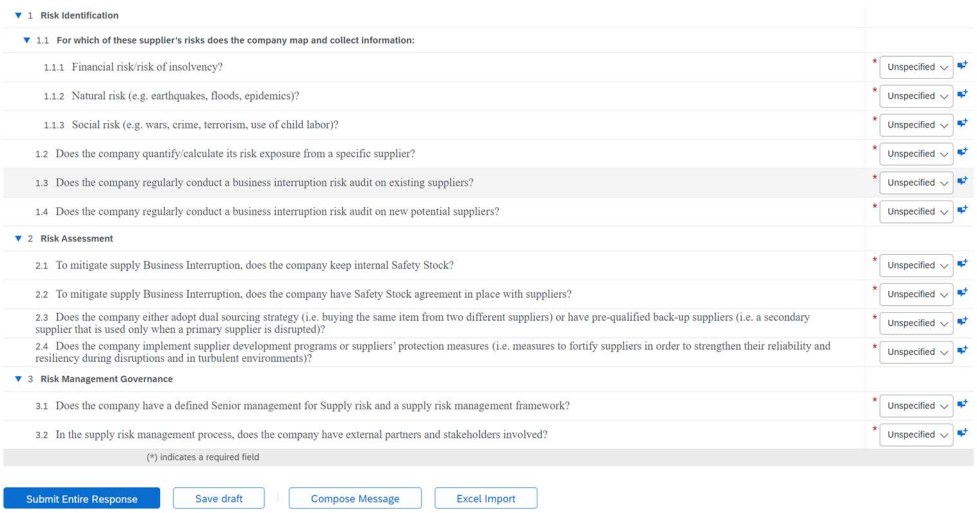

Figure 12 Ariba interface of the supplier questionnaire

Inclusion on Hilti BIRS tool

After receiving a supplier's response, the report of the output can be included in the Hilti Business Interruption Risk (BIRS) Tools, by uploading a document in the dedicated section (example in Figure below).

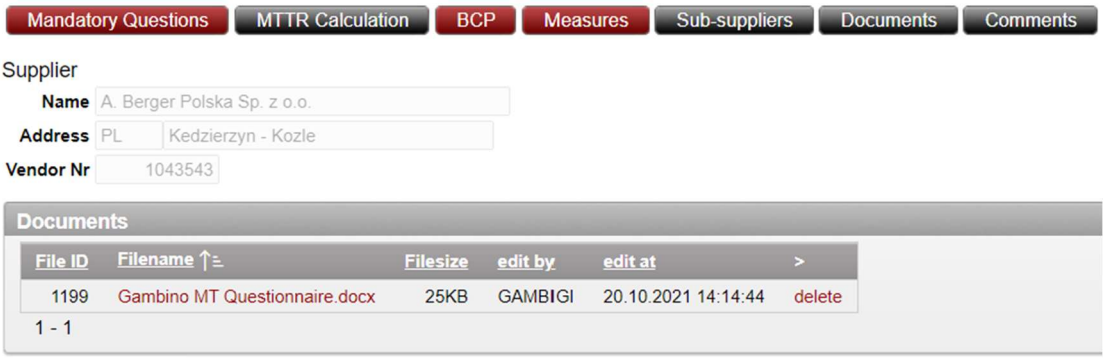

Figure 13 Hilti BIRS tool

A possible future implementation could be to have the results of the questionnaire in the BIRS tool in a tabular form in the dedicated Sub-suppliers section.
Data stored in tabular form could be the first step to integrate the result of the proposed questionnaire into the Business Interruption parameters (i.e., BI12, MTTR). Quantifying how much the focal company risk exposure from a specific supplier changes depending on the result of the proposed questionnaire, might be an interesting possibility of development for future research on this topic; besides being a valuable practical implementation for Hilti and companies in general.

Possible integration into Hilti Bonus/Malus system

The questionnaire is constituted of 10 questions, subdivided into 3 sections.
To attribute some scoring to the answers of the respondent it can be simply considered to associate each question with a scores: 0 if the answer is No, 1 if the answer is Yes.

The sum of the scores of all the questions in a section will give the score for that section on a scale from 0 to 4 for Risk Assessment and Risk Mitigation, and from 0 to 2 for Risk Management Governance.
So, the overall scoring result of the questionnaire can result in a range from 0 to 10.
Once obtained the final questionnaire score, the question is: How the questionnaire results can be integrated into a Bonus/Malus system for tactical sourcing?

In Hilti, the Bonus/Malus system applied to tactical sourcing events, fundamentally works as follow:

1) A price for a certain article is asked to the supplier: Direct price.
2) Others information submitted by the supplier are the input to compute a price which considers all the costs Hilti will sustain in a certain period for owning that article: Total Cost of Ownership (TCO).
3) Additional information, both as input from the supplier side and Hilti manager side, gives a Bonus/Malus percentage value which is applied to the TCO, giving as result the Comparison Price.

The information asked in this Bonus/Malus system relates to a variety of different fields which are considered relevant from Hilti point of view to prefer a supplier with respect to another one, for example:

- Supplier risk management score.
- Supplier sustainability score.
- Supplier product compliant with existing regulation, such as REACH, RoHS…
- Sourcing strategy.

These parameters give each a relative Bonus/Malus which ranges usually from +/- 2% to +/- 5 %, resulting at the end in an Overall Bonus/Malus of +/- 25%.

The questionnaire score, can thus be englobed into this list of additional information, contributing to the overall Bonus/Malus system.

The importance, thus the relative weight, of the proposed questionnaire into the Bonus/Malus system for tactical sourcing, might strongly depends on a very high number of factors (e.g. material group, proximity price level of the suppliers…), and mostly on the opinion and experience of the manager dealing with the tactical sourcing decision.

Whatever weight percentage interval [- Y %: + Y%] the supply manager considers appropriate to set for the questionnaire in the Bonus/Malus system, the relative Bonus/Malus can be computed linearly as:

$$BM\ from\ questionnaire\ (\%) = \frac{2YX}{N} - Y \qquad (12)$$

Where:

- X: questionnaire score from 0 to N.
- N: Number of questions of the questionnaire.
- Y: Weight percentage interval.

For easiness of implementation, the Questionnaire score can also be clustered in five levels and a Bonus/Malus percentage can be assigned to each level:

- X > 0,8 N = Bonus of Z %
- 0,6 N < X < 0,8 N = Bonus of Z/2 %
- 0,4 N < X < 0,6 N = No Bonus.
- 0,2 N < X < 0,4 = Malus of Z/2 %
- X < 0,2 = Malus of Z%

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Appendix

Literature – Key Words logical combinations

	Topic	**Risk Mitigation**		
	Keywords	Risk Mitigation Supplier	AND	
Filters	**Search within**	Article title	Abstract	Keywords
	Document type	Article	Book	Book chapter
	Source type	Journal	Book	Book series
	Subject Area	Business, Management and Accounting		
	Language	English		
	Age	From 2008		
	Cited by higher than	30		
	N°of papers resulting	65		
	N°of papers selected	10		

Table 6 Literature Table - Risk Mitigation

	Topic	**Sub-suppliers management**		
	Keywords	Sub-suppliers Multi-tier supply chain Supplier	OR AND	
Filters	**Search within**	Article title	Abstract	Keywords
	Document type	Article	Book	Book chapter
	Source type	Journal	Book	Book series
	Subject Area	Business, Management and Accounting		
	Language	English		
	Age	From 2004		
	Cited by higher than	30		
	N°of papers resulting	77		
	N°of papers selected	11		

Table 7 Literature Table - Sub-suppliers management