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Visibility in complex supply chains: an information management approach to support risk and disruption management decisions

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Note to the reader:

May it be of help during your journey

Abstract

The context in which firms operate today is characterized by several sources of uncertainty, caused essentially by market globalization and increasing complexity, resulting in additional risk exposure not only for individual firms but also for whole supply chains. Information seems to play a fundamental role for companies to deal with this uncertainty and achieve an effective management of their supply chain. The theoretical foundation of this research work is based on the analysis of the main concepts of supply chain risk management, supply chain disruption management, supply chain visibility and information management. From this literature review, it became clear that there is a lack of analysis of supply chain risk management and related decisions, as an information management problem. In order to fulfil this gap, there is the requirement to understand how visibility over supply chain processes can be created, in order to improve decision makers' capabilities focusing on mitigating supply chain risks.

This thesis aims at studying how information management processes support decision makers towards mitigating risks in supply chain, and at developing innovative information management solutions to enhance visibility in order to face supply chain risks within the context of complex supply chain. The objectives of this thesis are the identification of the different types of information related with risk categories, and how this information is organized to support the selection of disruption recovery strategies. The main goal of this work is to develop a multi-perspective and multi-viewpoint information management model of the supply network to support decision-making, by assessing the risk along the whole chain. This work is based on the Design Science Research paradigm, which will be applied through several research methods, namely literature review, case study research, and focus group methodology.

This doctoral thesis intends to contribute with new insights at the intersection between the research areas of information management and supply chain management. In particular, results include the improvement of decision-making capability of firms, belonging to the context of vehicle assembly, to face disruptions,

and to increase awareness of supply chain risks and disruptions through the adoption of the information management solutions.

Keywords: Supply chain risk management; Supply chain disruption management, information management; Supply chain visibility; Information management model; and Design science research.

Resumo

O contexto em que as empresas operam hoje é caracterizado por várias fontes de incerteza, causadas essencialmente pela globalização do mercado e pelo aumento da complexidade, resultando numa exposição adicional ao risco, não apenas para empresas individuais, mas também para toda a cadeia de abastecimento. A informação parece ter um papel fundamental para as empresas lidarem com essa incerteza e conseguirem uma gestão eficaz das suas cadeias de abastecimento. A fundamentação teórica deste trabalho baseia-se na análise dos principais conceitos de gestão de risco, gestão de disrupções, visibilidade e gestão da informação associados às cadeias de abastecimento. A partir dessa revisão de literatura, ficou claro que há uma falta de análise da gestão de risco associada às cadeias de abastecimento e suas decisões, como um problema de gestão de informação. Para preencher essa lacuna, existe a necessidade de entender como a visibilidade dos processos da cadeia de abastecimento pode ser criada, a fim de melhorar os recursos dos decisores na mitigação dos riscos associados às cadeias de abastecimento.

Esta tese tem como objetivo estudar como os processos de gestão da informação apoiam os decisores na mitigação dos riscos associados às cadeias de abastecimento e no desenvolvimento de soluções inovadoras de gestão da informação em aumentar a visibilidade para enfrentar os riscos associados num contexto de cadeias de abastecimento complexas. Para isso, são identificados os diferentes tipos de informação relacionadas às categorias de risco e como essa informação é organizada para apoiar a seleção de estratégias de recuperação de disrupções.

O principal objetivo deste trabalho é desenvolver um modelo de gestão de informação “multi-perspectivo” e “multi-ponto de vista” da rede de abastecimento para apoiar a tomada de decisão, avaliando o risco ao longo de toda a cadeia. Este trabalho é baseado no paradigma Design Science Research, que será aplicado através de vários métodos de pesquisa, a saber, revisão de literatura, pesquisa de estudo de caso e grupo focal.

Esta tese de doutoramento visa contribuir com novo conhecimento na intersecção das áreas de investigação de gestão da informação e gestão das cadeias de abastecimento. Em particular, os resultados incluem o aumento da capacidade na tomada de decisões pelas empresas pertencentes ao contexto de montagem de veículos para enfrentar disrupções e o aumento da sensibilização sobre riscos e disrupções na cadeia de abastecimento por meio da adoção de soluções de gestão de informação propostas.

Palavras-chave: Gestão de risco da cadeia de abastecimentos; Gestão das disrupções da cadeia de abastecimento, Gestão de informação; Visibilidade da cadeia de abastecimentos; Modelo de gestão da informação; e Design science research.

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List of Abbreviations and Acronyms

CIMO – Context-Intervention-Mechanism-Outcome
DSR – Design Science Research
EDI – Electronic Data Interchange
ERP – Enterprise Resource Planning
GDP – Gross Domestic Product
ICT – Information and Communication Technologies
IPT – Information Processing Theory
IM – Information Management
IS – Information Systems
IT – Information Technology
IV – Inventory Visibility
JIT – Just-in-Time
KPI – Key Performance Indicator
MC – Mother Company
MTO – Make-to-Order
OICA – Organisation Internationale des Constructeurs d'Automobiles (World Association of Car Manufacturers)
RFID – Radio-Frequency Identification
RQ – Research Question
SCs – Supply Chains
SCD – Supply Chain Disruption
SCM – Supply Chain Management
SCRM – Supply Chain Risk Management
SCV – Supply Chain Visibility
SLA – Service Level Agreement

Chapter 1. Introduction

1.1 Context and problem

Supply Chains (SCs) are susceptible to disruption! Already in the ‘80s, researchers suggested the existence of specific risks arising from the interconnected flows of materials, information, and funds in inter-firm networks (Kraljic, 1983; Treleven and Bergman Schweikhart, 1988). However, only recently did the interest from scholars and practitioners over this phenomenon increase. We argue that this is due to the following two aspects.

Firstly, recent studies have proven that supply chains exposure to disruption is increased on a global scale, both in frequency and intensity (BCI, 2016, 2017; Deloitte, 2013; Heckmann et al., 2015; JLT, 2018; Wagner and Bode, 2006). During the past decades, the world has experienced remarkable events that highlighted the severe effects that disruptions can have in supply chains. Cases such as “Nokia vs. Ericsson” in 2000, World Trade Centre’s terrorist attack in 2001, the world financial crisis in 2008, the tsunami in Fukushima’s nuclear plant in 2011, and Nepal’s earthquake in 2015, are just some of the most representative examples of disruptions in supply chains. The interest on risk management within supply chains arose from these events and has been strengthened by the research community ever since (Chang et al., 2015; Chatterjee and Shaw, 2015; Chopra and Sodhi, 2004; Park et al., 2013; Sheffi, 2005).

Secondly, the context in which supply chains have to operate is more susceptible to the impact of such disruptive events. Over the last years, all the industries have experienced changes in their business environment, due to market globalisation and a fiercer competition among supply chain players, which resulted in great pressure to make both inter- and intra- firm business processes either more efficient or more responsive and agile (Wagner and Bode, 2006). In order to meet these challenges and to adapt to this new business environment, many companies had to deal with growing adoption of outsourcing aimed at excelling in few core competences, global dispersion of partners, increasingly demanding consumers, and continuous reduction of production costs. Although such initiatives have proven their benefits in stable environments, the same might not be true in more dynamic ones (Zsidisin et al., 2005).

All these characteristics lead to growing uncertainty and, thus, to a greater exposure of the supply chains to risks and disruptions (Christopher and Peck, 2004; Fisher, 1997; Hult et al., 2004; Lee, 2002, 2004). Therefore, scholars have advised companies to tackle supply chain risks in similar fashion to tackling financial and other business risks, as well as to rethink their supply chain strategy and design (Christopher and Peck, 2004; Handfield and McCormack, 2007; Tomlin, 2006). Since Tang's (2006a) seminal work on the different perspectives of supply chain risk management, much attention has been given to the management of risks and disruptions in supply chains, both in academia and in practice (Accenture, 2014; Deloitte, 2013; Gualandris and Kalchschmidt, 2015; Lavastre et al., 2012; Manuj and Mentzer, 2008b, 2008a; Rao and Goldsby, 2009). Still, the current knowledge on these topics is limited.

In order to deal with disruptions, companies have to identify the different types of risk to which their supply chains are exposed. Several authors have proposed risk classifications matching the various types of risk with the management of their related process (Ho et al., 2015; Manuj and Mentzer, 2008b, 2008a; Rangel et al., 2015), leading to the following perspectives: supply management (De Boer et al., 2001; De Boer and Van Der Wegen, 2003), demand management (McKinsey, 2011; Sheffi and Rice Jr., 2005), information management (Manuj and Mentzer, 2008b, 2008a; Wagner and Bode, 2006), and product management (Manuj and Mentzer, 2008b; Tang, 2006a). Among the different perspectives, information management has been least researched when compared with the others (Tang and Musa, 2011).

Having this classification of supply chain risks as a starting point, recovery strategies for disruption related to these risk sources are linked with decisions involved in each of these processes. Specifically, in this work we are interested in four categories of risk (supply, demand, information, and product management), whose vulnerabilities lead to disruptions at operational level (such as: supplier order allocation, shift of demand across time, information sharing, and postponement) (Tang, 2006b).

Therefore, in order to support decision-making when facing disruptive events, researchers have suggested companies to have visibility over the specific process of interest (Barratt and Barratt, 2011; Barratt and Oke, 2007; Fawcett and Magnan, 2002; Goh et al., 2009; Nooraie and Parast, 2015; Van der Zee and Van der Vorst, 2005). Supply Chain Visibility (SCV) has been identified as an important factor to increase supply chain resilience (Blackhurst et al., 2011; Gualandris and Kalchschmidt, 2015; Pettit et al., 2010) and supply chain performance in general (Barratt and Barratt, 2011; Barratt and Oke, 2007; Caridi et al., 2010, 2014; Goh et al., 2009; Yu and Goh, 2014; Zhang et al., 2011). Researchers and practitioners have agreed on the need of visibility over large volumes of information to enhance decision maker's actions (Barratt and Barratt, 2011; Barratt and Oke, 2007; Goh et al., 2009; Nooraie and Parast, 2015; Schneider and Jandhyala, 2011). However, to the best of our knowledge, detailed analyses of supply chain risk and disruption management, as well as of related decisions as an information management problem are still missing in the literature.

This doctoral thesis contributes with new insights, at the intersection between Information Management (IM) and Supply Chain Management (SCM). In particular, we want to contribute to disruption management problems with a set of information management solutions aimed at considering the different perspective of the actors belonging to the supply chain. This set may provide decision makers with the most suitable information to endure the different disruptive events.

These information management solutions were developed and validated in several firms belonging to complex supply chains of vehicle assembly, both in the automotive and aeronautic sectors. Complexity here refers to the numbers of nodes, the number of tiers, and their interconnection (Caridi et al., 2010a; Serdarasan, 2013), but also to the number of product components and the extent of interactions between these components (Novak and Eppinger, 2001). First of all, automotive and aeronautic industries are considered prominent parts of the manufacturing sector and strongly contribute to the economic development of any country. The aeronautic sector is considered one of the most strategic sectors for the growth of a country, having contributed, in 2015 alone, with 3.5% of the global gross domestic product (GDP) (ATAG, 2016), while forecasts show a growing trend until 2032 (Deloitte, 2015). According to the world association of car manufacturers (OICA), the global production of vehicles in the period 2015-2017 grew by an average of 2.7%, while global sales grew by an average of 3.1% (OICA, 2017). Secondly, and most important in terms of relevance of this thesis work, when compared to other complex supply chain contexts, they show unique characteristics such as: huge entry barriers (Benzler and Wink, 2010); long product development cycle (AGP, 2013); and, very strict procedure for qualification and certification (Benzler and Wink, 2010), which makes the selection of alternative suppliers even more difficult due to risk sharing with partners (Figueiredo et al., 2008). Moreover, due to the scale of their operations, these sectors are particular sensitive to risk (Ernst&Young, 2017). These characteristics call for more research on how supply chain disruptions are being managed, and how internal and external information could be managed among supply chain partners to support risk and disruption management related decision-making.

1.2 Motivation and relevance

This thesis contributes with research at the intersection between IM and SCM. It aims at organizing two sets of information relevant to supply chain risk managers. On the one hand, there are different types of risk associated with the management of supply networks and, on the other hand, there is the information needed to manage this process. Once these two sets of information are available and organised, the decision maker can combine them to enhance visibility required to face disruptive events. Particularly, in this work we refer to the four categories of risk (supply, demand, information, and product management) that lead to disruptions at operational level (such as supplier order allocation, shift of demand across time, information sharing, and postponement) (Tang, 2006a).

The literature showed many attempts to link the concepts of SCV and supply chain risk and disruption management (Ambulkar et al., 2015; Blackhurst et al., 2011; Ghadge et al., 2012; Gualandris and Kalchschmidt, 2015; Ivanov et al., 2014; Macdonald and Corsi, 2013; Pettit et al., 2010), and to connect SCV and IM (Barratt and Oke, 2007; Caridi et al., 2010a; Goh et al., 2009; Kaipia and Hartiala, 2006;

Nooraie and Parast, 2015). In fact, many researchers identify a strong link between SCV and IM, highlighting the vital need to gain visibility when members need to share information across the supply chain (Klueber and O'Keefe, 2013), when information deliveries need to be fast (Chan, 2003), or in situations such as emergency relief operations in which the information is needed to coordinate the different humanitarian organisations (Maghsoudi and Pazirandeh, 2016). In particular, SCV can be seen as a synonymous of information sharing or as a first output of the broader IM process (Barratt and Oke, 2007; Caridi et al., 2010a; Kaipia and Hartiala, 2006; Nooraie and Parast, 2015).

To support disruption related decisions, decision makers need to process a considerable volume of information (Barratt and Barratt, 2011; Barratt and Oke, 2007; Goh et al., 2009; Nooraie and Parast, 2015; SAP, 2010; Schneider and Jandhyala, 2011). Although, over the years, many new techniques and tools have been provided to deal with the increasing volume of information, firms still employ combinations of such information technology (IT) solutions and, in many cases, they have to create their own bespoke systems to cope with systems' incompatibility among partners, as well as with the undue adoption of informal systems such as: e-mail, Microsoft Excel®, and face-to-face meetings. Therefore, the objective of this work is to respond to this challenge by studying how supply chain managers gather, process, and use information to endure disruptive events, in real settings.

In order to provide the required visibility over these large volumes of information we propose a set of information management solutions that can be integrated in companies' current systems to enhance decision maker's capabilities in dealing specifically with supply chain disruptions, at operational level. These information management solutions are: an information management model for disruption management, a conceptual model for information organisation, and a quantitative approach to assess supply chain partners' visibility. Moreover, to balance the practical relevance with the scientific rigour of these solutions we follow the Design Science Research (DSR) paradigm. In fact, this research paradigm was chosen because its ultimate goal is to guide research that aims to develop artefacts - in our case the information management solutions for supply chain risk and disruption management - that, once tested, are able to provide innovative solutions for specific business needs (Hevner and Chatterjee, 2010; Van Aken, 2005).

Considering the categories of information and the actors who share this information, this work defines two properties of these solutions, namely multi-perspective and multi-viewpoint. The multi-perspective property regards the different categories of information shared among supply chain members, while the multi-viewpoint property is related to the different roles played by the members of the supply chain in sharing the information. In particular, the main innovation of these solutions is the capability to integrate and organise internal and external information (regarding the supply network) in a way that is adapted to each node in the network and according to the different disruptive events.

1.3 Objectives and research questions

The main objective of this thesis is to study how supply chain managers exploit information management processes to support decisions related to risks and disruptions, and therefore at design information management solutions to enhance visibility to deal with such disruptions in complex supply chains.

Consequently, the research questions leading this thesis are the following:

- RQ1: How to design an information management model to support the disruption recovery process in supply chains?
- RQ2: How to improve the visibility that a company has over its supply chain?

To do so, the specific objectives of this research project are:

1. To identify the information related with the different categories of risk;
2. To organise the information associated with several disruptive events in order to support a selection of recovery strategies in complex supply chains; and
3. To quantify the visibility level of different partners belonging to the supply chain, in order to support managers in identifying the nodes where improvement actions are needed the most.

1.4 Thesis synopsis

From the beginning of this doctoral project we decided to elaborate this work as monograph despite the recent trend of thesis as collection of papers. This choice was made to increase the readability of the manuscript and to avoid repeating similar sections in each chapter, typical of the alternative. However, aside from the introduction and conclusions, each chapter of this thesis is based on an adaptation of one or more original research papers, either published or submitted to an international peer-reviewed journal or to a book chapter. Figure 1.1 shows the thesis outline and is followed by an overview of the content of each chapter.

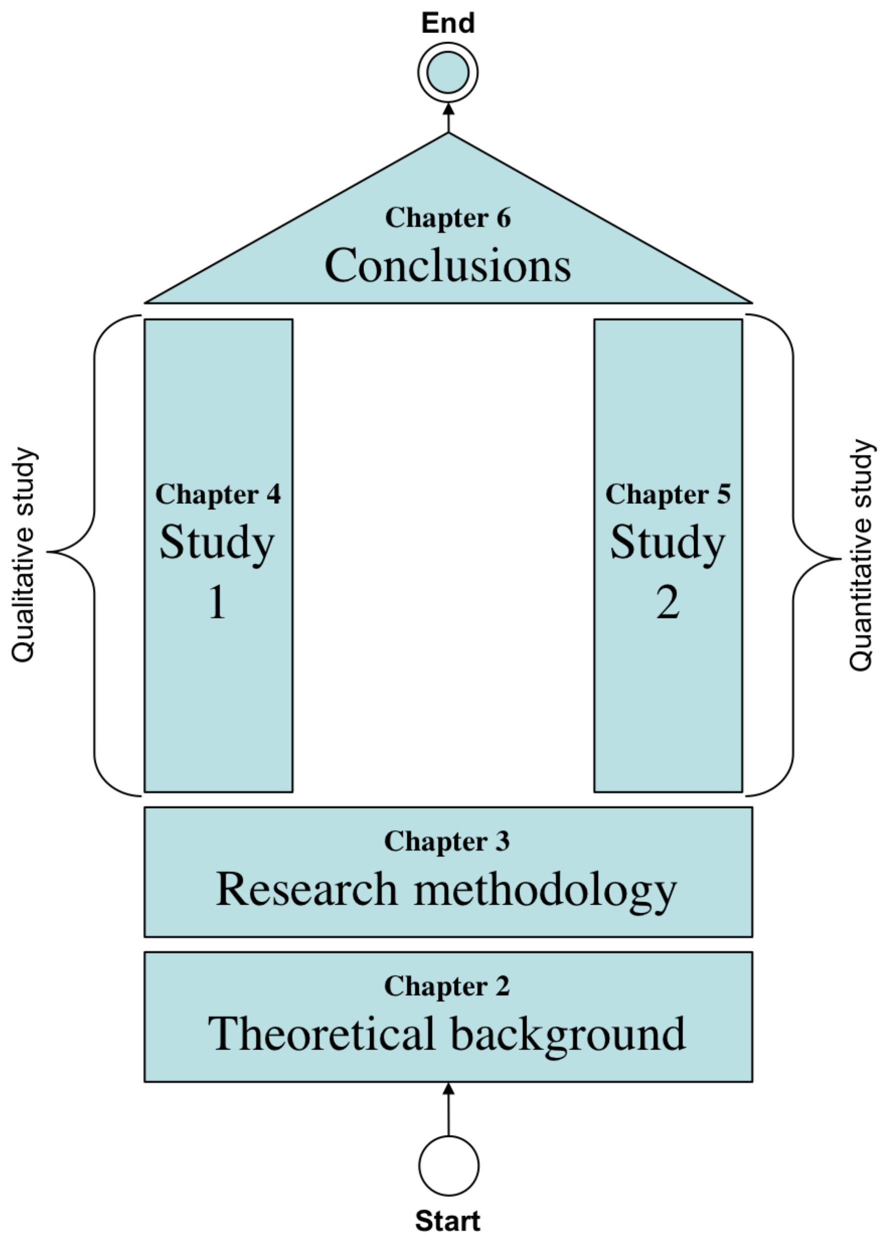

Figure 1.1 Thesis outline

Chapter 2 presents an exploratory literature review of the existing research of the past 15 years in the fields of Information Management, Supply Chain Visibility, Supply Chain Risk and Disruption Management. The review has been carried out aiming at discussing and synthesising the literature on these literature streams (Messina et al., 2016a). Additionally, it allowed to identify key emerging themes and future research related with information management in the context of supply chain risk and disruption management.

Chapter 3 introduces the Design Science Research (DSR) paradigm adopted for the design of the information management solutions that have been developed in the two studies, while also providing the research methods that have been used to conduct the latter.

Chapter 4 elaborates the theoretical results retrieved from Chapter 2 through a first exploratory case study (Study 1, *what an original name for the first study!*) aiming at analysing how managers handle the information when facing disruptions. This chapter also allows us to answer the first research question (RQ1). Outcomes of the chapter are the first two solutions, namely an information management model for disruption management and a conceptual model for information organisation.

Chapter 5 focuses on another problem related to SCV that is the lack of a univocal metric. After an additional literature review, this time focused on quantitative methods used to assess SCV, a metric of direct visibility is designed and tested in three companies belonging to the complex supply chain of vehicle assembly. This represents the quantitative study in the outline (Study 2) and allows to answer RQ2. Finally, **Chapter 6** summarises the results obtained in the previous chapters and provides the main contributions, both for researchers and practitioners, of this thesis. Limitations of the study and directions for future research are also addressed in this chapter.

Chapter 2. Theoretical background

[This chapter is an adaptation of the following publications:

- Messina, D., Barros, A. C., Santos, C., and Soares, A. L. (2016a). Risk and visibility in supply chains: an information management perspective. In *Information Management for Effective Logistics and Supply Chain.* IGI Global.
- Messina, D., Barros, A. C., Soares, A. L., and Matopoulos, A. An information management approach for supply chain disruption recovery. Under review in International Journal of Logistics Management]

The management of complex supply chains requires increased efforts by organisations that, on one hand, are increasingly pressured by customers in terms of service levels, on the other hand, must manage their supplier's base from various locations and with different local requirements. In this context, an appropriate management of information flows is needed to create the adequate visibility level for managing supply chain risk and avoid disruptions.

In fact, in the global and digital context in which firms operate, information assumes a distinctive role, as it supports effective decision-making process. By sharing what sometimes is sensitive and proprietary information with their network partners, companies aim at aligning their common objectives though ensuring the efficient management of the whole chain. Still, there is a need to create visibility over the specific information that will enable companies to identify and act upon the risks in order to avoid disruptions in their network.

Although the enormous efforts made by researchers and practitioners to bring clarity to both areas of research of this thesis, more precisely supply chain management and information management, the main concepts remain ill-defined. Moreover, due to the fact that these research areas present a certain level of overlap, it is difficult to identify the boundaries between supply chain risk and disruption, and information management and visibility. Therefore, the goal of this chapter is to define the concepts that constitute the theoretical foundation of this thesis project namely, risk, disruption, visibility, and information management in supply chains. Furthermore, it aims to identify the categories of information, both internal and external, needed to manage such complex networks as well as the supporting information management models.

2.1 Supply chain risk management

The word "risk" derives from the ancient Italian *risicare*, which means *to dare* (Bernstein, 1996). Its meaning has changed over time according to the perception that different people have of the world (Bernstein, 1996; Khan and Burnes, 2007). For example, in the Eastern culture, and in particular in the Chinese language, the *hanzi* for risk is composed of two symbols, the first one represents the word *danger* while the second means *opportunity.* So, they define risk as a mix of danger and opportunity, a trade-off well known for equity investors. On the contrary, in the Western culture, the word risk is immediately associated with negative events that have to be avoided (Damodaran, 2010).

Notwithstanding with these different perceptions, in this thesis we adopt the notion of risk as related to purely negative events. Risk is present in numerous firm activities and has been studied from many perspectives including strategy (Simons, 1999), finance (Jorion, 2007), production (Tse and Tan, 2011), and marketing (Xie and Shugan, 2001).

Risk is defined as a combination of the probability of being exposed to adverse events and the impact of that exposure, in terms of potential outcomes (Lowrance, 1980). Holton (2004) rephrases by saying that a risky event entails two conditions: exposure to an event and the uncertainty of possible outcomes; i.e. the presence of only one of the two components is not sufficient to classify an event as risky. In this regard, it should be noted that while the risk refers to the possibility that an event occurs, a disruption is the manifestation of this circumstance.

Therefore, risk management can be considered the systematic approach to setting the best course of action under uncertainty by identifying, assessing, understanding, acting on and communicating risk issues (Berg, 2010). More recently, the process of risk management has been standardised in the ISO 31000:2009, which says that risk management consists of five main processes, namely: communication and consultation, establishing the context, risk assessment, risk treatment, and finally monitoring and review (ISO, 2009).

Communication and consultation with all the stakeholders should occur regularly along the process. In an early stage, such regular communication is fundamental to understand the needs and concerns of the different actors involved. At a later stage, it helps understand the decisions taken and motivates the risk treatment selected.

The next process, **establishing the context**, concerns the identification of the main aspects that characterise the context under analysis. In our case, growing adoption of outsourcing, global dispersion of partners, increasingly demanding consumers, and continuous reduction of production costs are the main aspects characterising complex supply chains. Due to these characteristics, supply chains are exposed to many sources of risk that can lead to their disruption. **Risk assessment** process involves the activities of risk identification, analysis, and evaluation.

Risk identification is related to the identification of the risk events and sources to whom supply chains are exposed. According to Jüttner (2005), supply chain risk sources are variables that cannot be predicted with certainty, and from which disruptions can emerge. The rationale behind is that by knowing the cause that lead to disruptions, appropriate measures to reduce the likelihood of occurrence can be implemented (Heckmann et al., 2015). Many scholars attempted to classify and study these sources in the last years (Cavinato, 2004; Chopra and Sodhi, 2004; Christopher and Peck, 2004; Heckmann et al., 2015; Jüttner, 2005; Jüttner et al., 2003; Manuj and Mentzer, 2008a; Monroe et al., 2014; Svensson, 2000; Tang and Musa, 2011; Wagner and Bode, 2006, 2008). For instance, Svensson (2000) identified two sources (qualitative and quantitative), three sources are identified in the works of Jüttner (2005) (supply, demand, and environmental) and Wagner and Bode (2006) (supply, demand, and catastrophic) respectively, while Manuj and Mentzer (2008a) ended-up proposing eight different sources (supply, operational, demand, security, macro, policy, competitive, and resource).

For the purpose of this thesis we categorise the risk sources according to the area that caused the occurrence of risk. Therefore, internal and external events to the supply chain can arise from the following sides: supply, product/process, demand and information (Tang, 2006a). Taking into account that is impossible to enumerate all the potential sources of risk, in Table 2.1 we define and synthesise the most common.

Table 2.1 Supply chain risk sources and examples

	Supply side	Product/process side	Demand side	Information side
Definition	Risks related to upstream relationships and operations	Risks related to internal functions and operations	Risks related to downstream relationships and operations	Risks related to information properties and/or systems
Examples	Supplier capacity problems	Inadequate manufacturing or processing capability	Bullwhip effect	Leak of information
	Supplier quality problems	Insufficient capacity	Change in consumer behaviour	Lack of information quality/quantity
	Transportation delays	Quality problem	Insufficient inventory	Systems breach
	Supplier default/ insolvency/ bankruptcy	Changes in process sequencing		

Once the potential causes and the corresponding events have been identified, the next activity according to the standard is risk analysis. Risk analysis phase aims to determine the probability that the event will occur, and its impact on supply chain business. In general, two different levels - *low* and *high* – are associated to each dimension, and their combinations are represented in a 2x2 matrix as shown in Table 2.2.

Table 2.2 Risk probability and impact matrix

		Probability: Low	Probability: High
Impact	**High**	HI-LP	HI-HP
	Low	LI-LP	LI-HP

Many variants of the matrix have been proposed in the literature with slightly different definitions, increasing the number of levels, and/or adding colours to characterise the cells (Christopher and Lee, 2004; Manuj and Mentzer, 2008a, 2008b;

Monroe et al., 2014; Sheffi, 2005; Sheffi and Rice Jr., 2005). At this point the third and last activity of the risk assessment process, which is the risk evaluation, can take place. In this phase managers decide if the level of risk is tolerable or not for their supply chain.

After risk evaluation, managers proceed to **risk treatment** by deciding about the most suited mitigation strategies to adopt according to the analysis in the previous steps. Previous literature has suggested several strategies such as encouraging cooperation among supply chain's partners (Jüttner, 2005), risk control (Jüttner et al., 2003), conduct further analysis on specific risks (Hallikas et al., 2004), or promoting imitation ("follow-the-leader" behaviours) (Miller, 1992). Later, four mitigation strategies have been systematised: risk avoidance, risk reduction, risk sharing, and risk acceptance (Alexander and Marshall, 2006; Dorfman and Cather, 2012; Ghadge et al., 2013):

Risk avoidance **–** the decision maker decides not to perform an activity that could lead to an unacceptable risk level. For example, a company could drop a specific product or market if it is seen to be a high-risk opportunity.

Risk reduction **–** are all the actions that allow the decision maker to reduce the probability of the risk, or its impact, or both. An example is postponement, as used for example by Dell, in which product design and supply chain processes are based on delaying commitment and customisation until demand is known in order to decrease the impact of demand disruptions (Sheffi and Rice Jr., 2005).

Risk sharing **–** the decision maker shares with another supply chain partner the risk and the efforts to manage it. Typical examples can include collaboration with a partner to tackle a particular kind of risk, or to its extent, transfer the risk to an insurance company.

Risk acceptance **–** is a viable decision to address those risks that are of low impact to the normal business activities. Classical examples are employee quitting, a rejected check, or more in general the so-called, "*cost of doing business"* (Alexander and Marshall, 2006).

The strategies used for risk reduction and sharing in the supply chain may also be classified into two broad categories: redundancy and flexibility (Chang et al., 2015).

Redundancy consists in reducing the negative consequences of a disruption by keeping resources in reserve to act as “shock absorbers”. Practices such strategic stock, increasing inventory, spare capacity, and maintaining multiple suppliers (Chang et al., 2015; Messina et al., 2017; Sheffi and Rice Jr., 2005; Zsidisin and Wagner, 2010) are the most common example of redundancy. Strategic stock consists on having extra inventory of critical components, to ensure supply chain continuity while facing a disruption (Tang, 2006b). Also, additional inventory and capacity allow to create buffers in the supply chain in order to cope with demand uncertainty in a more efficient way (Christopher and Rutherford, 2004; Christopher and Peck, 2004). Having multiple suppliers or multiple sourcing allows a smoother handling of demand fluctuations, and disruptions affecting other supplier belonging to the supplier base (Tang, 2006b).

Flexibility, on the other hand, consists on building capabilities to sense threats and to manage them quickly. Facilitating close and collaborative relationships with partners, integration, postponement and promoting information exchange are typical examples of flexibility (Bode et al., 2011; Manuj and Mentzer, 2008a, 2008b; Sheffi and Rice Jr., 2005). Since supply chains are networks of linked firms, also the risk associated needs to be treated network-wise. Collaborative relationships and information exchange are complementary ways of decreasing uncertainty, and so to reduce the manifestation of a risk (Christopher and Peck, 2004). Information systems integration allows to cut down the costs of communication while providing relevant and accessible information to partners (Awad and Nassar, 2010). Finally, postponement applies concepts such as standardisation and design modularity to delay the point of product differentiation, allowing fast reconfiguration in case of disruptions (Tang, 2006b).

The last process considered by the standard is **monitoring and review**, and as happened with communication and consultation it should occur regularly along the whole process. Regular oversight guarantees, in fact, that firms address changes in their environment and processes, and that selected strategies work effectively.

Considering the focus of this thesis, we adopt the definition of supply chain risk proposed by Jüttner et al. (2003) in which it is considered as any kind of risk, generated from the first supplier to the end user, that affects the normal flow of material, cash, and information. Therefore, supply chain risk management (SCRM) is defined as the identification and management of supply chain risks through coordination or collaboration among supply chain partners to reduce supply chain vulnerability as a whole, thus ensuring profitability and continuity of the chain (Jüttner, 2005; Tang, 2006b). Although it has been made so much effort in the field of SCRM to minimise the causes and consequences of such risks, disruptions happen and more frequently than in the past.

2.2. Supply chain disruption management

Within the broader area of SCRM research, supply chain disruption (SCD) has become a relevant topic in the past decades. This interest, from researchers and practitioners, has been motivated by real world events which have showed the effects of such disruptions in global supply chains (Monroe et al., 2014). SCD is defined as any unintended and unexpected event that occurs in the upstream supply chain, the inbound logistics network, or the downstream, that threaten the normal course of business operations of the focal firm (Bode and Macdonald, 2016; Bode et al., 2011).

There has been a broad debate on how to define disruptive supply chain events. Some authors focused on its impact and severity, proposing low-, medium-, high-impact scale to define the effects of disruption (Ogden et al., 2005; Sheffi, 2005; Sheffi and Rice Jr., 2005). Other researchers seem to focus their attention more on the causes that lead to occurrence of the disruptive events. The possible causes have been classified as natural or man-made (Helferich and Cook, 2002; Ritter et al., 2007; Sawik, 2013), purposeful or accidental (Kleindorfer and Saad, 2005; Kleindorfer and Wassenhove, 2004), and according to the supply chain level imputed to be responsible for the event, i.e. supplier related or customer related (Chopra and Sodhi, 2004). Taking into account that the same disruptions can be generated by different causes, the latter define the “nuance” of the disruption and lead to the proper recovery strategies. This research focuses on disruptive events occurring at operational level, such as serious delays in deliveries, labour strikes, or machine breakdowns (Chatterjee and Shaw, 2015; Chopra and Sodhi, 2004; Park et al., 2013; Sheffi, 2005). In particular, we tackle these events by studying how the available information supports disruption related decisions.

The disruption management process begins with the occurrence and discovery of the disruption, moves through the actions to recover from it, and ends with the complete recovery and consequent redesign actions to improve the process (Blackhurst et al., 2005; Bode and Macdonald, 2016; Macdonald and Corsi, 2013; Sheffi, 2005; Sheffi and Rice Jr., 2005; Zobel et al., 2012). Figure 2.1 shows the three phases of the disruption management process.

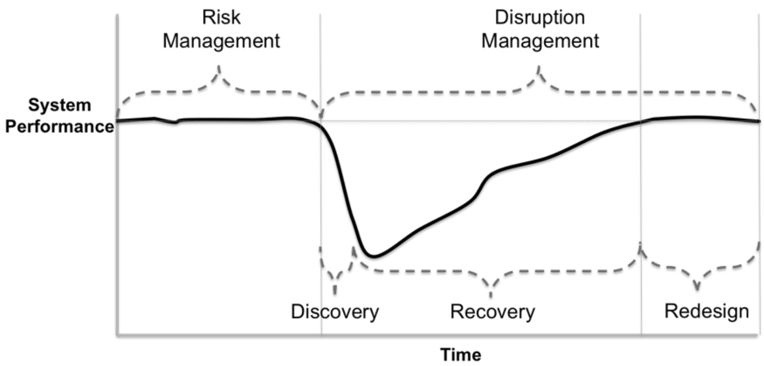

Figure 2.1 Disruption management process phases (adapted from Macdonald and Corsi, 2013)

The two phases representing the core of managing supply chain disruptions are discovery and recovery (Blackhurst et al., 2005; Bode and Macdonald, 2016; Macdonald and Corsi, 2013; Melnyk et al., 2014). Discovery is related to the scanning and identifying of anomaly signals (Bode and Macdonald, 2016), and represents the moment when managers become aware that a supply chain disruption is occurring (Macdonald and Corsi, 2013). Although visibility and thus information is required in all the phases of the process, for the discovery this is imperative. At this purpose, findings of Bode and Macdonald (2016) confirm that discovery stage acts as constraining factor to the other stages. For these reasons, reducing the time gap between the occurrence of an event and its identification is crucial for managers.

After the discovery of the disruption, and based to the causes that led to it, managers need to put in place actions to reduce the severity of the occurrence and to return it to its previous state or a more resilient one (Macdonald and Corsi, 2013). In order to recover from disruptions, researchers agree with the definition of two streams, namely flexibility and redundancy, presented in the previous section.

Still, some recovery strategies are only possible to use if previous mitigation strategies have been implemented. For example, a company may only use a second source supplier if the company has a multiple sourcing strategy, or it can only count on suppliers' ability to speed-up orders if a collaborative relationship exists.

From the literature analysis above, we identify a clear interconnection among the concepts of disruptive event, disruption cause, and recovery practices in order to cope with disruptions in supply chains, which we have synthesized in Figure 2.2.

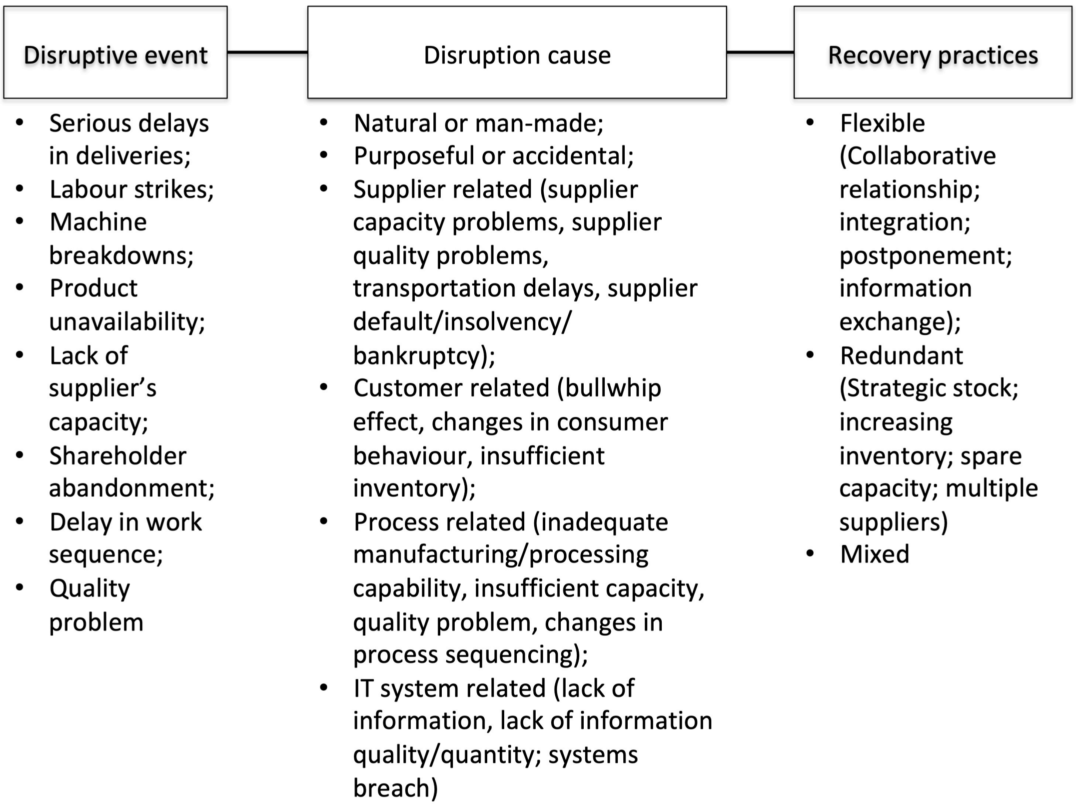

Figure 2.2 Interconnection among the main concepts of disruptive event, disruption cause, and recovery practices

Before moving to the last phase of redesign, managers need to evaluate the actions taken in order to see whether or not they were able to increase their resiliency. The effects of improved resiliency can be translated in terms of performance. Performance measures are related to cost, quality, service level, collaboration, and time (Christopher and Peck, 2004; Craighead et al., 2007; Jüttner and Maklan, 2011;

Kim et al., 2015; Scholten et al., 2014; Tang, 2006b). Through this evaluation, managers can understand and quantify whether they were able to grow and increase their resilience.

The final phase of the disruption management process is the redesign. This phase is related to the actions decision makers need to take in order to enable a quick recovery of future occurrences (Blackhurst et al., 2005; Bode et al., 2011; Macdonald and Corsi, 2013).

In recent years, attention has been given to the analysis of the individual stages of the disruption management process, especially to disruption identification and recovery (Ambulkar et al., 2015; Blackhurst et al., 2011; Chopra and Sodhi, 2014; Jüttner and Maklan, 2011; Wieland and Wallenburg, 2013). Still, the analysis of the supply chain disruption management process as a whole continues to be an understudied topic, as only few studies consider the whole process (Bode and Macdonald, 2016; Bode et al., 2011). Looking at the whole process is beneficial because, it allows a smooth and more efficient transition to the new cycle (after recovery, another cycle starts, beginning with risk management). Although previous studies allow for a better understanding of supply chain disruption management process, there is a consensus on the need for more empirical and theoretical insights, especially on how visibility can enhance the management of the process as a whole.

2.3 Supply chain visibility

As global networks become more complex, companies are realising the importance of visibility in their supply chains in order to react faster to changes and disruptions. Enslow (2006) reports that the lack of supply chain process visibility is the main concern for almost 80% of 150 large companies surveyed globally. This is also confirmed by a 2008 IBM's survey of 400 supply chain executives worldwide, as reported in Zhang et al. (2011). Even though supply chain visibility (SCV) has been a very welcomed concept in the supply chain management community, it has been defined following several perspectives as synthesised in Table 2.3.

Table 2.3 Perspectives of supply chain visibility

Perspective	Definition	References
Information Management	SCV is an organisation's ability to collect and analyse distributed data, generate specific recommendations, and match insights to strategy.	Tohamy et al., 2003
	SCV is the extent to which members of a supply chain have access to or share information, which they consider as useful to their operations and will be of mutual benefit.	Barratt and Oke, 2007
	SCV is defined as the ability to access/share information across the supply chain.	Caridi et al., 2010; Lamming et al., 2001; Nooraie and Parast, 2015; Swaminathan and Tayur, 2003
	SCV has been linked to the capability of sharing timely and accurate information on demand, quantity and location of inventory, transport related cost, and other activities throughout the entire supply chain.	Barratt and Oke, 2007; Closs et al., 1997; Kaipia and Hartiala, 2006; Whipple et al., 2002
	Level of SCV is determined by the extent to which the shared information is accurate, trusted, timely, useful, and in a readily usable format.	Closs et al., 1997; Kaipia and Hartiala, 2006; Whipple et al., 2002
	SCV is the capability of a supply chain player to have access to or to provide the required timely information/knowledge about the entities involved in the supply chain from/to relevant supply chain partners for better decision support.	Goh et al. (2009)
Supply Chain Configuration	SCV depends on the supply chain configuration, analysed in terms of two main dimensions: supply chain virtuality (the extent to which a company relies on its supply chain for manufacturing products) and, supply chain complexity (which is related to the structure of the supply chain).	Caridi et al. (2010)
Logistics Management	SCV represents the transparent view of time, place, status, and content. From this perspective, SCV emphasises the capability to trace products as well as their spare parts or components in transit from the manufacturer to the final destination.	Hickey (2005)
Event Management	Defining SCV as the ability to sense to exceptions and respond, based on what is important in the business.	McCrea (2005)

We adopt the definition of Goh et al. (2009) because it clearly specifies its use for collaborative decision support. Hence, supply chain visibility shall provide a decision maker the visibility of a specific decision point in the supply chain (Goh et al., 2009; Kulp et al., 2004). As the concept of SCV becomes clearer, the understanding of its effects on supply chain players becomes a logical choice for research.

Many authors have suggested the need for firms to gain visibility of various aspects, including being able to see demand levels in real-time (Croson and Donohue, 2003), to see how much inventory a customer is holding (Fleisch et al., 2005; Petersen et al., 2005; Zhang et al., 2011), or to see process data (Van der Zee and Van der Vorst, 2005). This visibility of materials, transaction activities, planning activities, and supplying processes is crucial to informed decision-making (Griffiths et al., 2007). In particular, demand visibility should help in reducing the waste and lack of product availability caused by the bullwhip effect (Delen et al., 2007; Koçoğlu et al., 2011). The primary purpose of SCV is to improve supply chain performance (Pidun and Felden, 2012; Rungtusanatham et al., 2003; Wang and Wei, 2007). As a natural consequence, many authors suggest evaluating the benefits of visibility in terms of supply chain performance improvements, e.g. cost, quality, service level, flexibility, and time (Kulp, 2002; Lee and Whang, 2000; Yu et al., 2001).

Towards achieving these benefits, the information exchanged needs to have the following properties: timeliness, accuracy, and accessibility (Barratt and Barratt, 2011; Barratt and Oke, 2007; Caridi et al., 2010a, 2014). Therefore, high levels of visibility are characterised by the quality and usefulness of the information within a supply chain. Just as quality is a competitive differentiator, also the effective use of information may differentiate today a company from its competitors. Poor visibility and uncoordinated multi-tier processes can thus result in significant ‘‘just in case’’ inventory carrying costs, premium freight expenses, and extended cycle times (Zhang et al., 2011).

2.4 Information management in supply chains

In this section, we analyse how information is managed in supply chains, in order to identify the adequate strategies for risk mitigation or disruption recovery. An important aspect of the supply chain management is to establish how information is acquired, organised and used among members, towards a proper risk management of the supply chain (Hung et al., 2011). Also, an effective management of the information flow is critical for increasing visibility over the network (Barratt and Oke, 2007) to support decision-making process and mitigate risk (Yu and Goh, 2014b).

Information management is a broad concept that has various meanings and interpretations among researchers. For example, the term is often equated with the management of information resources and IT, or the management of information policies or standards (Choo, 2002). Wilson (2003) refers to planning, organising, directing and controlling, and the use of technology for effective management of information and knowledge resources and assets within the internal and external environment to gain competitive advantage. According to Robertson (2005), the real issue is getting the right information to the right person at the right time and in a usable form.

This thesis adopts the definition of Detlor (2010, p.103) due to its completeness and structured way of presenting the concept: "information management is the management of the processes and systems that create, acquire, organise, store, distribute, and use information". Thus, IM helps people and organisations access, process and use information efficiently and effectively. In particular, supply chain visibility is achieved through a proper distribution of the information in the supply chain, also called information sharing.

Information sharing is a highly studied topic both in information management (Trappey and Hsiao, 2008) and in supply chain management literatures (Fawcett et al., 2007). Information sharing can be seen as the action through which organisations share relevant, accurate, complete, and pertinent information with their partners, thus fostering connectivity with them, reducing information asymmetry, and enhancing supply network visibility (Baihaqi and Sohal, 2013; Cao et al., 2010; Hung et al., 2011; Legner and Schemm, 2008; Li and Lin, 2006; Uusipaavalniemi and Juga, 2008). The main objective of sharing information is to increase supply chain performance by potentiating a more efficient management of the supply chain (Bottani et al., 2009; Fantazy et al., 2011; Kaipia and Hartiala, 2006; Smirnov et al., 2008; Xu, 2011).

Higher levels of supply chain performance are achieved through supply chain *collaboration* (Haug, 2013), *coordination* (Maçada et al., 2013), and *uncertainty reduction* (Bindel et al., 2012), all of these enabled by information sharing. Supply chain *collaboration* is characterised by long-term relationships between partners, in order to pursue common goals (Cao et al., 2010), and is facilitated by sharing complete and relevant information among partners (Hung et al., 2011; Jardim-Goncalves et al., 2013). Information sharing is not achieved only by investing in information and communication technologies (ICT) but depends also on a company's willingness to share relevant information to provide to decision makers (Fawcett et al., 2007).

The process of sharing information and decision-making alignment supports greater *coordination* between partners (Datta and Christopher, 2011; Legner and Schemm, 2008; Toloie–Eshlaghi et al., 2011). Supply chain coordination is characterised by a clear definition of processes and responsibilities of partners in order to be aligned with the objective of the whole network. According to Chan and Chan (2009), supply chain collaboration and coordination are enablers of uncertainty reduction.

Supply chain *uncertainty* arises when information is not shared in a timely manner to all partners so, in order to be able to respond to network's needs, it is necessary to have access to a broad database (Cao et al., 2010). There are practices to manage uncertainty, such as transparent information flow, integration of partners' information systems (IS), and adoption of a decentralised information structure with effective information distribution (Cao et al., 2010; Datta and Christopher, 2011; Shih et al., 2012).

Many authors have identified quantity and quality of the information shared as the two main characteristics of the information sharing process (Baihaqi and Sohal, 2013; Hüner et al., 2011; Hung et al., 2011; Li and Lin, 2006; Omar et al., 2010; Samaddar et al., 2006). Quantity is the extent to which organisations belonging to a network share a number of distinct categories of information with their partners, while quality is related to the timeliness, accuracy, and reliability of the information shared among partners. Sharing good quality information reduces supply chain uncertainty, drives effective and efficient collaboration, and facilitates the decision-making process (Baihaqi and Sohal, 2013; Chan and Chan, 2009).

Information management is concerned with the identification of the types of information that are shared among partners (Montoya-Torres and Ortiz-Vargas, 2014). Taking into account that partner relationship and the confidentiality of the information influence the level of information sharing, supply chain partners need to ponder on the types of information to share for a better decision-making (Omar et al., 2010). The information shared can be grouped into two broad categories: internal and external information. Internal information is mentioned herein as any information present at firm level or supply chain level gathered from companies' ICT systems, such as Enterprise Resource Planning (ERP), electronic data interchange (EDI) or supply chain management (SCM) systems. On the contrary, external information is defined as any information that may be obtained from the supply chain environment, and gathered from institutional reports, stock market, public institutions, and consultancy reports, among others. Table 2.4 presents a synthesis of the external and internal information.

Table 2.4 External and internal information

Type of information	Information category	References
External information	Market	Jüttner et al (2007); Lavastre et al (2012)
	Financial	Wagner and Johnson (2004)
	Fiscal and Regulatory requirements	Wagner and Bode (2008)
	Legal requirements	Lavastre et al. (2012); Wagner and Bode (2008)
	Geopolitical	Gilaninia, Shahram and Mahdikhanmahaleh (2013)
	Third-party logistics (3PL)	Mentzer et al. (2000); Voss and Hsuan (2009)
	Intellectual property	Chopra and Sodhi (2004)
Internal information	Product	Chi (2010)
	Inventory	Datta and Christopher (2011)
	Demand	Toloie–Eshlaghi et al (2011)
	Order	Hung et al (2011)

2.4.1 Information management model

Some efforts have been made in the literature to research common information management models even though these were related to construction sector (Ajam et al., 2010) or to a specific type of information in retail context (Legner and Schemm, 2008). A common information management model would enable organisational connectivity (Haug, 2013), especially when partners share similar information. Such common information management model would then be supported by information systems to operationalize the information management activities: collecting, organising, and disseminating accurately and timely the partner's sharable information (Fawcett et al., 2007).

Few publications, to the best of our knowledge, analysed the specific problem of defining the sub-processes composing information management (Choo, 2002; Davenport, 1997; Detlor, 2010; Marchand et al., 2000). Davenport (1997), defines the concept of information ecology. Information ecology studies how people create, distribute, understand, and use information at its centre. Also, the author suggests considering the information management process as a series of sub-processes, namely: determining information requirements, capturing information, distributing information, and using information. On the other hand, Marchand et al. (2000) start from the assumption that among competitors, higher performance is achieved through a better use of information. They also define information orientation as being the interaction between people, information, and technology. Within the information orientation it is possible to identify capabilities associated with these three aspects that managers need for effective information use, which are: information technology practices, information management practices, and information behaviour and values. It is within information management practices that the authors define five steps for an effective information management, which are: sensing, collecting, organising, processing, and maintaining. In a similar vein, Choo (2002) suggests that organisations need to put efforts in managing information resources and processes, as they do with human resources and financial assets. Also, the author proposes a process view of information management, in which information management is regarded as a continuous cycle of six closely related activities: identification of information needs; acquisition and creation of information; analysis and interpretation of information; organisation and storage of information; information access and dissemination; information use. Finally, Detlor (2010) aims at clarifying the meaning of the term "information management", by adopting a process orientation perspective. Process orientation deals with the management of all information processes involved in the information lifecycle with the goal of helping organisations to reach their competitive objectives. According to this perspective, the author identifies six predominant information processes to be managed: information creation, acquisition, organisation, storage, distribution, and use.

Based on this literature related to information management models, we propose an improved version of an information management process model, as Table 2.5 shows.

Table 2.5 Information management process model

Information management process model		**Proposed by**			
Stages	**Description**	*Davenport (1997)*	*Marchand et al.(2000)*	*Choo (2002)*	*Detlor (2010)*
Identifying needs	Identifying what and why information is needed, how it is going to be used, and the attributes that will enhance its value, quality, and usefulness.	**X**		**X**	
Sensing	Detecting and identifying information concerning: economic, social and political changes; competitors' innovations that might impact the business; market shifts and customer demands for new products: anticipated problems with suppliers and partners.		**X**		
Creating	Generating and producing new information.				**X**
Gathering	Collecting relevant information from internal and external sources.	**X**	**X**	**X**	**X**
Organising	Indexing, classifying, and linking information to support its retrieval when it is needed.		**X**	**X**	**X**
Storing and maintaining	Physically housing the information in databases or file systems in order to avoid the repeated collection of information and updating it to ensure that the best information available is used.		**X**	**X**	**X**
Processing	Accessing, analysing, and presenting the information in a way that supports decision-making.		**X**	**X**	
Sharing	Distributing or disseminating to the adequate users according to the information needs.	**X**		**X**	**X**
Using	Applying the information made available for better decision-making.	**X**		**X**	**X**

The information management models are supported by information systems that operationalize the information management activities, such as collect, organise, and disseminate accurate and real-time information (Fawcett et al., 2007). Even though previous research has confirmed the strategic importance of information and several authors were interested in developing information models to proper manage this information flow (Chi, 2010), there is still a need to explore in depth this field in order to analyse how different information models influence the risk management decision process of supply networks.

2.4.2 Information management model for disruption management

This section proposes an extended version of the generic information management model presented in Table 2.5. The new version of the information management model, in Figure 2.3, has been proposed to guide managers in the collection, process, and use of information in order to implement actions to improve the disruption management process.

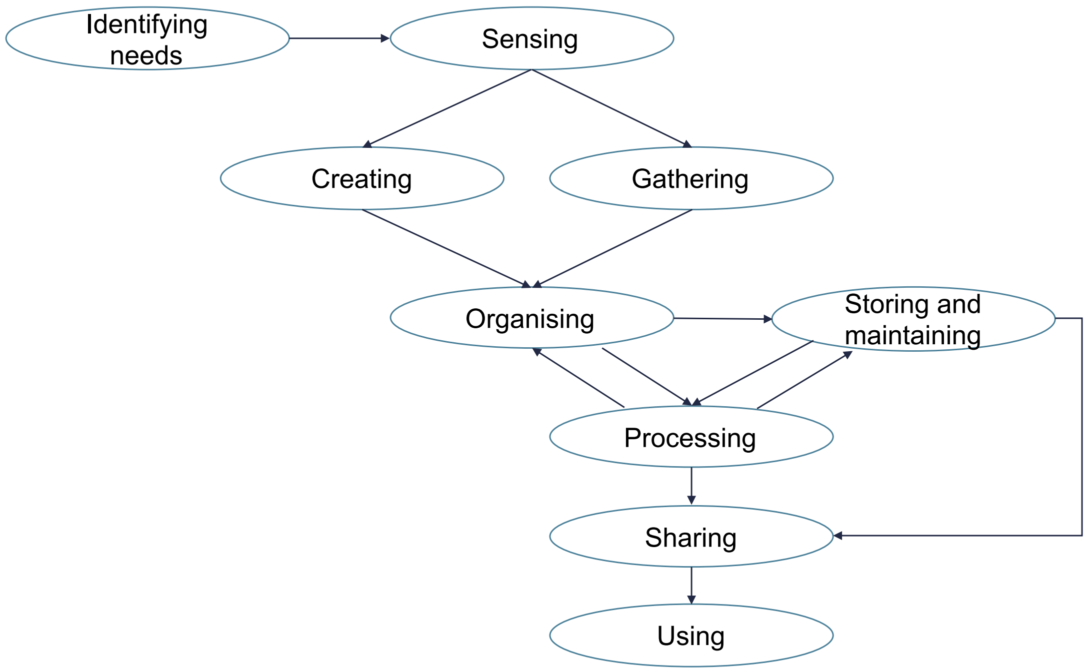

Figure 2.3 Information management model for disruption management

A description of the stages tailored for disruption management is as follows:

Identifying needs: Identifying what information is needed to deal with disruptions and why, for which strategy it is going to be used, and the attributes that will enhance its value, quality, and usefulness.

Sensing: Detecting and identifying information concerning: economic, social, and political changes or instabilities; market shifts and customer demands that can affect the normal business of a firm; anticipated problems with suppliers and partners.

Creating: Generating and producing new information about risks and disruptions.

Gathering: Collecting relevant information from internal and external sources to deal with negative occurrences.

Organising: Indexing, classifying, and linking information to support its retrieval in case of a disruption.

Storing and maintaining: Physically housing the information in databases or file systems in order to avoid the repeated collection of information and updating it to ensure that the best information available is used.

Processing: Accessing, analysing, and presenting the information about disruptive events in a way that supports decision-making.

Sharing: Distributing or disseminating to the adequate partners involved in the process affected.

Using: Applying the information made available for better decision-making for fast recovery from supply chain disruptions.

Our variant of information management model is going to be used as basis for the development of our first artefact, later in Chapter 4 of this dissertation.

2.5 Conceptual model for disruption recovery

In this section we considered the interconnection among the main concepts of disruptive event, disruption cause, and recovery practice represented in Figure 2.2, and our information management model for disruption management in section 2.4.2 to propose the conceptual model for recovery practice selection in Figure 2.4.

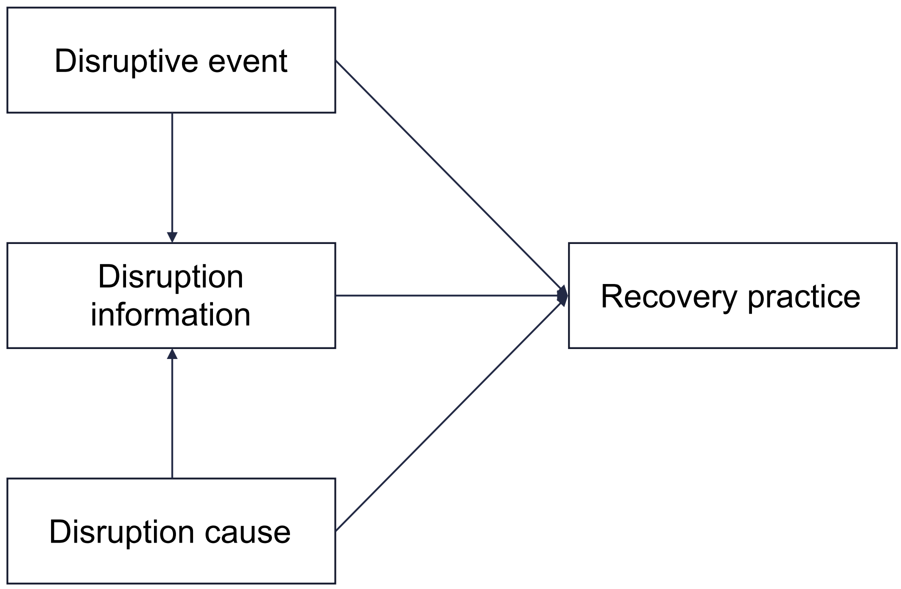

Figure 2.4 Conceptual model for recovery practice selection

This conceptual model puts forward that disruption information is composed with information about disruptions events and causes, and that all these three concepts are needed for the selection of disruption recovery practices. In particular, the conceptual model uses the relationships encountered in the literature, and integrates the part related to disruption information, derived from our information management model, to better understand the role information plays in the selection of the most appropriate recovery practices. The adoption of the model should guide decision makers in exploiting the information needed to select recovery practices according to the occurrences faced and the causes that led to such events.

2.6 Concluding remarks

This chapter reviews the literature on supply chain risk management, supply chain disruption management, supply chain visibility and information management in supply chains trying to bring clarity in the two areas of research of this thesis, and to ensure a consistent utilisation of the different terms. For what concerns the area of supply chain management, we reviewed both supply chain risk and disruption management processes in order to identify the boundaries and overlaps among the two concepts. In particular, it should be noted that while risk refers to the probability of the occurrence of an event, disruption refers to its manifestation. Great overlap between the areas can be found concerning mitigation and recovery strategies. Finally, we arrive at the conceptual model in Figure 2.4 that links these four concepts and will be further developed with the results from the empirical work in Chapter 4.

For what concerns the information management area, we were able to identify properties and benefits of enhanced visibility, both at the information exchange and at supply chain levels. In this way we were able to highlight the link between supply chain visibility level and information properties (accessibility, quantity, and quality), we will further develop this aspect with the results from the empirical work in Chapter 5. This chapter also provides a characterisation of the external and internal information flows that decision makers need to manage risk related situation in complex supply chains. Therefore, this research proposes an extended version of information management model tailored to support decision-making and to improve the overall disruption management process.

Chapter 3. Research design

This chapter presents the research methods adopted for designing this thesis in order to answer the research questions introduced in Chapter 1. In particular, the chapter begins by addressing the research paradigm used to frame our research, the theory at support, and afterwards, the research methods adopted to conduct the two studies that represent the core of this work.

The two studies were performed aiming at collecting empirical evidences and designing IM solutions to support risk and disruption related decisions. In particular, Study 1 was designed to answer RQ1:" How to design an information management model to support the disruption recovery process in supply chains?", while Study 2 was designed to address RQ2: "How to improve the visibility that a company has over its supply chain?".

3.1 Design Science Research Paradigm

This work follows the Design Science Research (DSR) paradigm (Hevner et al., 2004; Simon, 1996; Van Aken, 2004). This research paradigm was chosen because its ultimate goal is to guide research that aims to develop artefacts - in our case information management solutions to support risk and disruption related decisions - that, once tested, are able to provide innovative solutions for specific business needs.

The importance of the design activity has been recognised in several disciplines, bearing key outcomes particularly for the areas of information systems (IS). According to its nature, IS represent the meeting point between information technology and human interface, and for this reason it is characterised by challenging problems related to design activity in order to provide unique and creative solutions (Hevner and Chatterjee, 2010). DSR paradigm was born based on the seminal book of Herbert Simon "Sciences of the Artificial" (Simon, 1996), and from the research of a pool of scholars in IS (i.e. Hevner et al., 2004; Van Aken, 2004).

Figure 3.1 shows the characterisation of the activities, embedded in each of the three main blocks of the DSR paradigm, necessary for the development of this thesis project. Starting from the “environment” block we decided to focus in increasing the resilience in the complex vehicle assembly sector, as explained in section 1.1. Increased supply chain resilience enhances firms’ ability to absorb disruptions or to return to a stable condition faster (Blackhurst et al., 2011; Sheffi and Rice Jr., 2005). Afterwards, we carried out literature review and performed case research in order to build the foundation of the “knowledge base”. The case research served not only to create this knowledge base, but also, together with focus groups, to developed and evaluated information management solutions that support operational decisions in supply network, which constitute the content of the “information system research” block.

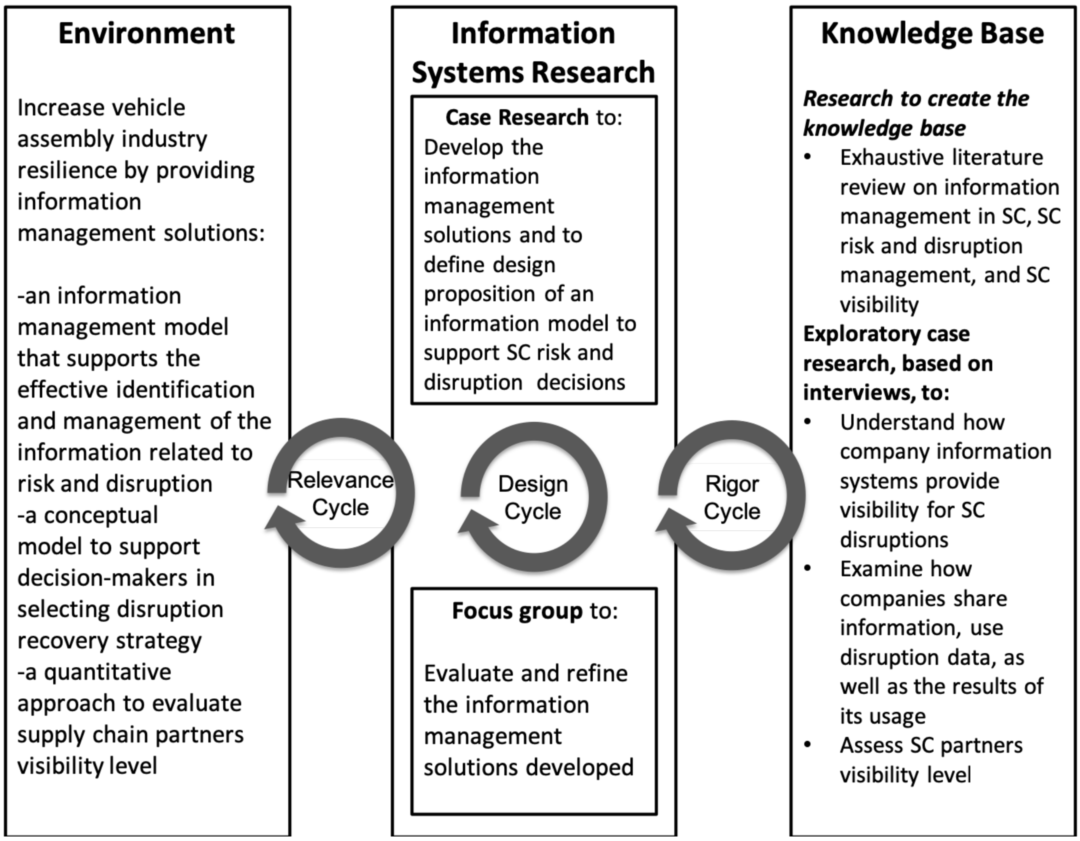

Figure 3.1 Design Science Research Paradigm for this thesis

According to Van Aken (2005), DSR paradigm tries to create the so called “Mode 2 knowledge creation”. “Mode 1 knowledge creation” refers to purely academic and mono-disciplinary, while Mode 2 is multidisciplinary and aims at solving relevant problems. Therefore, the purpose of DSR is to bridge the gap between purely academic knowledge and practical knowledge, which is achieved by developing new knowledge for practitioners in order to allow them to design solutions for specific field problems (Van Aken, 2005). DSR peculiarities are that, on the one hand, it allows for the design of useful artefacts grounded in the scientific literature, and, on the other hand, the artefact must be tested in the field. To perform a good DSR project some fundamental aspects must be considered, such as the design and construction of a viable artefact (Hevner et al., 2004), its rigorous validation (Peffers et al., 2012), and its knowledge contribution (Gregor and Hevner, 2013). Artefacts in DSR can be:

- Conceptual artefacts, such as constructs, models, methods, and frameworks (Hevner et al., 2004; Peffers et al., 2012);
- Formal logical instructions, such as algorithms and instantiations (Hevner et al., 2004; Peffers et al., 2012);
- System design, language/notation, guidelines, requirements, patterns, and metrics (Offermann et al., 2010);
- Social innovations (Van Aken, 2004);
- New properties of technical, social, or informational resources (Järvinen, 2007);
- Architectures, design principles, and design theories (Vaishnavi and Kuechler, 2015);
- Design propositions (Denyer et al., 2008; Van Aken, 2015).

While their evaluation, according to Hevner et al., 2004 and Peffers et al., 2012, can be made through:

- Logical argument;
- Experiments;
- Prototype;
- Case research;
- Expert evaluation

Finally, to complement DSR approach, Hevner (2007) proposes the three cycles of activities represented in Figure 3.1. The *relevance cycle* bridges the contextual environment with the design science activities; the *rigor cycle* connects design science activities with the knowledge base; and the *design cycle* allows to iterate the development and evaluation of the artefact (Hevner and Chatterjee, 2010; Hevner, 2007).

3.2 Information Processing Theory

According to information processing theory (IPT), firms are information processing systems that face uncertainty, which they have to respond (Galbraith, 1974; Tushman and Nadler, 1978). The purpose of IPT is to support organisational decision makers during tasks' execution (Galbraith, 1973, 1974).

The concepts at the base of IPT are uncertainty and information, as synthesised by Galbraith (1974) in the sentence "the greater the task uncertainty, the greater the amount of information that must be processed among decision makers during task execution in order to achieve a given level of performance". In particular, uncertainty refers to the difference between the amount of information needed to perform the task, and the amount of information already possessed by the organization. While, the information needed to execute a task depends on the number of input resources utilised, the diversity of outputs, and the level of performance to achieve (Galbraith, 1974). Examples of the adoption of IPT in similar areas to those of this thesis can be found in the following recent publications (Bode and Macdonald, 2016; Bode and Wagner, 2015; Fan et al., 2017; Flynn et al., 2016).

In order to complete the different tasks with high level of performance the various groups within an organisation must be coordinated. Therefore, organisations have to create strategies to obtain an integrated pattern of behaviour across the different interdependent groups. The integrating strategies proposed by Galbraith (1974) to deal with the increasing information loads due to the increasing task uncertainty are synthesised in Figure 3.2, below.

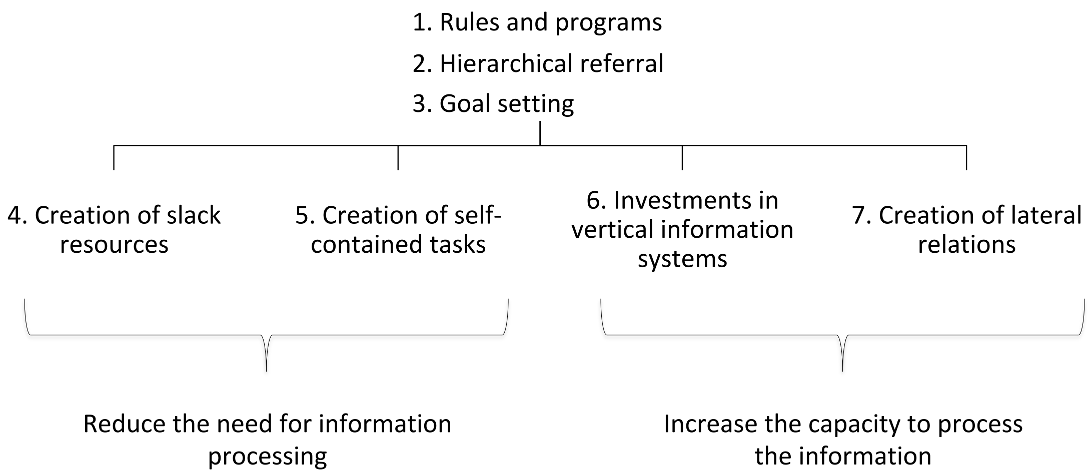

Figure 3.2 IPT organisational integrating strategies

Rules and programs: Represent the simplest method to coordinate interdependent tasks and sub-tasks by specifying set of necessary behaviours before their executions. The primary benefit of rules and programs is to reduce the need of communication among sub-units. They perform the same function for organisation that habits perform for individuals, i.e. they eliminate the need to treat each situation as new. In our context such rules and programs can be related to risk and contingency plan, but also to established risk and disruption management processes (Galbraith, 1973, 1974). As the organisation faces new and different situations, other integrating devices must supplement the adoption of rules.

Hierarchical referral: As the organisations depending on rules encounter new situations, it has no ready-made responses. To handle such situations new managerial roles are created and organised in a hierarchy. Additionally, the hierarchy refers also to a hierarchy of authority and reward, meaning that the decisions taken by the role occupant are decisive in shaping the behaviour of the performers of the task. Therefore, new situations, for which there is no pre-planned response, are referred upward in the hierarchical chain in order to create new response (Galbraith, 1974, 1977). In our context, the managers and their subordinates facing disruptive events represent the hierarchical chain to follow to deal with such events.

The weak point of hierarchical communications lies in the fact that each link has a finite capacity for handling information. As sub-tasks increase in uncertainty, more exceptions that need to be referred upward in the chain arise, leading to the overload of the hierarchy. In this case, the organisation needs to develop new processes to supplement rules and hierarchy.

Goal setting: As the uncertainty of a task increases, the volume of information that needs to be processed from the point of action to the point of decision-making may overload the hierarchy. In order to deal with this problem efficiently, organisations must bring the point of decision-making down to the point of action where the information originates (Galbraith, 1974). To do so, the organisation can act by increasing the discretion of employees at lower level or by undertaking processes to set goals that allow to cover the primary interdependencies. Unfortunately, the solution of increasing the level of discretion of lower level's employees may jeopardise the obtainment of an integrated pattern of behaviour across groups due to the misalignment between local goal and global goal of a company. Instead, in the other solution the organisation needs to specify target to be achieved allowing employees to select behaviours according to the target. In this way, a decision is made, and new targets are communicated to the affected sub-units in order to keep their behaviours integrated. In our context, for example, mother companies can set goals related to local risks and disruptions to avoid hierarchical overload while increasing the decisional autonomy of lower level's managers.

The ability of an organisation to efficiently coordinate its activities by goal setting, hierarchy, and rules depends on the frequency of occurrences and the capacity of the hierarchy to handle them. At this point, an organisation can decide about employing two strategies to reduce the amount of information that is processed, also referred as information processing needs, or two strategies to increase its capacity to handle more information, also referred as information processing capabilities (Galbraith, 1974; Tushman and Nadler, 1978).

The two strategies to reduce information processing needs are: creation of slack resources and creation of self contained tasks.

Creation of slack resources: When an organisation does not have the information processing and computational capacity to deal with the coordination requirement, can respond by increasing the resources available rather than utilising the existing resources more efficiently (Galbraith, 1974). These additional resources are called slack resources. The amount of slack resources required depends on the degree of task uncertainty. In our context, slack resources can be related to machine duplication leading to over-utilised manpower, under-utilised machine time, increasing inventory, and consequently increasing costs.

Whether slack resources are chosen to absorb the increased task uncertainty depends on the relative costs of the other three strategies.

Creation of self-contained tasks: Allows to reduce the amount of information processed by shifting the basis of authority from functional tasks to one in which each group has all the resources needed to perform their task. Also, in this way the decisions are moved closer to the point where information originates (Galbraith, 1977). In our context, self-contained units can be created around major section of the final product, for example the wings of an aircraft as in the case of our wing assembler that have two different facilities according to the alloy of the wing produced; or around product lines, as in the case of our truck assembler that produce different configurations of the same vehicle.

The costs associated with this strategy are related to the duplication of resources needed by each group in order to guarantee less resource sharing and to minimise the need of specialised resources that need to be shared and scheduled.

In contrast, the other two strategies, investments in vertical information systems and creation of lateral relations respectively, consider the required level of information as given, and create processes and mechanisms to acquire and process more information during the execution of a task.

Investments in vertical information systems: Consists of increasing the capacity of the existing communication channels, creates new channels, and introduces new decision mechanisms by investing in new information technologies. On the one hand, the effect of this strategy is the same of creating slack resources and self-contained tasks, meaning that it allows decreasing the number of occurrences that need to be referred upward the hierarchy. On the other hand, the reduction of exceptional occurrences is gained at the cost of more information processing at planning time (Galbraith, 1974, 1977). In our context, such investments can be related to the upgrade of existing channels or related to new and more automatic technologies that allow analysing the environment in order to limit the occurrence of disruptive events.

Creation of lateral relations: Consists in employing lateral decision processes, such as direct contact, or the creation of task forces and liaison roles, to cut across line of authority in order to avoid hierarchical overload. The simplest form of lateral relation is the direct contact between two managers that share the same problem. It allows decentralising decisions without creating self-contained group. The cost of the strategy is the greater amount of managerial time spent in group processes, and the expenses to create liaison and integrating roles. In our context, two departments' manager can create a task force to deal with a disruptive event that affects both departments.

In summary, the organisation can choose to follow one or some combination of the four strategies presented when facing greater uncertainty. In particular, the organisation will choose the least expensive strategy, or combination of strategies, for its environmental context. We tackle this problem using as lens of analysis the perspective of IPT as this theory is used to explore the adoption of information management model, as a proxy of the decision process, in dealing with supply chain disruptions, and this will be further explained in section 3.3.1.

3.3 Empirical work

3.3.1 Study 1

The first study is a qualitative study aimed at developing the first two information management solutions, namely: an information management model, presented previously in section 2.4.2, which provides the required visibility to the decision makers in order to improve disruption management process; and a conceptual model, based on the model in section 2.5, which supports the selection of disruption recovery strategy. According to DSR types of artefact, our information management solutions belong to the model category (Hevner et al., 2004; Peffers et al., 2012).

Taking into account the exploratory nature of this work, case research is appropriate as the adopted research methodology (Eisenhardt, 1989; Voss et al., 2002; Yin, 2009). Case research is carried out to understand how some companies' information systems' solutions provide visibility to manage supply chain disruption. We are examining how companies share information, use disruption data, as well as the results of its usage, taking into account the perspective of the different end users.

Therefore, the unit of analysis is information related to disruption, at company level. This approach allows us to study the experiences of managers in a real life context and thus increases the practical relevance of the findings (Yin, 2009).

The choice of using a “focal” perspective instead of a “supply chain” perspective to conduct the case study was related to the difficulty of having access to other contacts, both of suppliers and clients, during the preliminary meeting held with the firms involved in the study. Not being able to reach other firm’s supply chain partners we then decided to opt for a “focal” perspective that would allow us, at least, to have a vision and understanding of the supply chain from the perspective of the company itself. This has also allowed us to justify the analysis of the information, both internal and external, which the firm share with its partners.

Many authors provided recommendations to guarantee rigor and usefulness of case studies (Voss et al., 2002; Yin, 2009): (1) extensive knowledge about the context, both theoretical and practical; (2) ensuring design quality through construct, internal, and external validity, as well as reliability; (3) research logic selection (theory generation, testing or elaboration); (4) case selection (single or multiple, and holistic or embedded); (5) case protocol development.

Theoretical and practical knowledge was built during the literature review (Chapter 2), and from previous studies (Messina et al., 2016, 2015). For what concerns the design quality, validity and reliability are ensured in accordance with the data reported in Table 3.1. Due to the qualitative nature of this work, internal validity is not considered (Yin, 2009).

Table 3.1 Criteria ensuring quality of the research (Based on: Yin, 2009)

Criterion	Definition	Description of our application
Construct validity	Identify most suitable operational measures for the concepts under analysis	Diversity in interviewees' selection, confirmation of the interview transcription (by the interviewee itself), and data triangulation
External validity	Define the domain of generalizability of the findings of the study	Replication of case study logic in the same context but with different cultures and/or countries
Reliability	Allow replicating the operation of the study, such as sample selection and data collection, to obtain the same	Case study protocol development to replicate the study and results

results

Taking into account that we are analysing how firms process information to generate visibility for risk and disruption related decisions, we decide to adopt information processing theory (IPT). According to IPT, firms are information processing systems that face uncertainty, which they have to respond (Galbraith, 1974; Tushman and Nadler, 1978), and, in our case, such response is achieved by adopting flexibility and redundancy. In particular, in order to mitigate uncertainty and ambiguity, firms need to enhance their capability to gather, process, and act upon the information (Galbraith, 1974; Tushman and Nadler, 1978). For IPT, the activities of gathering, processing and acting upon the information represent information processing capabilities, while the effects of uncertainty and ambiguity are considered as information processing needs. In order to be effective, a firm has to fit its information process capabilities with its information processing needs (Tushman and Nadler, 1978). However, IPT originally arose to examine such fit at intra-organisational level, and thus, it is not directly applicable to supply chain context.

In order to accommodate supply chain level of analysis we use theory elaboration (Ketokivi and Choi, 2014) specifically applied to risk and disruption related problems. Theory elaboration is considered appropriate where a general theory exists but where the research context plays a fundamental role. In our case we elaborate IPT theory taking into account both supply chain level of analysis, as well as risk and disruption related problems (Ketokivi and Choi, 2014). This research focuses on disruptions generated in the supply chain that threaten the normal course of operations of any firm within the chain. A disruption is a non-routine situation that requires an extra effort in terms of information processing in order to make sense of (Daft and Weick, 1984). Therefore, with these models we want to elaborate IPT in order to help companies identifying the information required in a less-known context represented by the different phases of the disruption management process.

Finally, a purposive sampling strategy has been used to select three companies in vehicle assembly business, namely aircraft wings, trucks, and cars (Patton, 2002; Yin, 2009). Vehicle assembly context was chosen for its characteristics: global dispersion of partners, complex production, medium-long lifecycle of products, and high uncertainty (Messina et al., 2017; Sheffi, 2005). Also, the cases under analyses were chosen taking into account the countermeasures implemented to overcome disruptions, acting predominantly as flexible, redundant, and a mix of both. The selection procedure was based on the following criteria:

- Firm should belong to complex supply chain;
- Firm should assemble complex product(s) that required an extensive use of information to ensure that the work runs smoothly;
- Firm had suffered at least one disruption at operational level in the year previous to the interview;
- Firm required to share a conspicuous amount of different types of information, among supply chain's and 3PL's partners, to deal with such disruption(s).

3.3.1.1 Data collection, analysis and validation

Data collection was carried out through semi-structured interviews, based on the stages of the information management model presented in section 2.4.2, according to the interview protocol (in Appendix A-2). In particular, during the interviews respondents were asked to provide examples of disruptions suffered by the firm and in which the interviewee had acted personally for the recovery of the latter. Therefore interviewees had to be aware of the information needed to recover from such disruptions. Also, once these disruptive events were identified, all the answer to the following questions had to refer to the identified event.

We were able to conduct a total of 17 interviews, at company plants. The interviews lasted between 43 and 77 minutes, with an average of 60 minutes per interviews, for a total of almost 17 hours of recording. Interviews with durations longer than 60 minutes were due to the fact that respondents spent more time to provide a more thorough description of the material at support, for data triangulation.

Since we aimed to study how companies use information to gain visibility over supply, demand, and product management processes (Tang, 2006a), the interviewee profiles selected were precisely Supply Manager, Demand or Logistics

Manager, Production Manager, and Information System Manager. Involving managers from different company duties belonging to the internal supply chain allowed us to collect multiple views of the information management process and use of the information systems during disruptive events. Hence, we were able to identify information shared within the firm and among supply chain partners, both upstream and downstream.

Table 3.2, below, provides a summary of the cases selected for this study.

Table 3.2 Study 1 - case study data

Interviewee code	Interviewee's profile	Company Code	Sector	Year of foundation	Number of employees of the plant	Supply chain position
A	IT Manager	Wing Co	Aircraft wings assembly	2012	400	1st Tier
B	Purchasing Manager					
C	Avionic material planning Manager					
D	Non-avionic purchasing Manager and Logistic Manager					
E	Order and outbound logistic Manager	Truck Co	Trucks assembly	1964	437	OEM
F	Maintenance and facility Manager					
G	Production Manager					
H	Inventory Manager					
I	Production Planning and Outbound Logistics Manager					
J	Procurement Manager					
K	Warehouse and Internal Logistics Manager					
L	Supplier Manager					
M	Supplier Manager	Car Co	Cars assembly	1995	3600	OEM
N	Stock Manager					
O	Inbound & Outbound Logistics					

	Manager					
P	Critical Part Manager					
Q	IT Key User					

To perform the data analysis, all the interviews were recorded, transcribed and then coded with the support of MAXQDA® software (in appendixes A- 3-8). Also, to guarantee construct validity, transcripts of the interviews were sent to the interviewees. Furthermore, to improve the analysis of the cases and its practical relevance, we use the conceptual model for disruption recovery, depicted in Figure 2.4 (presented in section 2.5).

Once the analysis of the cases was completed, each firm was provided with a report showing the results obtained for that company. Afterwards a workshop was held, involving the interviewees and other members of the company, to discuss the main results obtained, relatively to the characterisation of the different stages of the information management model and to the conceptual model, and to assess them in a qualitatively way. In particular, during the workshops, a discussion was created about the disruptive events identified and the necessary information to recover from these events, in order to identify in which phase of the disruption management process this information would be more beneficial to face such events in the future. Also, we provide a comparison of the cases by highlighting firm's best practices and weaknesses compared to the other cases involved in the study. Finally, we derived two design propositions, the first one related to the design of the information management model while the second related to the design of the conceptual model, suggesting actions that decision makers should implement in the redesigning phase to improve the management of future disruptions. To increase the practical relevance of this work, design propositions were developed adopting the CIMO-logic proposed by Denyer et al. (2008). In order to ensure DSR rigour, the validation of these design propositions was made through focus groups with supply chain experts (Hevner et al., 2004; Krueger and Casey, 2009; Peffers et al., 2012).

Validation workshops were carried out as focus groups following the prescriptions of Eriksson and Kovalainen (2008) and Krueger and Casey (2009). The focus group methodology has been selected, because it allows to explore how expert's viewpoints are constructed and expressed, during group interactions (Eriksson and Kovalainen, 2008). Three focus groups were carried out, involving both the interviewees and additional members of the firms. Each focus group lasted about 90 minutes, in which two or three researchers acted as group moderators to foment the discussion among group members but at the same time avoiding to introduce bias "piloting" their answers. Taking into account that we were not allowed to video nor audio record the sessions, the research group acted as moderator but also helped the remaining researcher(s) to take notes and to keep track of the results obtained in the workshops. Also, additional data was gathered immediately, in the form of notes, at the end of each focus group.

For what concerns the design propositions validation, workshop's attendants were asked to assess them based on two criteria, namely relevance and ease of implementation. Relevance refers to how beneficial the implementation of such solution can be to improve visibility and so to improve the disruption management process, while ease of implementation refers to how easily the firm can implement such solution in their current conditions. The assessment of the criteria was based on the two five-points Likert scales listed below in Tables 3.3 and 3.4.

Table 3.3 Scale to judge the relevance of the design propositions

Relevance	
Score	**Description**
1	Not relevant at all
2	Slightly relevant
3	Moderately relevant
4	Very relevant
5	Extremely relevant

Table 3.4 Scale to judge the ease of implementation of the design propositions

Ease of implementation	
Score	**Description**
1	Very difficult
2	Moderately difficult

3	Neither easy nor difficult
4	Moderately easy
5	Very easy

At the end, another report with the results of the validation workshop was provided to the companies.

3.3.2 Study 2

The objective of Study 2 was to propose the third information management solution, i.e. a quantitative approach to assess the visibility that a company has over its supply chain, both internal and external. In this case, the artefact designed belongs to the algorithm/approach category (Hevner et al., 2004; Peffers et al., 2012). In order to achieve this goal, we structured the research design in two phases.

The first phase consisted in identifying the various dimensions of the model, and on the definition of the mathematical formulation for their evaluation. This phase was based on the literature about visibility assessment, and on the data collected through a focus group (Krueger and Casey, 2009) with a panel of expert practitioners. In particular, the purpose of the focus group was to test the practical relevance of the metric and to improve its usability.

For the second phase, the aim was to test the effectiveness of the metric, and at the same time to obtain some preliminary results of its adoption. Taking into account the nature of this study, case study research seemed to be an appropriate research method (Eisenhardt, 1989; Yin, 2009). Case study research is carried out to study the effects that accessibility, quantity, and quality properties of the information shared among partners have on the resulting supply chain visibility assessment.

Similar to the first study, also here cases have been conducted assuming the perspective of the decision maker of a plant that needs to access the information to make effective decisions. Therefore, the unit of analysis is the information about supply chain partners operations directly accessible at plant level. This approach allows us to identify the set of accessible information and the level of visibility that managers have of their supply chain to make their decisions.

In order to guarantee the rigor and usefulness of the cases we follow the recommendation provided in the literature (Voss et al., 2002; Yin, 2009), in particular: (i) extensive knowledge about the context, both theoretical and practical; (ii) ensuring design quality through construct and external validity, and reliability; (iii) research logic selection (theory generation, testing or elaboration); (iv) case selection (single or multiple, and holistic or embedded); (v) case protocol development.

Theoretical and practical knowledge has been achieved during the literature review, and based on previous studies (Messina et al., 2016; Messina et al., 2019, 2015). To ensure design quality we used a diversity of informants aiming at obtaining a vision of the environment as complete as possible, and to guaranty construct validity. The replication of the study in the same context characterized by different cultures allows to guarantee external validity. Finally, the adoption of a case study protocol allow to repeat the data collection procedures, and to ensure the reliability of the study (Yin, 2009).

Also in this case study data collections allows for theory elaboration (Ketokivi and Choi, 2014). The reasoning behind theory elaboration is similar to that of theoretical testing, but, in this case, the researcher, instead of testing a set of hypothesis, tries to extend the theory previously testes (Dubois and Gadde, 2002; Ketokivi and Choi, 2014; Voss et al., 2002). Therefore, this thesis elaborates on information processing theory, through the development of a quantitative approach to assess supply chain visibility.

Three companies in vehicle assembly business, namely aircraft wings and automotive components, have been selected as case studies. Vehicle assembly context was chosen for its characteristics of global dispersion of partners, complex production, medium-long lifecycle of products, and high uncertainty (Messina et al., 2016; Sheffi, 2005).

Finally, a purposive sampling strategy was used to select the cases for this exploratory study, allowing for a literal replication logic (i.e. we expected to obtain similar results while differences would be related with the specific characteristics of each sector) (Eisenhardt, 1989; Patton, 2002; Yin, 2009). The selection procedure was based on the following criteria:

- Firm should belong to complex supply chain;
- Firm should produce complex product;
- The metric should be used for mono-product supply chain (i.e. if a company produce a family of products, each product belongs to a different supply chain);
- Sharing information directly at least with one upstream or downstream partner;
- Having a certain level of bargain to promote changes.

3.3.2.1 Data collection, analysis and validation

Data collection was carried out through a visibility assessment tool (in Appendix B) and was based on the evaluation of the dimensions of the shared information. We were able to conduct a total of three supply chains' assessments, at company plants. Based on the assessment tool, each participant was asked to evaluate the accessible information in terms of quantity, timeliness and accuracy based on three different four-point Likert scales that are going to be presented with greater details, later in Section 5.3.2.

As we are studying how companies evaluate the information to gain visibility over supply, demand, and product management processes (Tang, 2006), interviewee profiles selected were Procurement Manager or Supply Chain Manager. This allows us to have a broad view of the information flowing within the supply chain and its consequences in terms of visibility level. Hence, we were able to identify and assess the information shared within the firm and among supply chain partners, both upstream and downstream. Table 3.5 below summarises the main characteristics of the cases for the study.

Table 3.5 Study 2 - case study data

Case Code	Sector	Company business	SC Position	Company contact profile
A	Aircraft	Wing assembly	1st Tier	Procurement manager
B	Automotive	Elastomeric components manufacturer	1st Tier/ 2nd Tier	Supply chain manager
C	Automotive	High precision components manufacturer	1st Tier	Supply chain manager

To perform data analysis, all the assessments were combined in order to determine the visibility level of each node. Afterwards, the latter were recombined aiming at obtaining overall upstream, downstream and internal visibility levels. In addition, the adoption of the approach by the experts interviewed allowed to test its effectiveness, and to validate according to DSR the results obtained with the previous case study (Hevner et al., 2004; Peffers et al., 2012).

Chapter 4. Study 1: Information management for the recovery of supply chain disruptions

[This chapter is an adaptation of the following publication:

- Messina, D., Barros, A. C., Soares, A. L., and Matopoulos, A. An information management approach for supply chain disruption recovery. First revision submitted to International Journal of Logistics Management]

4.1 Motivation of the study

This study focuses on information management as a way to achieve improved visibility in the supply chain which is an enabling factor for supply chain members to effectively apply recovery strategies during disruptive events (Barratt and Barratt, 2011). Supply chain visibility is defined as the capability of a supply chain player to have access to or to provide the required timely information from/to relevant supply chain partners for better decision support (Goh et al., 2009). Companies achieve supply chain visibility by using information systems to gather, process, and share supply chain data (Barratt and Barratt, 2011). Still, there is a lack of empirical research on how to provide such visibility, instrumental to support decision-making.

In the specific, the study aims to identify and analyse the actions taken and the information used by decision makers during and after disruptive events in order to improve the disruption management process. Studying how managers in the supply chain deal with disruptions enables to answer the first research question:

RQ1: "How to design a reference information management model for companies to improve their disruption recovery process?"

We tackle this problem using information processing theory as lens of analysis (Galbraith, 1973; Tushman and Nadler, 1978) as this theory is used to explore the adoption of the information management model, as a proxy of decision makers information processing capability, to deal with supply chain disruption.

4.2 Findings

4.2.1 Within-case analysis

Within-case analysis provides a broad picture of the organisational structure of the companies involved in the study, but also to characterise the starting point of each of these organisation in terms of risk maturity, visibility of the supply chain, and available technologies.

4.2.1.1 Case WingCo

WingCo is a large company producer of aircraft wings, based in Europe and subsidiary of a multinational company with headquarters outside Europe. WingCo has as its sole customer its Mother Company (Wing_MC), which is an OEM. Wing_MC is also responsible for many operation management aspects of WingCo. For example, Wing_MC is responsible for the selection of airplane parts' suppliers, for the annual production, orders, and related forecasts. In this case, airplane parts are all the components that need to be assembled in the final product, while non-airplane parts are all the remaining, such as spare parts, machinery, and tools.

Since WingCo is a 1st tier supplier owned by the mother company, both companies have a collaborative relationship. WingCo assembles wings for two aircraft models, one based on composite alloy material and the other on metal alloy material.

WingCo defines its production as *quasi*-just-in-time (JIT) with the application of several principles from lean manufacturing and Kaizen. In terms of risk management, the management of the process does not seemed mature taking into account that not all the interviewees were aware about the presence of a formal risk management process nor the presence of risk plans, and motivate this aspect with the fact that Wing_MC is responsible to implement such process. The identification of the disruption is generally made when this latter occurs by querying the system. The firm implements a reactive approach in dealing with this kind of events, due primarily to a scarce visibility of the information loaded into the system, and a lack of defined alert systems aiming at warning timely the user about a potential disruption. Principal causes of disruption are related with inaccuracy of the information loaded into the system, and delay in deliveries. This can be related to the fact that Wing_MC tends to control the operations of WingCo, acting as mediator in the relationship between WingCo and its suppliers. Also, Wing_MC is installed in a country with a different time zone than WingCo, which leads to delays in the communication and consequently in reacting to disruptive events. For what concerns the strategies to face and recover from disruption, WingCo has implemented primarily practices such as, buying machines from the same brand to take advantage of the standardised spare parts, and the adoption of flexible machines that allow to execute different operations. This is confirmed also for the necessity of information especially in the recovery phase, as showed in Figure 4.1. Other countermeasures are also applied but with greater care, such practices are machine duplication, and multiple suppliers, generally related to non-airplane parts. WingCo evaluates the effects of disruptions in a qualitative manner.

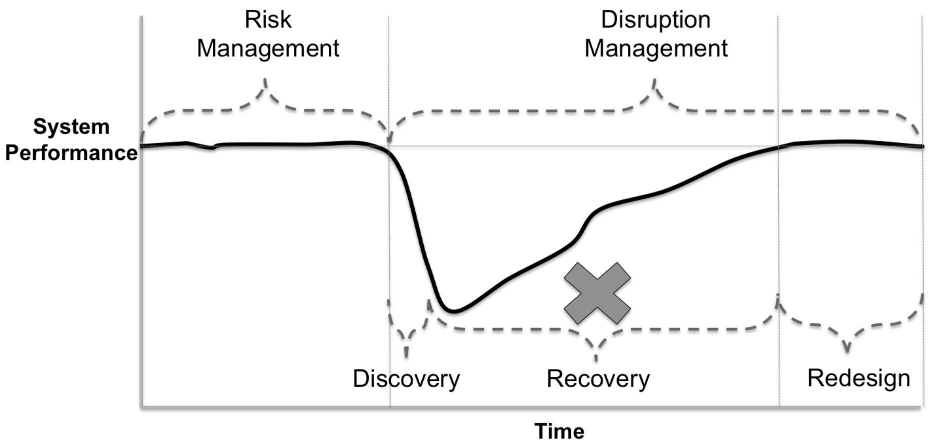

Figure 4.1 Phase in which WingCo needs more information to mitigate disruptions

For what concerns the information management WingCo seemed more prone to use internal information, especially related to purchasing orders and level of stock, to deal with negative occurrences. Also, the IT systems supporting such activities appeared to be more oriented to ensure a proper management of the internal functions when dealing with disruptions than towards external partners. Moreover, most of these systems are informal leading to a narrowed visibility limited to their 1st tier suppliers.

4.2.1.2 Case TruckCo

TruckCo is a large company producer of trucks, based in Europe, and belonging to a multinational with two main divisions, one European (Truck_MC1) and one non-European (Truck_MC2). Truck_MC2 is responsible to determine the global production, while the Truck_MC1 is responsible for all the other activities such as sales, after sales, logistics, and forecasts. Both Truck_MC are suppliers of TruckCo, while Truck_MC2 is also its only customer. The three firms have collaborative relationships, based on mutual trust. TruckCo assembles a truck with three different configurations. The combination of kits, within each configuration, leads to several versions of a similar vehicle.

TruckCo production is make-to-order (MTO) and consists of a rich portfolio of different configurations of the same truck. TruckCo has an established risk management process. Truck_MC2 sets formal rules and contingency plans to follow, also the presence of several sensors both in the system and on the machines, in conjunction with different checkpoints along the plant, allow TruckCo to be proactive in detecting and facing disruptions. Proactivity is enhanced due to the fact that operators and managers of an area have complete visibility over the information entered into the system, according to their clearance. Event identification is usually performed through IT systems, and auxiliary systems are adopted in different areas. The system automatically detects potential disruptions, but the operator has to query the system, in order to search for these events. Other ways to communicate occurring or potential disruptions are by direct internal line, e-mail, or face-to-face meeting. Causes of such events are related with components delivery delays, shortage on stock, quality problem, and in some cases to supplier and shareholder bankruptcy. The presence of formal rules, and high level of collaboration among members of different teams, allow TruckCo to be aware of their context, and provide flexibility. Concepts such as visibility, transparency, lesson learned, and proactive attitude are indicative of a strong resiliency firm's culture. Recovery from disruptions is achieved through practices such as multiple suppliers, multiple shipments modes, intervention of external subcontractors, and extra stock. All these practices allow TruckCo to be more robust in case of disruptions occurrence. This is confirmed by the need of more information in the risk management and redesign phases, as reported in Figure 4.2. The interviewed managers were not able to quantify the monetary losses related to the occurrence of a disruption, but translate them qualitatively in terms of delays. The non-monetary quantification of the losses can be related to the fact that the Truck_MC1 is deputed to such evaluations.

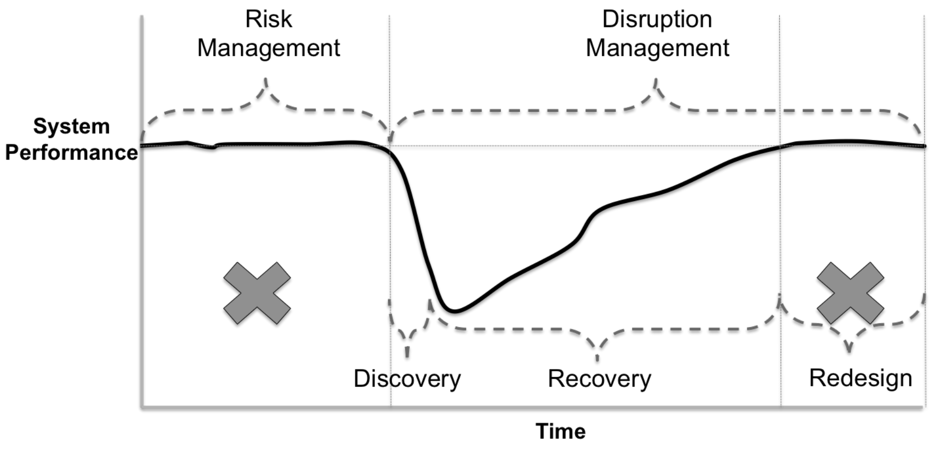

Figure 4.2 Phases in which TruckCo needs more information to mitigate disruptions

Regarding the information management TruckCo manages to balance the adoption of internal and external information coming from both Truck_MCs. In the specific, the information coming from Truck_MC2 is completely visible and due to the presence of track and trace systems in some case the order delivery is followed in real-time, while for Truck_MC1 the visibility over the information is still limited to the sent of the order while the delivery time need to be estimated by TruckCo. TruckCo's IT systems in conjoint with several sensors allow to provide good level of internal and external visibility to cope with the occurrence of negative events. Still, such systems provide great level of visibility related to 1st tier suppliers and in some case a limited and non accurate visibility over 2nd tier suppliers based in Europe.

4.2.1.3 Case CarCo

CarCo is a large company producer of cars, based in Europa and belonging to a European multinational (Car_MC). Car_MC is responsible for the supplier selection, forecasts, global production, sales, and after sales. CarCo and Car_MC have collaborative relationship. CarCo is a car assembler of three different models, available in different configurations. Also, CarCo produces for Car_MC but in rare occasion also for final customers.

CarCo production is MTO with principles of Lean manufacturing, in particular for what concern waste minimisation. CarCo has an established risk management process implemented. This process is continuously maintained updated through two daily meeting in which all area managers are involved to discuss potential risky situation for the day, and there is also a system that provide information about risk identification, while the evaluation and further management is deputed to the experience of the different managers. CarCo is predominantly reactive, in dealing with disruption, with attempts to be more proactive. Even though the system provides complete visibility over the information entered does not allow the level of proactivity desired by the users. Event identification is performed through centralised IT system, and a conjoint of auxiliary systems when needed. The system automatically identifies potential disruptions, but the operator has to query the system, for greater details. Other ways to communicate occurring or potential disruptions are by phone, e-mail, or face-to-face meeting, both internal and with stakeholders. Main cause of disruptions is related with not timely communication that manifests itself with components delivery delays, and shortage on stock. Disruption recovery is achieved through a mix of the two strategies. Practice such as flexible process and reconfiguration of the workload allows CarCo to change the production orders or put some cars on hold to overcome most of the disruptions, related to unique supplier. Other practices such as, multiple suppliers, multiple shipments modes, and extra stock are also implemented. These practices allow CarCo to be flexible but at the same time robust in facing these events. At this purpose Figure 4.3 shows the phases where the information is more useful. The interviewees were not able to quantify the monetary losses related to the occurrence of a disruption, but translate them qualitatively in terms of delays. The monetary quantification of the losses is made centrally at Car_MC.

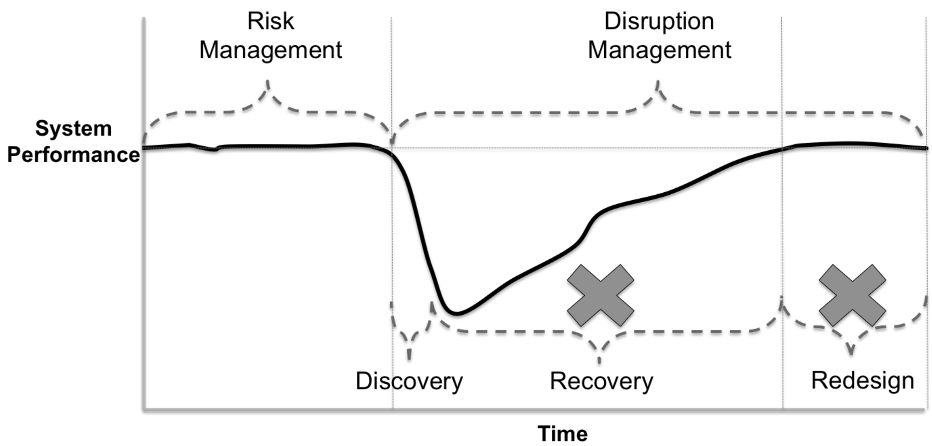

Figure 4.3 Phases in which CarCo needs more information to mitigate disruptions

Concerning the management of information, CarCo is also able to balance the access of both internal and external information provided by Car_MC. Such access to external information, in fact, provide to CarCo awareness about their context necessary to deal with disruptions. The adoption of several IT systems provides the required visibility, over their 1st tier suppliers. Also, these systems and additional tools are used to deal with negative occurrences and to help the analysis of these latter but, on the other hand, do not ensure that level of automatization required to support decision-making. In fact, decision makers put in place actions relying on their experience.

4.2.2 Cross-case analysis

Cross-case analysis provides a characterisation of the main aspects of the three phases that constitute the disruption management process, but also of each stage of the developed information management model and the analysis of the consequences that these stages entail in terms of visibility. Also, relatively to the information management model's stages, taking into account that interviewees belonging to the same firm use the same information systems, the analysis is performed in an aggregated way according to the firm.

4.2.2.1 Supply chain disruption management

To understand how the process is carried out by the cases analysed, interviewees were asked to provide examples of occurrence of disruptive events and related causes. Taking into account that the study focuses on disruptive events at the operational level, we identify two categories of disruption causes, namely internal and external, as reported in Figure 4.4.

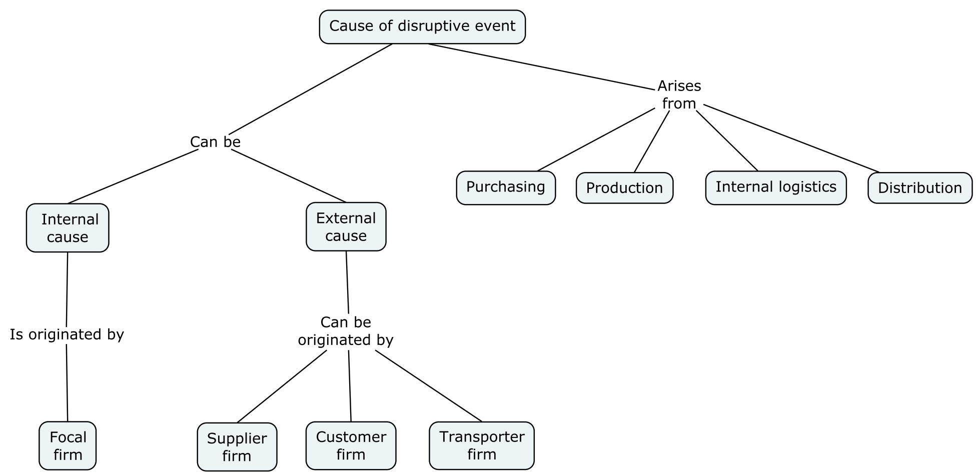

Figure 4.4 Disruption cause categories (adapted from Chen and Paulraj, 2004)

Table 4.1 provides a summary of the identified causes of disruption divided into internal and external.

Table 4.1 Causes of disruptions

Internal	External
Malfunctioning sensors, Incorrect information, Maintenance team unavailable, Not real-time information about the position of the product throughout the process.	Incorrect information, Delivery delay, Supplier insufficient capacity, Lack of communication, Incorrect forecasts, Supplier bankruptcy, Supplier insolvency, Transportation delay.

The following analysis shows the results in terms of the various phases of the disruption management process.

Discovery

After the identification of disruptive events and related causes, according to Figure 4.4, starts the first phase of the disruption management, i.e. the discovery. In all cases the predominant factor characterising this phase is speed. Discovery time of the different disruptions spanned from near real-time to six days at most. Also, disruptions characterised by longer discovery times were associated with non-immediate communication of the occurring disruption to the members involved.

Another important factor of the discovery phase is the discovery mode. According to the participants, discovery can happen in two ways: by an alert or by querying the system. The first one is related to the generation of an alert identifying the occurrence of a disruption and consequent communication to the interested parties. The other is a semi-automatic procedure in which after receiving an alert the decision maker has to query the system in search for anomalies; the systems provided with sensors were more efficient in this aspect.

Recovery

Moving to the core phase - the recovery - several factors seem to play an important role in determining the recovery efforts required to overcome the disruptions. These factors are: the presence of risk and/or contingency plans, the cause of disruption, and the information used to implement recovery strategies.

Regarding the presence of plans supporting the decision makers in recovery from disruptions, eight participants confirmed their existence, five their absence, while the last four asserted the presence of partial rules or other countermeasures as support. Table 4.2 provides a synthesis of this aspect.

Table 4.2 Presence of plans according to the interviewees

	Plans		
Interviewee code	**Existed**	**Used**	**Updated**
F, I, J, P	Yes	Yes	Yes
O, Q	Yes	No	Yes
D, G	Yes	Yes	No
E, M, N	Partial	Yes	Yes
L	Partial	Yes	No
A, B, C, H, K	No	-	-

Among the eight participants confirming the presence of plans, in four cases the plans were constantly updated and used, in two of them the plans were not used to recover, while the remaining two participants used the plans even if not updated. The fact that two participants did not use the plans to support the recovery leads to the next aspect identified; decision makers base their decisions on experience. Decision makers stated that they do not fully trust their systems due to unreliability of the information they contain, which is why they often have to resort to their experience and intuitions. Also, in those cases where no plans or rules are available, relying on experience is the only solution.

Regarding the relevance of the cause and the information needed to recover from disruptions, Table 4.3 synthesises the cases found.

Table 4.3 Causes and information types needed to implement the recovery strategies

Disruptive event	**Cause**	**Recovery strategy**	**Information category needed to implement the recovery strategy**
Product unavailability	Delivery delay	Speed up further processes to recover for time lost	***Int:*** Order, demand, inventory ***Ext:*** Legal requirements
	Incorrect forecast	Multiple shipment mode	***Int:*** Demand, inventory ***Ext:*** Market, Third-party logistics (3PL)
	Malfunctioning sensors	Collaborative efforts with partners to align the information	***Int:*** Order, inventory Ext: -
Lack of spare part	Incorrect information	Part retrieved from machine of the same	***Int:*** Order, product, demand, inventory

		brand	***Ext:*** Legal requirements
Lack of supplier's capacity	Incorrect information	Collaborative efforts with partners to align the information and Multiple shipment mode	***Int:*** Order, product, inventory ***Ext:*** 3PL, legal requirements
Machine breakdown	Maintenance team unavailable	Flexible machines	***Int:*** Product **Ext**: -
Shareholder abandonment	Supplier bankruptcy	Multiple supplier	***Int:*** Order, inventory ***Ext:*** Legal requirements, geopolitical, financial
Delay in work sequence	Not real-time information about the position of the product throughout the process	Speed up further processes to recover for time lost	***Int:*** Product **Ext**: -
Quality problem	Supplier insolvency	Multiple supplier and Strategic stock	***Int:*** Order, inventory ***Ext:*** Legal requirements, geopolitical, financial
Lost track of material	Lack of communication	Collaborative efforts with partners to align the information and speed up further processes	***Int:*** Order, inventory ***Ext:*** Legal requirements, 3PL

Table 4.3 will be discussed more in-depth in the next section and in the discussion.

The final part of the recovery phase is related to the evaluation of the recovery efforts in terms of performance. Unexpectedly, none of the respondents were able to provide such quantitative evaluations. Participant B provided an example that reinforces this aspect: *Losses in terms of costs or time are not evaluated quantitatively but estimated qualitatively*. Also, it seems that the perception of suffering extra costs is more related to recovery strategies involving costly transportation mode, as stated by participant E: *in general, the parts are sent by ship. When we need to switch to air shipment we incur in additional costs*. This perception is completely different when related to problems suffered by suppliers and transporters. In these cases, presences of ironclad service level agreements (SLAs) act as a shield in protecting the focal firms interviewed. Participant M provided an example supporting this fact: *Extra costs […] that in a second period will be charged to the supplier. Our SLA establishes precise conditions for such problems*.

Redesign

Finally, redesign actions can be grouped in three categories: update of existing plans (F, I, J, O, P, Q), follow-up with problematic suppliers (K, L, M, N), changes to improve processes or tools (A, B, C, D, E, G, H). Unexpectedly, even though interviewees O and Q stated that they did not use the existing plans to support the recovery (see Table 4.2) but they contribute to maintain the plans updated with new occurrences. Seven interviewees that did not have any plans tried to improve the processes to compensate this aspect while the remaining focused more on the supplier follow-ups to overcome their problems first.

4.2.2.2 Information management model and visibility

Identifying the needs

The first stage of the information management model is related to the identification of the types of information useful to face disruption. During the interviews, we asked the participants to provide a detailed list of information used to recover from disruption and any information that would have been useful to have, both internally and from upstream/downstream partners. These types were grouped in three categories: internal, external, and wanted (Table 4.4). The wanted category represents the need of additional information, independently if internal or external, to deal with disruption.

Table 4.4 Stage 1 - Identifying needs. Information categories according to firms

WingCo	Internal: Purchasing orders (quantity, quality, price, product type); Order specifications and technical drawings; Stock level; Current supplier (order delivery date, delivery status, contracts, service level agreement); Forecast. External: Potential supplier (price quotation, capacity, quality level); 3PL contracts Wanted: None	*For the kind of materials I am responsible for, the more detailed is the information about the purchasing order such as quantity, quality, price, and product type, the better;* […] *I am responsible for all the contracts with suppliers and service providers;* *We do not need additional information aside the one in the systems*
TruckCo	Internal: Purchasing orders (ID vehicle, quantity, quality, price); Current supplier (delivery date, transit time, contracts, service level agreement, capacity, historical data); Forecast; Order (specifications, bill of materials (BOM), master plan); Contingency plan (disruptions description, criticality, severity, likelihood, corrective action, historical data); Stock (level, position, integrity); Process (sequence, entry-exit point); Equipment (internal information, preventive/ predictive/ corrective	*Delivery date, ID vehicle, transit time (from plant-to end customer or until the last delivery point of shipment), all the information relevant for customs;* *[Externally] we also require the supplier to verify its stock, and we check our own stock to remove the non-conformity* *I would like to have real-time information about the product on the production process, and also, position, level, and condition (valid, not valid) of stock.*

	maintenance plan). <u>External:</u> Market changes; Potential supplier (price quotation, capacity, quality level, stock level); Current supplier (Geopolitical information about the country, financial risk assessment report); 3PL contracts; Energy consumption. <u>Wanted:</u> More accurate information about supplier stock level, delivery time, transit time; real-time information about BOM and internal stock (level, position, integrity).	
CarCo	<u>Internal:</u> Purchasing orders (ID vehicle, quantity, quality, price); Current supplier (delivery date, transit time, contracts, service level agreement, capacity, historical data); Forecast; Order (specifications, bill of materials (BOM), master plan); Stock in house (level, position, integrity); Stock in transit (level, position); Process (sequence, entry-exit point); Advance Shipping Notice (ASN). <u>External:</u> Market changes; Potential supplier (price quotation, capacity, quality level, stock level); 3PL contracts. <u>Wanted:</u> None	*I need detailed information about our suppliers, such as delivery date, transit time, capacity, and service level agreement;* *Externally one of our department [marketing] monitor changes about the market;* *I don't need additional information instead I would like to have better communication among partners*

The internal and external information reported in Table 4.4 represent a specification of the information types presented previously in Table 4.3. From the analysis of Table 4.4, it is possible to observe that TruckCo needs a greater amount of external information to manage disruptions compared to WingCo and CarCo. This kind of external information allows TruckCo to be more aware of the global context in which it operates, and so being proactive in managing potentially negative situations. Also, TruckCo is the only case in which the category information wanted is present. Regarding this aspect, it is noteworthy that this is not concerning, as expected, to additional information but to its characteristics, as it is possible to notice by the use of words such as “more accurate” and “real-time”.

Sensing

The second stage of the model is related to the ability of the systems to scan both internal and external environments in search of vulnerabilities. Table 4.5 provides a summary of the result from environment scanning.

Table 4.5 Stage 2 - Sensing

WingCo	<u>Internal:</u> Information automatically	*Internally the information is automatically*

	detected by the systems, then the operator needs to share this information with the partners involved. External: None	*detected by the system, then I have to share it with our partners;* *MC is responsible for all the external information*
TruckCo	Internal: Information automatically detected by the systems, the identification in some areas is provided automatically by the systems and in other areas the operator needs to look for failures or disruption. External: the operator needs to look for geopolitical and market changes and then communicate them.	*The system has only information related to virtual inventory. When a problem occurs in terms of mismatch among level of the inventories the [engineering] department is involved to check the conformity of the physical inventory.* *We are also developing tools that allow to take into account global situation (such as level of risk of the country in which the supplier is installed, financial stability, partnerships etc.)*
CarCo	Internal: Information automatically detected by the systems, while the operator makes the evaluation manually. External: Marketing department looks for market changes and then alerts the interested parties.	*[The system] alerts us about any detour from the planned situation, then I need to evaluate it manually;* *Externally one of our department [marketing] monitor changes about the market and communicate them to us*

TruckCo systems appear to be more "sensitive" than WingCo, and this could be related to greater presence of sensors along TruckCo plant. Also, only TruckCo and CarCo have systems examining directly the external environment, while for WingCo it is the Mother Company (MC) that performs this analysis.

Creating and gathering

Stages three and four, respectively, are associated to the ability of the systems to create and gather information about vulnerabilities, both internal and external. Tables 4.6 and 4.7 synthesise these system features.

Table 4.6 Stage 3 - Creating

WingCo	Internal: New information is related to the alignment of production plan, and inventory due to more updated information; problems with supplier (delivery, quality). Internal support systems and tools: SAP, ERP, MRP, dedicated ticket platform, internally developed tools in Access, e-mail, excel. External: None External support systems and tools: None	*New information is created to align production plans and inventory with more updated information;* *Internally we use SAP and other systems we developed in Access;* *We do not have any system that allow us to manage the information coming from external sources […] MC is deputed to manage such information [from external sources]*
TruckCo	Internal: New information is related to the alignment of production plan, inventory, and contingency plan due to more updated information and corrective actions implemented; problems with supplier (delivery, quality).	*Rarely suppliers communicate a shortage […] and so we need to create new information to align the production plan;* *EDI automatically integrated into our internal management system IBM AS/400 (equivalent to SAP);*

	Internal support systems and tools: IBM AS/400, ERP, internally developed tools in Access, sensors, contingency plan, and report. External: Forecast update, information related to malfunctions or problems (to be communicated to external subcontractor). External support systems and tools: EDI, e-mail.	*Once the problem is identified, we have the support of an external subcontractor to verify our physical stock;* *External support is provided via e-mail, and EDI*
CarCo	Internal: New information is related to the alignment of production plan, and inventory due to more updated information; problems with supplier (delivery, quality). Internal support systems and tools: Proprietary system (B2B platform), and additional systems when the principal is not enough. External: Forecasts and order updates, information related to malfunctions or problems (to be communicated to external subcontractor). External support systems and tools: E-mail, Excel.	*We create new information about the inventory [changing the old information with more updated one] when problems occur;* *The transporter needs to use our [B2B] platform to make new requests;* *I need to communicate to our external subcontractor all the information about malfunctions;* *Excel spreadsheet and e-mail are used for some information about our suppliers*

Table 4.7 Stage 4 - Gathering

WingCo	Wing_MC is responsible for the main information entered into the system. Internal support systems and tools: SAP, ERP, MRP, dedicated ticket platform, internally developed tools in Access, shared folder (internal server), e-mail, excel, and phone. External support systems and tools: e-mail and excel.	*Wing_MC is responsible for the information entered into our systems;* *The information of a new production plan (forecasts, delivery dates and so on) is loaded manually into SAP while others [information] are communicated via e-mail or by phone;* *[External] information reach my e-mail account and then I have to load it into our system*
TruckCo	Truck_MCs are responsible for the main information entered into the system, relatively to their respective markets. Internal support systems and tools: IBM AS/400, ERP, internally developed tools in Access, centralised system within equipment, sensors, barcode reader, share point, internal DB (for supplier risk management), contingency plan, report, e-mail, excel, face-to-face meeting. External support systems and tools: Web platform, EDI, share point, e-mail, excel.	*Truck_MC1 is responsible for the information [present in the system] related to EU market while Truck_MC2 is responsible for the information about non-EU market;* *[In some case] we can use pre-loaded information using barcode reader at the entrance of the product;* *[For non-EU market] we receive informal order by e-mail or excel*
CarCo	Car_MC is responsible for the main information entered into the system. Internal support systems and tools: Proprietary system (B2B platform), and additional systems when the principal is not enough, e-mail, excel, and phone. External support systems and tools: B2B platform, EDI, e-mail.	*The information is uploaded in the central system by Car_MC;* *In some case we can use system we developed on our own because the main system isn't "complete" enough;* *I prefer to use our [B2B] platform but sometimes I use also the e-mail*

Creating and gathering stages appear quite similar in all cases, with the exception of the presence of external information in TruckCo and CarCo. Two aspects that arose from the analysis are related to the role played by MCs and the supporting systems. In all cases MCs act as providers of sets of information needed to face disruptions. Regarding the supporting systems, many of them are very informal and do not allow to track the information exchanged.

Organising

Continuing with the analysis of the stages, the next one is related to the organisation of the information to make it available in case of disruption. The related information is reported in Table 4.8.

Table 4.8 Stage 5 - Organising

WingCo	Different areas organise the information in different classes regarding: Tickets subject; Delivery date agreed with customer; Purchasing order; and Current supplier. Information retrieval can be made according to anyone of the attributes that define each object within a class.	In my department is organised and retrieved according to ticket subject
TruckCo	Different areas organise the information in different class regarding: Internal customer; Equipment; Vehicle Identification Number; Process; Area of expertise; and Current supplier. Information retrieval can be made according to anyone of the attributes that define each object within a class.	*The information is classified in terms of equipment (Code: Family-sub family-ID) and through code filter I'm able to retrieve all the malfunctions related to that piece or that family of pieces*
CarCo	Information primarily organised by suppliers, but it is possible to use different classes such as Vehicle ID, and transporter. Information retrieval can be made according to anyone of the attributes that define each object within a class.	*Primary information is organised by supplier and I can retrieve it by any of its attributes*

The information appears efficiently organised to facilitate its retrieval when needed, according to the different perspectives analysed. However, the information is organised to perform the different processes under "normal conditions", and none of the system is equipped with interface specifics for disruptive situations. Further discussions about this aspect will be made in the next section.

Storing and maintaining

The sixth stage refers to the ways in which the information is stored and maintained within the systems. Information about this stage is reported in Table 4.9.

Table 4.9 Stage 6 - Storing and maintaining

WingCo	Information stored into internal DB, and internal systems. Each manager is responsible to keep the information they entered updated and avoid duplication.	*The information is internally stored into our database and each manager is directly responsible to maintain the information updated*
TruckCo	Information stored into internal DBs, share point, and internal systems (of the equipment). Each manager is responsible to keep the information they entered updated and avoid duplication.	*The information is stored into an internal DB and some in share point. The direct responsible is also in charge of maintaining it updated*
CarCo	Information stored into internal DB. Each manager is responsible to keep the information they entered updated and avoid duplication.	*We store our internal material flow (amount of cars sold, number of entry and exit pieces) into an internal DB, and we are responsible for the information entered*

Table 4.9 does not provide significant differences about how the companies store and maintain the information within the systems. The three cases store and maintain the information internally; this is due to the sensitivity of the information, and in WingCo case, to the partnership with government departments.

Processing

The next stage concerns the analysis and presentation of the information to enhance decision-making. Information related to this stage is synthesised in Table 4.10.

Table 4.10 Stage 7 - Processing

WingCo	Graphics related to ticket analysis; Analysis and decision-making based on the experience.	*The information is processed through graphics related to the analysis of the tickets*
TruckCo	Analysis made automatically by the system, decision-making based on strings of text, KPI, and on the report automatically provided by the system; the developed tools provide also graphic, and colour code.	*The AS/400 provides a report to support decision-making related to daily deliveries*
CarCo	String of text and KPI; Analysis and decision-making based on the experience.	*Strings of alphanumeric text (that provide me information about production forecasting, and material on stock, followed by all the information loaded by the supplier)*

Table 4.10 shows the features of the information systems implemented in supporting the decision-making. As it is possible to see, there are features that facilitate this stage, in particular TruckCo systems facilitate data processing for decision-making, while WingCo and CarCo rely more on the experience of their managers.

Sharing and using

The last two stages of the information management model are related to the systems adopted to share the information and the consequent use of the information shared. Tables 4.11 and 4.12 provide a summary of the stages.

Table 4.11 Stage 8 - Sharing

WingCo	Internal support systems and tools: e-mail, excel, face-to-face meeting, SFTP. External support systems and tools: e-mail.	*Internally the information is shared informally [chat and e-mail] among colleagues. No external communication aside with MC through e-mail.*
TruckCo	Internal support systems and tools: e-mail, excel, face-to-face meeting, share point. External support systems and tools: web platform, share point, EDI, encrypted USB, phone, e-mail, and excel.	*Internally the information is shared through e-mail, phone or personally in short meeting;* *Externally we use multiple communication means depending on the type of information such share file, EDI, e-mail, phone, and encrypted USB*
CarCo	Internal support systems and tools: Proprietary system, e-mail, excel, face-to-face meeting. External support systems and tools: B2B platform, e-mail, and excel.	*We have regular meeting twice a day with our supervisor in which we evaluate all the pieces that have less than 2 day of stock in-house;* *Externally we use mostly e-mail and excel*

Table 4.12 Stage 9 - Using

WingCo	Internal: disruptions tracking in order to capitalise from past occurrences, selection of alternative suppliers for non-airplane parts, selection of flexible equipment or of the same brand. External: - Wanted: More visibility.	*Internally we [in our department] take trace of the information about disruption to avoid that it happens again in the future then we opt for machines of the same brand [to retrieve compatible components];* *I would like to have more visibility over the information available*
TruckCo	Internal: disruption tracking in order to capitalise from past occurrences; switch in production sequencing, product re-check from problematic suppliers, root-cause analyses, selection of alternative suppliers, follow-up, training, lesson learned, operator's turnover to improve the learning process. External: Supplier audit, training, vital	*To solve faster the problem, we do root-causes analysis in order to put in place containment actions to solve the problems. Any action is recorded into "shortage note" in order to be more efficient;* *We audit our supplier and provide training to avoid the same situation;* *It would be useful to have a system that*

	information is communicated. Wanted: Complete visibility; Would be useful having a system that automatically analyses the information related to disruptions.	*tracks all previous failure to analyse better the presence of "paths" and to make the decision process more agile in similar situation*
CarCo	Internal: disruptions tracking in order to capitalise from past occurrences; switch in production sequencing, product re-check from problematic suppliers, root-cause analyses, selection of alternative transportation mode, follow-up. External: Training for worst suppliers, temporary task forces to solve problems, vital information is communicated. Wanted: Improved communication.	*We have to write a report for the shortage division in which we report the number of car that weren't produced and the root-cause analysis of the situation;* *In case of disruption we make the follow up of the worst suppliers involved, and we try to make a task force in order to solve the problem. Sometimes we train their workers too;* *I would like to have better communication among partners*

The sharing and using phases reveal the practices adopted in the different cases, whether they acted predominantly as flexible, redundant, or a mix of both, to address and overcome interruptions. Also, from the analysis of Table 4.11 it is possible to identify two categories related to the supporting systems adopted, namely internal and external. While from the analysis of Table 4.12 we identify three categories related to the actions entailed by the use of this information, which are: internal, external, and wanted.

Regarding the information systems adopted, WingCo basically uses informal systems to support the information sharing, especially towards the external partners, while the other cases try to adopt more formal systems, such as platforms. For the use of the information shared, WingCo has a limited set of flexible strategies it can implement mostly related to non-avionic parts. This is due to the great control that Wing_MC exerts on the firm. Also, the participants stated the need for more visibility to compensate this excessive control and being proactive.

TruckCo shows more possibilities in using the information to improve the disruption management process. Actions are dedicated to capitalising from past occurrences and to provide training, both internally and to suppliers. TruckCo participants required more visibility to enhance their ability to sense vulnerabilities and being more proactive. The majority of these participants would also like to have a stronger decision support from their systems.

CarCo's actions appear to be similar to those of TruckCo, but in this case the training is only provided to problematic suppliers. Surprisingly, CarCo interviewees did not specify the need for greater visibility of the information, but instead they would prefer more efficient communication between partners.

Finally, the adoption of several systems and tools generates different consequences in the way companies manage their information. WingCo imputes the adoption of different systems to a non-complete reliability of the information within the systems, and thus having multiple systems allows them to overcome this problem. Also, CarCo uses different systems in the different areas. This is not due to unreliability of the information, as is the case of WingCo, but to the fact that the main system does not always provide the required analysis tools. On the contrary, if the presence of multiple systems and tools allows TruckCo to be more aware, it requires a tremendous effort to manage this amount of information.

4.3 Discussion

Based on the previous analysis, this section provides suggestions about interventions that decision makers should implement in the redesigning phase to develop and implement the information model, in order to improve the recovery of future disruptions. Moreover, two design propositions are provided from the supporting evidence, and have been validated during focus groups.

In order to increase the practical relevance of this work, design propositions were developed adopting the CIMO-logic proposed by Denyer et al. (2008). CIMO-logic has been used because involves class of problematic context (C), for which the proposition suggests intervention(s) (I) through generative mechanisms (M) in order to deliver the wanted outcome(s) (O). Design propositions generated according to CIMO-logic suggest what to do, in particular situations, to obtain expected results while offering understanding of why this happens (Denyer et al., 2008).

The first design proposition focuses on the types of information shared. Table 4.3 shows the categories of information that companies use to face disruptions. Also, as reported when analysing the data in Tables 4.3 and 4.4, companies that were able to integrate internal and external information showed more awareness of the context and faster disruption discovery. Evidences related to the need of visibility, both internal and external, to improve disruption discovery can be found in the literature (Barratt and Barratt, 2011; Bode and Macdonald, 2016).

From the analysis of the tables cited and the above discussion at support, the following design proposition is derived:

Design proposition 1: In supply chain disruptions, information management, in particular information organisation integrating internal and external information, enhances visibility over supply chain to improve disruption recovery.

At this purpose, results from the validation workshops allow to confirm the need to have greater visibility over both internal and external information. Internal information, related to changes in production, misuse or loss of stock and, root-cause analysis; and external information, such as disruption alert, market forecast, suppliers' available capacity, and delivery delay and follow-up resulted the most useful for decision makers to enhance and/or redesign the discovery phase. These results confirmed the need for more and better information of both types in order for managers to have a more complete picture of the environment in which they operate and so to be more aware of the changes occurring in this context. Also, such visibility should lead to faster disruption discovery, corroborating the results found in previous literature (Barratt and Barratt, 2011). Finally, for what concerns supply chain disruption management, this research is one of the few (Bode and Macdonald, 2016) that takes into account all the phases to have a broader view of the process. In particular, discovery time and mode are fundamental for an appropriate disruption management. The relevance of discovery time was already confirmed in the literature (Bode and Macdonald, 2016), while the discovery mode was considered less relevant. At this purpose firms should opt for automatic disruption discovery to avoid omissions.

The second design proposition focuses on the information organisation to enhance decision-making processing. In particular, from the analysis of the data in Tables 4.2, 4.3 and 4.8 it was possible to identify two noteworthy traits: firstly, the presence of risk or contingency plans as a starting point for disruptions recovery, and the other related to organising information. Regarding recovery and redesign phases, in this case a central role is played by the presence of risk and contingency plans. Risk and contingency plans represent, according to the literature, valuable guidelines for managers to efficiently recover from disruptions although this value is bound to the fact that these plans are maintained updated (Bode and Macdonald, 2016; Jüttner and Maklan, 2011; Tang, 2006b). The presence of such plans or, at least, some guidance, is vital in supporting decision makers while facing disruptions (Jüttner and Maklan, 2011; Macdonald and Corsi, 2013; Ponomarov and Holcomb, 2009). Past occurrences need to be recorded and overhauled in order to maintain these plans updated. As it was possible to analyse, the participants of the study had their systems set to support the processes in "normal conditions", but not in a "disruption mode". This discussion lead to the final proposition:

Design proposition 2: In supply chain disruptions, information management, in particular a knowledge base of past disruptions provides organisational memory supporting structured decision-making for improved disruption recovery.

Results from validation workshops showed that having knowledge of the impact of changes occurring in the production plan, and about various aspects of the supply base, such as contract visibility, production lead-time, available capacity, and stock level would improve the selection of recovery strategies in future occurrences. Also, the presence of tools that allow to simulate disruptions at operational level would be extremely beneficial.

In general terms the solutions proposed were well accepted by the firms participating in the study. In fact, all the cases agreed about the need of integrate more internal and external information to obtain higher supply chain visibility but also on the need of having a knowledge base of the past occurrences in order to improve decision-making supports related to supply chain disruption's recovery in the future. In this regard, all the firms assessed the relevance of the solutions as "very relevant" or "extremely relevant" (assessing them between 4 and 5 as score). Different results, on the other hand, were obtained when assessing the ease of implementation of such solutions. In this case in fact, two out of three cases assessed all the solutions as "very easy" to implement. At this purpose only WingCo provided different results in the assessment of the two solutions, assessing the first as “very difficult” to implement (giving it a 1 as score) while assessing the second as “very easy” to implement (giving score of 5). In fact, for WingCo the difficulties related to the implementation of the first solution are related, as reported in the previous analysis, to the excessive control exerted by Wing_MC and on its role as information provider, giving less autonomy to WingCo to deal with such occurrences. In line with the result of the workshops, and based on the conceptual model in Figure 2.5, we propose a model that is specifically tailored to support decision makers along the recovery process. We suggest organising the information according to the model in Figure 4.5, in this case filled with the information retrieved from the cases. The information organization proposed in the model increases the ability of supply chain managers to act upon disruptions at operational level, and represents a valuable asset for practitioners in their early stage or in those cases in which firms have not structured guidelines.

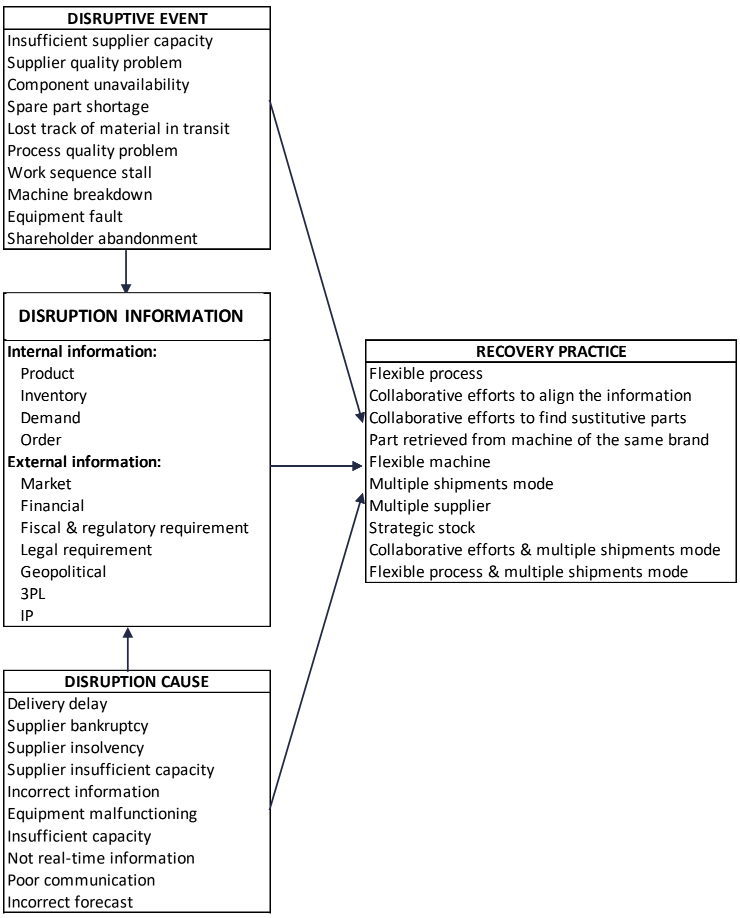

Figure 4.5 Conceptual model for disruption recovery derived from case research

We propose to apply the model in two different modes: static and dynamic. The static mode can be used as a disruption recovery catalogue, to overwhelm the absence of risk and contingency plans. The dynamic mode, on the other hand, can be used to train the model to automatically provide the information that requires attention first, to select the most suited recovery practice.

4.4 Concluding remarks

Findings of Study 1 can be generalized for other companies belonging to the vehicle assembly sector that consider information as crucial for facing and overcoming disruptions, but also for those firms belonging to supply chains in other sectors that show similar characteristics to the companies interviewed and / or who suffered similar interruptions in their daily-base work. Additionally, Study 1 has generated several important discussions for both community of practitioners and researchers. Firstly, the analysis of information systems in real setting showed that most of these systems are incompatible and still fail to provide visibility in the supply chain. The adoption of our information management model for disruption management allows taking into account the different perspectives and needs of managers in approaching such problems.

The second contribution arrived from the analysis of disruptions occurring at operational level to propose a conceptual framework aiming at supporting decision makers in the recovery from day-to-day disruptive events. We believe that the conceptual model in Figure 4.3 represents a valuable example of how to organise the information, with the specific goal of enhancing the recovery phase during disruptions.

Unfortunately there is no “silver bullet” that allows to associate, all the time, a recovery practice to a certain kind of disruptive event. This depends on a lot of factors such as: access to the information; presence of risk and/or contingency plans; relationships between the firm and its mother company, and consequently autonomy in taking decisions; predilection for the choice of flexible or redundant recovery practices regarding the disruptions management; and contractual constraints/agreements present in the SLAs. Instead it is possible to identify “paths”, it means that for a given type of disruptive event and related cause it is possible to identify a set of recovery practices that can be applied to face it, taking into account the factors mentioned above.

Two complementary examples retrieved from the analysis of the cases and represented in the Figure 4.6, below, should help clarify this aspect.

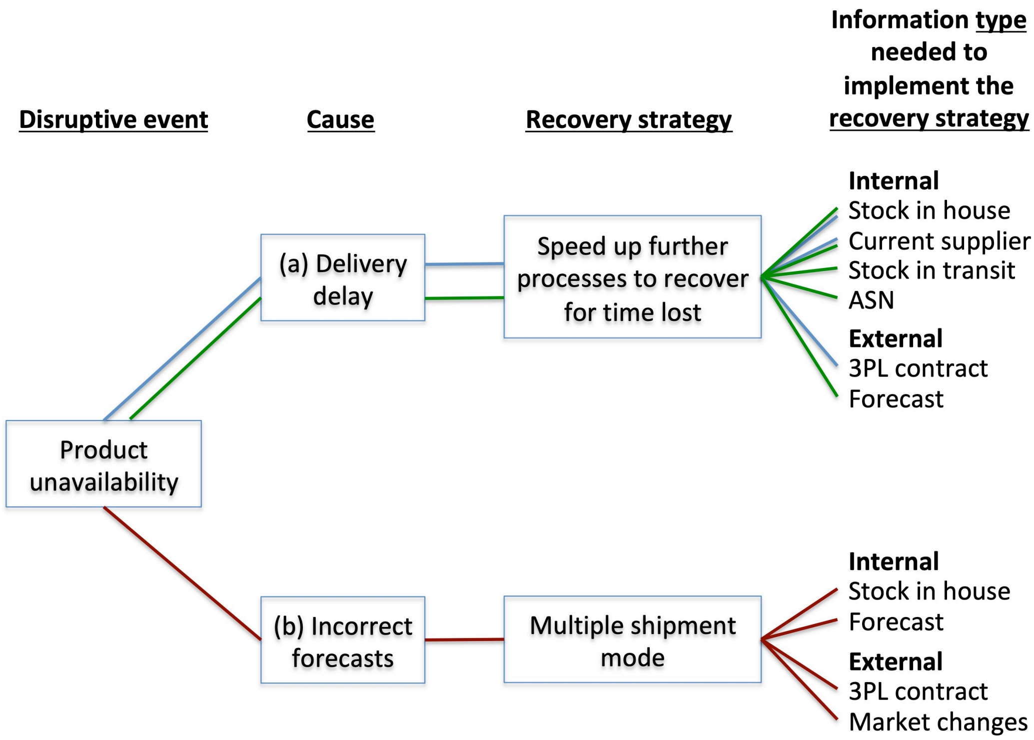

Figure 4.6 Examples of identified "path" retrieved from the cases

The first example, (a), shows that even if the cases suffered the same event and adopted the same strategy to recover from disruption, the types of information needed to implement the recovery strategy are different. On the other hand, the example (b) shows that even though the case suffered the same event of example (a), the cause that led to it, the recovery strategy adopted, and the types of information needed are completely different from the previous case. Therefore, for a given type of disruptive event and related cause we were able only to provide indication about a set of recovery practices that firms belonging to the supply chain can implement to deal with such occurrences.

A better understanding of how firms can manage disruptions and facilitate recovery is vital for both communities. Practical implications were retrieved from the analysis of the cases, that allow confirming the increasing need of visibility in order to enhance resilience.

Chapter 5. Study 2: A quantitative approach to assess supply chain visibility

[This chapter is an adaptation of the following publication:

- Messina, D., Barros, A. C., Soares, A. L. How visible is your supply chain? A quantitative approach to assess supply chain visibility. Submitted to Benchmarking: An International Journal]

5.1 Motivation of the study

Companies need to deal with rising complexity of goods, growing adoption of outsourcing to excel in few core competences, global dispersion of partners, increasingly demanding consumers, and continuous reduction of production costs. A solution to this problem that many researchers and practitioners seem to agree on is supply chain visibility (SCV) (Barratt and Barratt, 2011; Barratt and Oke, 2007; KPMG, 2018; Zhang et al., 2011). SCV refers to the capability of supply chain players to have access to or to provide the required timely information from/to relevant supply chain partners for better decision support (Goh et al., 2009). Researchers and practitioners nowadays recommend a particular type of supply chain visibility, the so-called end-to-end visibility (KPMG, 2016; Somapa et al., 2018). End-to-end visibility is the visibility from supplier's supplier to customer's customer (Martin Christopher and Lee, 2004). Despite being highly recommended, it appears far from achievable, and it is limited, in the majority of cases, to first-tier partners (Caridi et al., 2010a; KPMG, 2018; Somapa et al., 2018). In particular decision makers believe that one of the main aspect that hinders this visibility is the lack of a common SCV metric (Saint McIntire, 2014; Somapa et al., 2018). Other concerns are related to the lack of information coordination and collaboration among supply chain partners (Barratt and Barratt, 2011; Simatupang and Sridharan, 2005; Somapa et al., 2018), and to partners systems incompatibility (Barratt and Barratt, 2011).

Several authors have attempted to provide qualitative and quantitative methods to assess visibility (Barratt and Barratt, 2011; Barratt and Oke, 2007; Brandon-Jones et al., 2014; Caridi et al., 2010b, 2013; Lee and Rim, 2016; Saint McIntire, 2014; Williams et al., 2013; Yu and Goh, 2014b; Zhang et al., 2011) focusing on dyadic or linear supply chains (Caridi et al., 2010a). This is not enough to capture the real complexity of the problem. In this study we describe an approach based on the categories and properties of the information shared between supply chain members, which allows managers to assess the degree of visibility in complex supply chains.

5.2 Literature review on SCV assessment

Although supply chain visibility has been a very welcomed topic both in information management and supply chain management literatures, there is not an agreement about its definition. Many authors approached SCV according to multiple perspectives (Messina et al., 2016), for example, those related to data and information management (Barratt and Barratt, 2011; Barratt and Oke, 2007; Brandon-Jones et al., 2014; Caridi et al., 2010b, 2013; Goh et al., 2009; Goswami et al., 2013; Tohamy et al., 2003; Williams et al., 2013), to supply chain partners' capability (Caridi et al., 2014; Klueber and O'Keefe, 2013; Nooraie and Parast, 2015; Zhang et al., 2011), to supply chain configuration (Caridi et al., 2010a), to the impact it has on business process (Barratt and Oke, 2007; Caridi et al., 2014; Kaipia and Hartiala, 2006; Kim et al., 2011; Lee and Rim, 2016; Saint McIntire, 2014), and to event management (Francis, 2008; McCrea, 2005).

With this panoply of definitions, it is understandable why it is such a hard task for decision makers to find an adequate and effective way to assess visibility. Still, some attempts have been made to evaluate supply chain visibility through the adoption of qualitative and quantitative methods (for an exhaustive review on both methods refer to Somapa et al. (2018)). Two predominant approaches are clear in the literature: the first deals with visibility focusing on the categories and properties of the information shared (Barratt and Barratt, 2011; Caridi et al., 2010b, 2013; Williams et al., 2013; Zhang et al., 2011) while the second focuses on the effects that this exchange of information have on business performance (Barratt and Oke, 2007; Kaipia and Hartiala, 2006; Lee and Rim, 2016; Saint McIntire, 2014). Although presenting different focuses, it is possible to find a common element between these approaches, which represents the key-aspect of information sharing. In line with the first approach, we are interested in analysing supply chain visibility according to the characteristics of the information shared. In this regard, the works of Caridi et al. (2010b) and Zhang et al. (2011)are considered the most relevant when dealing with such aspects (Lee and Rim, 2016; Williams et al., 2013). Caridi et al. (2010b) provided a quantitative model to assess supply chain visibility in complex supply chains (longer than two tiers). Starting from the assumption that the information is accessible for the analysis, the researchers adopted the geometric mean to evaluate the quantity and the quality of four categories of information, namely transactions, status information, master data, and operation plans, in terms of freshness and accuracy (Caridi et al., 2010b, 2014, 2013). In this work, the authors also provide a node weight by combining its localisation from the focal firm with its significance in terms of goods supplied. The study of Zhang et al. (2011), on the other hand, proposes the two capabilities of accessing and providing the available information about the inventory to/from supply chain partners. With this purpose in mind, they tried to quantify inventory visibility (IV) through a mathematical model to support decision-making.

Although these two studies are considered the most relevant in quantifying supply chain visibility, they are not without limitations. The study of Caridi et al. (2010b) assumes that all the information is accessible, which is an aspect that is not always true in reality, and also provides the assessment regarding only inbound supply chain, in spite of the metric being meant for assessing SCV globally. Regarding the study of Zhang et al. (2011), the main limitation appeared to be related to the type of information, given that authors considered only inventory information and also did not take into account the quality.

In order to overcome these limitations, and to maintain the relevance of the metric, we propose an approach based on the categories and properties of the information shared among supply chain partners. In particular, we focus our attention on the following properties of information sharing: accessibility, quantity, and quality of information shared (Barratt and Barratt, 2011; Caridi et al., 2010b, 2013; Williams et al., 2013; Zhang et al., 2011).

5.3 A quantitative approach for supply chain visibility assessment

In complex networks, companies achieve supply chain visibility by taking into account both internal and external visibility. Internal visibility here refers to the visibility that a firm obtains by sharing directly information among its internal functions. On the other hand, external visibility, as it is referred within this context, is the visibility that a firm has over the information shared directly with upstream and downstream partners.

Therefore, in order for decision makers to have a global view of their supply chain, visibility over their internal functions, suppliers, and customers must be considered.

5.3.1 Dimensions of the model

To provide such global view of the supply chain, firms need to exchange different categories of information across it. These categories of information can be grouped into internal and external. Internal information is the information present at firm level or supply chain level gathered from companies' information technology systems, while external information refers to any information related to supply chain environment, and gathered from institutional reports, stock market, public institutions, and consultancy reports, among others (Messina et al., 2016).

We refined the generic categories of Messina et al. (2016), to increase their level of detail and their interpretability, through adoption of terms used by managers in real contexts, which resulted in the following categories of information (I):

Internal

1. **Capacity:** capacity of equipment and manpower to execute extra work;
2. **Production process:** description of the sequence of processes needed to make a product;
3. **Stock level:** level of available inventory in-house, on transit, and backlog;
4. **Supplier/customer order:** refers to both confirmed order and communication of changes to/from the interested parties. For supplier and firm, it includes also forecasts.

External

5. **Geopolitical constrains:** geographical and political conditions where the partners are based, and which can affect the manufacture of the final product;
6. **Track and trace:** capability of a firm to track and trace the position of goods starting from the production line until the delivery to the end-customer;

7. **Logistics service provider contract:** contractual conditions agreed, which linked the firm with logistics service provider, such as carriers;
8. **Supplier/customer contract:** contractual conditions agreed linking the firm and supply chain partners;
9. **Alternative supplier:** alternatives to normal suppliers;
10. **Market changes:** demand fluctuation based on changes in customer's behaviour (for supplier and firm refer to forecasts).

In order to build the metric, the set of information (I) can be split into two subsets according to their accessibility properties, namely accessible information (A) and not accessible information (NA). Thus:

$$I = A \cup NA \quad \wedge \quad A \cap NA = \emptyset$$

Taking into account that supply chain visibility is the consequence of supply chain actors having access to the information, only the accessible information categories (A) need to be taken into account. Therefore, for the analysis:

$$I = A \quad \wedge \quad NA = \emptyset$$

The visibility metric considers two additional properties of the accessible information, specifically quantity and quality (Caridi et al., 2010b, 2013). Quantity refers to the amount of information available that is shared among partners. On the other hand, quality is obtained from the combination of the timeliness (degree to which the information is available on-time) with accuracy (degree to which the information is correct and precise) of the information shared (Barratt and Barratt, 2011; Caridi et al., 2010b, 2013; Kaipia and Hartiala, 2006; Williams et al., 2013). Onwards, information properties such as accessibility, quantity, timeliness and accuracy represent the dimensions of the model. The logic/formulation adopted to conduct the assessment is based on the previously explained work of Caridi et al. (2010b).

5.3.2 Node visibility assessment

Our metric allows decision makers to assess the visibility that any firm has over its supply chain by directly sharing information with their internal, upstream, and downstream partners. In order to use the metric decision makers need to assess the quantity, timeliness, and accuracy of the accessible information, for each node *k* under analysis.

For what concerns the quantity and quality, the afore mentioned dimensions are measured through the adoption of three different four-point Likert scales described in Tables 5.1 (quantity), 5.2 (timeliness), and 5.3 (accuracy). The choice to use an even-numbered Likert scale instead of an odd-numbered one, has been made to avoid the possibility that respondents would choose neutral response, therefore being forced to make a decision among alternatives (Rea and Parker, 2014). The adoption of such quantitative scales represents a trade-off between rigour and usability of the metric because it allows decision makers to formulate their assessment based both on data and on their perception (Caridi et al., 2010b).

Table 5.1 Scale to judge the quantity of the information exchanged among partners

Score	Description
1	Unsatisfactory
2	Most of the time we ask for more information from our partner
3	In some case we ask for more information from our partners
4	Satisfactory

Table 5.2 Scale to judge the timeliness of the information exchanged among partners

Score	Description
1	Unsatisfactory
2	Information is updated only upon request
3	Information is updated most of the time without request
4	Real time

Table 5.3 Scale to judge the accuracy of the information exchanged among partners

Score	Description
1	Only in few occasions
2	Sometimes

3	Most of the time
4	Always

In order to proceed with the assessment, decision makers need to look at their global supply chain, in Figure 5.1, and to identify those nodes with whom they share information, in Figure 5.2.

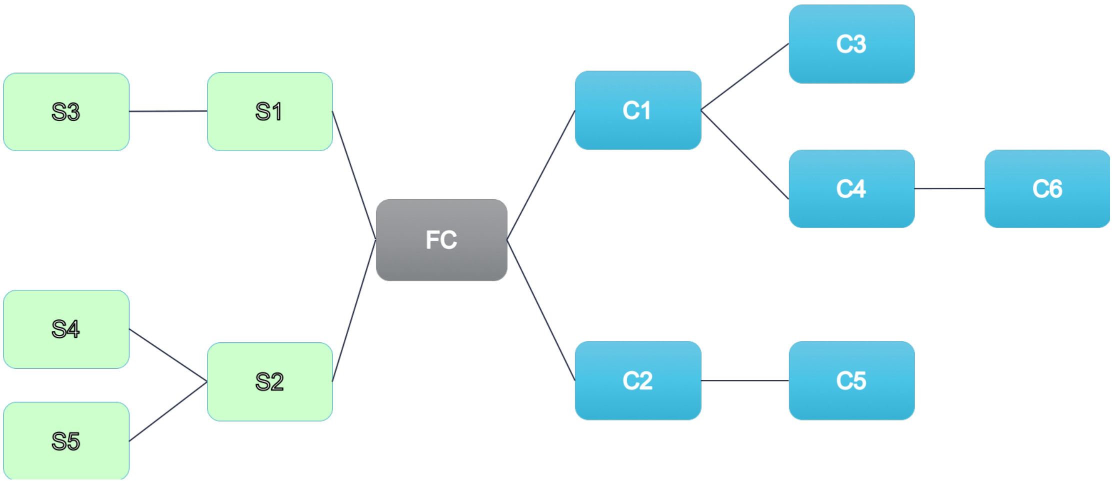

Figure 5.1 Global supply chain

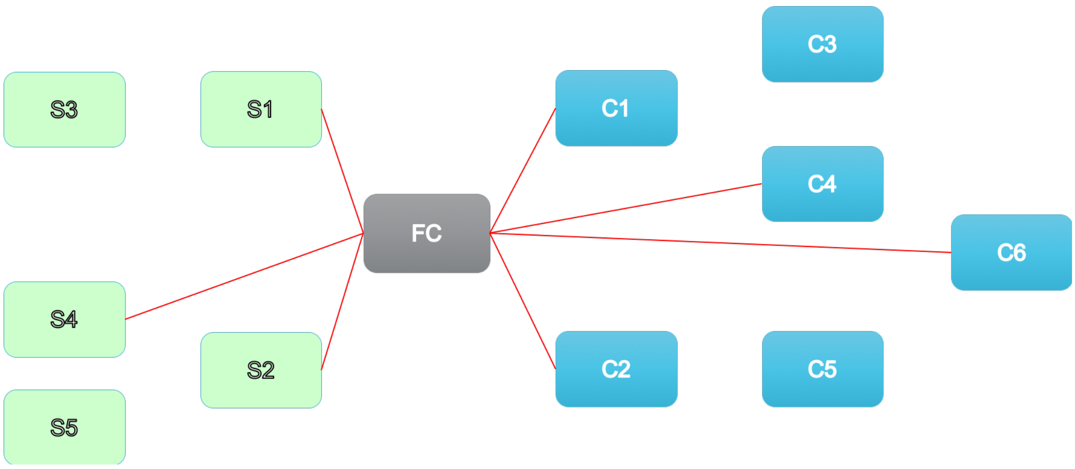

Figure 5.2 Nodes with whom the company shares information directly

At this point, decision makers proceed with the assessment of the three dimensions of the model for those nodes to which they share directly information, following the notation in Table 5.4.

Table 5.4 Notation for visibility assessment

	I									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Quantity	$A_{q,1}$	$A_{q,2}$	$A_{q,3}$	$A_{q,4}$	$A_{q,5}$	$A_{q,6}$	$A_{q,7}$	$A_{q,8}$	$A_{q,9}$	$A_{q,10}$
Timeliness	$A_{t,1}$	$A_{t,2}$	$A_{t,3}$	$A_{t,4}$	$A_{t,5}$	$A_{t,6}$	$A_{t,7}$	$A_{t,8}$	$A_{t,9}$	$A_{t,10}$

Accuracy	$A_{a,1}$	$A_{a,2}$	$A_{a,3}$	$A_{a,4}$	$A_{a,5}$	$A_{a,6}$	$A_{a,7}$	$A_{a,8}$	$A_{a,9}$	$A_{a,10}$

After all the individual assessments have ended, it is possible to combine them through the use of geometric means, which results in an overall assessment of each of the three dimensions. The elementary visibility indices are presented in Table 5.5.

Table 5.5 Elementary visibility indices at node level

Index	**Formula**
Total amount of visible information	$\text{Visibility\_quantity}_k = \sqrt[n]{\prod_{i=1}^{n} \text{Aq, i}}$
Timeliness of the visible information	$\text{Visibility\_timeliness}_k = \sqrt[n]{\prod_{i=1}^{n} \text{At, i}}$
Accuracy of the visible information	$\text{Visibility\_accuracy}_k = \sqrt[n]{\prod_{i=1}^{n} \text{Aa, i}}$
Total quality of visible information	$\text{Visibility\_quality}_k = \sqrt{\text{Visibility\_timeliness}_k * \text{Visibility\_accuracy}_k}$
Overall visibility of category *i* information	$\text{Partial\_visibility}_{i,k} = \sqrt[3]{\text{Aq, i} * \text{At, i} * \text{Aa, i}}$

Where *i* represents the category of information accessible, and *n* represents the total number of accessible categories of information. At this point the overall visibility of the node *k* can be calculated:

$$\text{Overall\_visibility}_k = \sqrt{\text{Visibility\_quantity}_k * \text{Visibility\_quality}_k}$$

Taking into account the assessment of the individual dimensions of the model, the perceived visibility level can range between 1 and 4. Consequently, we define three levels of visibility: low ($1 \leq$ visibility level <2), medium ($2 \leq$ visibility level <3), and high ($3 \leq$ visibility level ≤ 4). To improve the results readability, it is also possible to associate a heat map to the different visibility level, as presented in Figure 5.3.

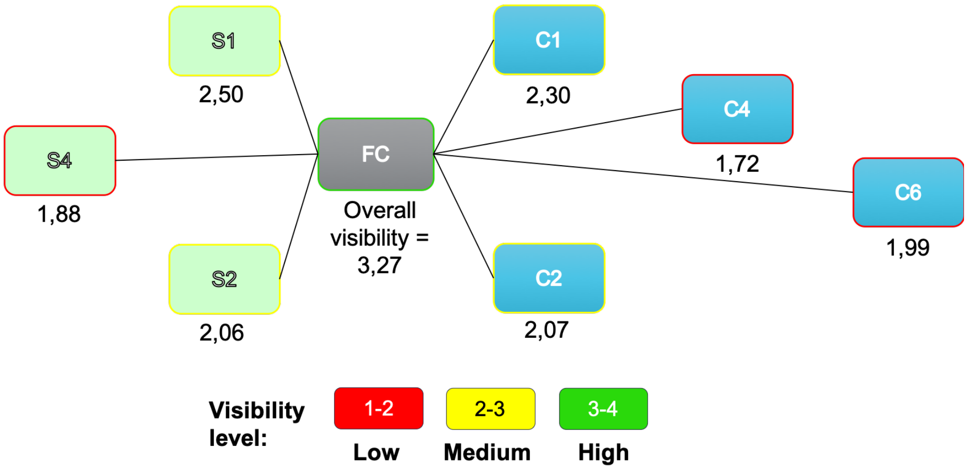

Figure 5.3 Example of nodes overall visibility assessments

For diagnostic purpose, decision makers can use this overall visibility index to identify the nodes where improvement actions are needed. It is also possible to obtain a more fine-grained analysis by comparing the visibility of different categories of information, last row in Table 5.5.

Once all nodes have been assessed, two global visibility measures can be obtained as averages of the visibility at node level for each group, namely upstream and downstream. The two visibility indices are reported in Table 5.6.

Table 5.6 Upstream and downstream visibility indices

Index	**Formula**
Overall visibility of upstream partners	Upstream_visibility= $\frac{1}{NU}\sum_{k=1}^{NU} \text{Overall\_visibility}_k$
Overall visibility of downstream partners	Downstream_visibility= $\frac{1}{ND}\sum_{k=1}^{ND} \text{Overall\_visibility}_k$

Where *NU* is the number of nodes of upstream partners, and *ND* is the number of nodes of downstream partners. Decision makers can use these latter indices for benchmarking with competitors or with companies belonging to similar sectors.

5.4 Results

The main goal of this phase was to test the effectiveness of our quantitative approach, while at the same time allowing us to have some clues about the applicability in real settings.

Table 5.7 summarises the numerical results obtained when applying the quantitative approach to the sample, while the following Figures (5.4, 5.5, and 5.6) show the same results in an illustrative way.

Table 5.7 Empirical results

Case code	Partner assessed	Visibility index					
		Quantity	Timeliness	Accuracy	Quality	Overall	Global
A	Suppl_1	2.29	1	1.26	1.12	1.6	2.65
	Suppl_2	3.03	3.03	2.3	2.64	2.83	
	Suppl_3	2	1.41	1.73	1.56	1.77	
	Suppl_4	3.46	3.46	4	3.72	3.59	
	Suppl_5	3	4	4	4	3.46	
	Internal	3.4	3.4	3.54	3.47	3.43	3.43
B	Supplier	2.45	2	3	2.45	2.45	2.45
	Internal	4	4	3	3.46	3.72	3.72
	Customer	2.7	3.15	2.62	2.87	2.78	2.78
C	Suppl_1	3.56	2.35	3.56	2.89	3.21	3.12
	Suppl_2	3.56	2.35	3.36	2.81	3.16	
	Suppl_3	3.1	2.35	3.56	2.89	2.99	
	Suppl_4	3.56	2.55	3.78	3.1	3.32	
	Suppl_5	3.1	2.17	3.56	2.78	2.93	
	Suppl_6	3.78	2.77	3.78	3.23	3.49	
	Suppl_7	2.63	2.21	2.91	2.54	2.58	
	Suppl_8	3.56	2.35	3.56	2.89	3.21	
	Suppl_9	3.56	2.35	3.56	2.89	3.21	
	Internal	2.77	2.17	2.17	2.17	2.45	2.45
	Customer	3.09	2.75	3	2.87	2.98	2.98

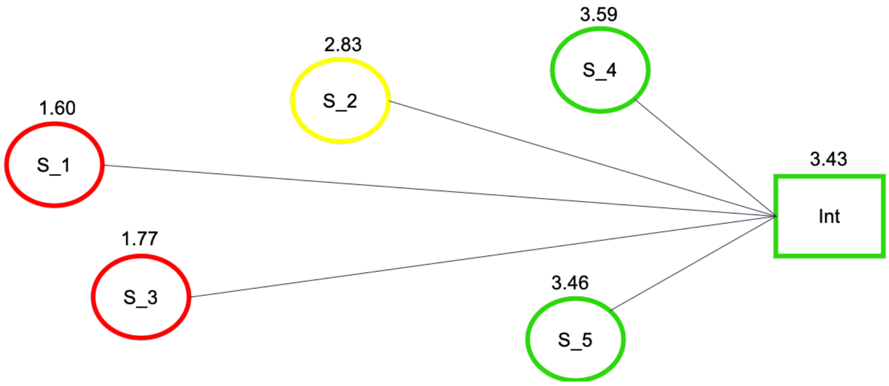

Figure 5.4 Case A results

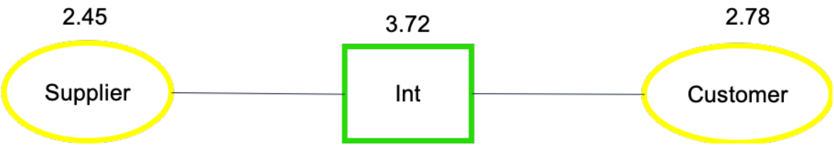

Figure 5.5 Case B results

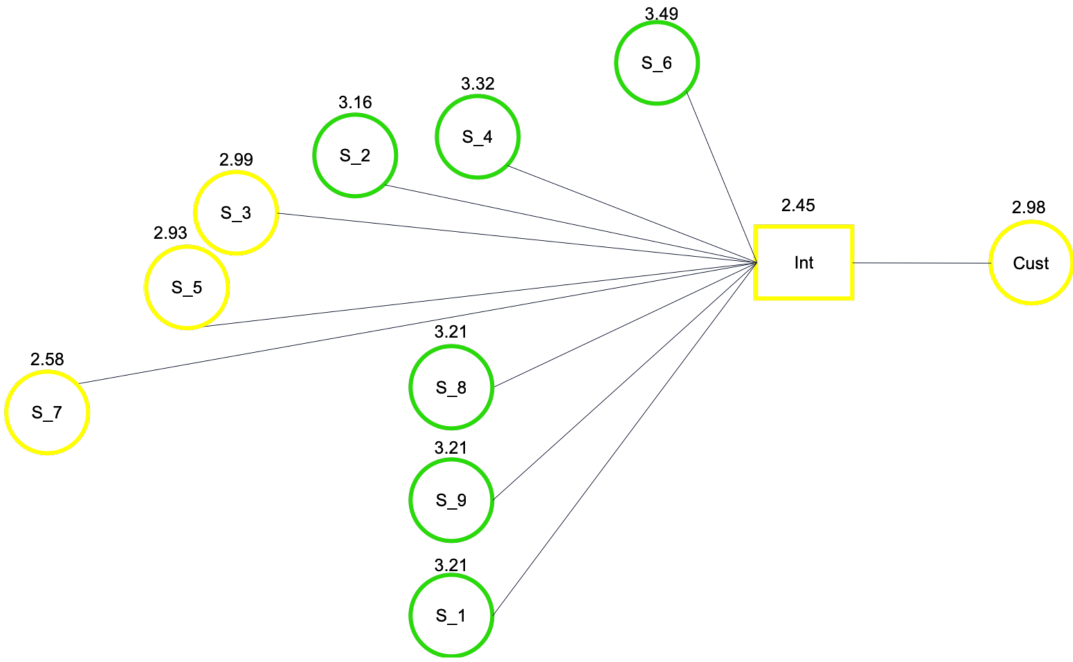

Figure 5.6 Case C results

Since we were able to analyse only three cases, the results are not robust enough to be generalised. However, they present some preliminary insights about the applicability of the metric for diagnostic purposes.

Firstly, it provides decision makers with a quick overview of the visibility level over their supply chain partners. All the cases showed a medium-high level of global visibility. Nevertheless, it is possible to observe that suppliers 1 and 3 are the two that demonstrated lowest levels of visibility when compared to other partners belonging to its upstream supply chain, as exemplified by Case A. Therefore, in this case, decision makers should focus their attention on improving the overall visibility of the two suppliers.

Secondly, it provides indications to identify which dimension of the accessible information should be improved in order to enhance the overall visibility of the node of interest. Continuing with the previous example, at this point, decision makers should analyse solutions to improve the timeliness, which is dimension that demonstrated lowest visibility level, and which can be achieved either alone or involving the interested partner (in this case Supplier 1). In this regard, the metric could also be used to conduct a more fine-grained analysis in order to identify the category of information showing the lowest timeliness value.

Thirdly, the metric can be used for benchmarking purposes aimed at analysing whether partners belong to the same supply chain, as showed previously, to a different one, or even if the same partner belongs to multiple supply chains.

Finally, the managers involved in the study evaluated the results of the study accurate and conform to their perceptions. The approach proved to be easy to use and not time consuming. However, the most useful aspect of the approach, according to managers, is that it is able to show the weaknesses of the supply chain according to different levels of detail. This allows decision-makers to take targeted actions aimed at increasing the visibility level of their partners, and, therefore, of the entire supply chain.

5.5 Discussion

Results confirmed that end-to-end visibility is far from being achieved and that visibility is still limited to first-tier partners. This can be traced back to an inadequate collaborative environment in which partners do not feel comfortable to share sensitive information.

This aspect confirmed our choice to take into account the accessibility property of information. Information accessibility is crucial and should not be taken for granted, as in Caridi et al. (2010b). Related to the information categories, we also extended the two works analysed (Caridi et al., 2010b; Zhang et al., 2011) by providing a more detailed and completed set of internal and external information categories.

Finally, our model showed its capability to accommodate supply chain problems by considering both the supplier and the customer sides, aspect that end up to not being addressed in the work of Caridi et al. (2010b). The model we propose has been developed to include also supplier’s supplier and customer’s customer in the analysis.

5.6 Concluding remarks

This study provides a quantitative approach aiming at assessing partners visibility level in order to support decision makers actions to enhance overall supply chain visibility. Also, it provides several contributions to practitioners and researchers communities.

The main contribution is the visibility assessment by means of a quantitative approach. This represents a first attempt to provide a conceptualisation of visibility in supply chain for enhanced decision-making. In particular, the originality of this approach is that it allows for an analysis of the supply chain partners based on the properties and categories of information shared. Although the cases under analysis were able to assess only first-tier partners, the approach is flexible enough to be adapted for considering supplier's supplier and customer's customer. Furthermore, its application is the first in the literature to assess all supply chain sides, namely upstream, internal, and downstream.

Moreover, the visibility indices obtained represent valuable tools to support decision makers in identifying the weak points within the chain, and to guide their actions to improve the visibility levels. Decision makers can also use the tools for benchmarking purposes, within the same supply chain or among supply chains, or to compare visibility levels before and after the implementation of actions aiming at improving the global visibility. These indices can be easily included into a company scorecard or used as key performance indicator (KPI).

The main limitation of this study is related to the small number of cases analysed, which did not allow to generalise the results obtained. Also, the lack of weight to differentiate the different partners does not allow to consider critical situations, such as the absence of an alternative partner or of a substitute product. Further research should point towards these directions in order to increase the robustness of the proposed approach. Also, the application of the approach in different manufacturing sectors could highlight any aspect that may influence the global level of visibility.

Chapter 6. Conclusions

This chapter summarises the results obtained in the previous chapters and presents the main contributions achieved during this thesis. More specifically, it begins with a recapitulation of the main findings and addresses the research questions posed in Chapter 1. Afterwards, the major academic contributions and the most relevant managerial implications are delineated. Finally, limitations and directions for future work are proposed.

6.1 Main findings

As described in Chapter 1, in the last years a growing number of academics and practitioners showed their interest in supply chain risk and disruption related issues due to the combination of two factors: (1) an increasing intensity and frequency of supply chain exposure to disruptions on a global scale, and (2) a turbulent context characterised by the adoption of outsourcing, global dispersion of partners, increasingly demanding consumers, and continuous reduction of production costs.

In Chapter 2, a literature review of the existing research was performed, which considered the past 15 years in the fields of Information Management, Supply Chain Visibility, Supply Chain Risk and Disruption Management, and was aimed at identifying the challenges for information management when applied to supply chain management processes and related decisions. This study concluded that there still no clarity on the adoption of the terms representing the pillars of this work, among researchers and practitioners. Moreover, studies addressing the identification of information categories needed to manage such complex networks and the information management model at support are also scarce within the literature. Therefore, the main objective of this doctoral thesis was to study how supply chain managers exploit information management processes to support risks and disruptions related decisions, in order to design information management solutions that may enhance visibility aimed at dealing with such disruptions in complex supply chains.

Based on the results obtained in Chapter 2, we started setting the base for the development of our first artefact. In fact, we proposed a more fine-grained version of information management model, when compared to the few examples found in the literature, and which served as starting point for the subsequent Study 1.

In Chapter 4, the first exploratory case research (Study 1) has been conducted through interview of 17 managers, all of which involved in different company duties, from three firms belonging to the vehicle assembly sector. The objective of Study 1 was to identify and analyse the actions taken and the information used by decision makers during and after disruptive events in order to improve the disruption management process. Another objective was to start designing and testing the first two artefacts, namely an information management model for enhanced visibility and a conceptual model to support recovery practice selection. Findings showed that companies have to adopt many different IT solutions to cope with the incompatibility of partner' systems, and that these systems still failing to provide the required visibility, both internal and external, which is needed to deal with supply chain disruptions. Also, the non-systematisation of past occurrences led to ineffective recovery practice selection.

Finally, in Chapter 5, the second case study (Study 2) has been performed by asking three managers of three different companies in the vehicle assembly sector to assess the partners' accessible information based on three properties: quantity, timeliness, and accuracy. The objective of Study 2 was to study the effects that the above information properties shared among partners had on the resulting visibility assessment. Another objective was to start the design and test of our third and last artefact, a quantitative approach aimed at assessing partners visibility level in order to support decision makers actions, which would enhance overall supply chain visibility. Results of the study allowed us to test the effectiveness of the approach, and at the same time provided some hints about its applicability in real settings. In particular, the approach showed its potential as a valuable tool to support decision makers in identifying the weak points in the chain, and to guide their actions to improve the visibility levels.

At the end of this thesis we are finally able to answer our research questions:

RQ1: How to design an information management model to support the disruption recovery process in supply chains?

A: Disruptive events are non-routine situations that generate huge level of stress and that require extra efforts to be addressed. In addition, results of the cases showed that decision makers have to deal with: (i) a panoply of information systems to overcome partners' systems incompatibility problems, and (ii) the absence or not completeness of risk and contingency plans to use as guidance. This led to the fact that decisions were made more often based on experience than on the data.

Therefore, to design a reference information management model (in section 2.4.2), or more in general, an information management solution, it is mandatory to take into account these aspects. Additionally, in order to provide decision makers with an overview of their supply chain, such solutions should be flexible enough to accommodate the different information needs of partners in different positions in the supply chain (multi-viewpoint property), and to aggregate the internal and external information shared among partners (multi-perspective property). Also, information should be organised according to the conceptual model (in Figure 4.5) proposed in order to enhance the recovery from disruptive events and to return to the normal conditions as fast as possible.

RQ2: How to improve the visibility that a company has over its supply chain?

A: Results of the cases showed that companies' visibility are still limited to first-tier partners. On the one hand, in order to improve the overall level of supply chain visibility, companies should foster collaboration by providing a secure environment where partners are more willing to share larger volumes of information and with higher quality. This should hinder opportunistic behaviour of partners and avoid overloading the systems with information with scarce relevance.

On the other hand, in order to increase the visibility level of a specific partner, managers can implement actions aimed at improving the properties of the information shared. In this regard, the proposed approach (in section 5.3) can be used by decision makers both to quickly identify those nodes that show the lowest level of visibility and also to evaluate and compare the actions undertaken in terms of increased visibility.

6.2 Main contributions

This doctoral project has generated several contributions, both for academics and practitioners. It contributes to the areas of Information Management and Supply Chain Management by bringing clarity regarding the main concepts representing the pillars of this research, while ensuring consistency in their adoption. Also, we provide a characterisation of the external and internal information flows that decision makers need for managing risk related situations in complex supply chains. Finally, we propose a more fine-grained information management model compared to the other in the literature that represents the basis for the development of our first artefact.

We also contribute to the area of Supply Chain Disruption Management by studying how decision makers manage the information to achieve improved visibility in order to effectively apply recovery strategies during disruptive events. Contributions to scientific knowledge are related to a better understanding of how firms can manage disruptions and facilitate recovery phase. We also shown an application of the first two artefacts designed during this doctoral thesis. The information management model should support decision makers along the information lifecycle to provide enhanced visibility, and a characterisation of each stage of the model for disruption purpose is provided. The conceptual model, on the other hand, should support decision makers in organising the information for recovery from operational disruptions. Also in this case, we were able to characterise the different blocks with disruption information retrieved from the case studies.

Additionally, related to the area of Supply Chain Visibility we contribute by studying how decision makers assess the information shared directly with partners. Contribution to scientific knowledge is related to a conceptualisation for those researchers interested in analysing visibility, considering the categories and properties of the information shared. We propose a quantitative approach that supports decision makers in assessing partners' visibility level, the third and last artefact developed during this thesis. Moreover, we shown two applications of the approach as a diagnostic tool to identify the weakest node and provide guidance to enhance the current visibility level, while also being used as benchmarking tool to compare firms belonging to the same supply chains or to different ones.

Furthermore, its application is the first in the literature to assess all supply chain sides, namely upstream, internal, and downstream.

Finally, contributions related to information processing theory are threefold. By adopting IPT to our context we extended the theory, originally developed to be applied to face intra-organisation problems, to accommodate both information processing capabilities and information processing needs to face disruptions at supply chain level. On the one hand, we contribute to information processing needs by developing our information management model that allows to bring clarity on the information lifecycle and to provide the visibility necessary in order to reduce uncertainty and so to reduce the possibility of being exposed to supply chain disruptions. On the other hand, we contribute to information processing capabilities by developing both our information management model and our conceptual model. In fact, the information management model should provide the rationale to improve the management of the single stages characterising the information lifecycle especially related to the capability of decision makers to gather and process the information, while the conceptual model should allow to improve the decision makers capability to act upon the information related to disruptive events in particular to select the most suited recovery practices to deal with that.

Overall, this doctoral thesis represents a first attempt to approach supply chain risk and disruption related problems by adopting an information management's perspective. The results of this doctoral project led to the following research outputs, in Table 6.1.

Table 6.1 Doctoral thesis research outputs

International peer-reviewed journals
• **Messina, D.**, Barros, A. C., and Soares, A. L. (?) How visible is your supply chain? A diagnostic metric to assess supply chain visibility. Submitted to Benchmarking: An International Journal • **Messina, D.**, Barros, A. C., Soares, A. L., and Matopoulos, A. (?) An information management approach for supply chain disruption recovery. First revision submitted to International Journal of Logistics Management
Book chapters
Messina, D., Santos, C., Soares, A. L., and Barros, A. C. (2016). Risk and Visibility in Supply Chains: An Information Management Perspective. In *Handbook of Research on Information Management for Effective Logistics and Supply Chains* (Vol. i, pp. 34–57). IGI Global. https://doi.org/10.4018/978-1-

5225-0973-8
International conferences

- **Messina, D.**, Barros, A.C. and Soares, A.L. (2018). How much visibility has a company over its supply chain? A diagnostic metric to assess supply chain visibility. In 22nd Cambridge International Manufacturing Symposium, 27–28 September 2018, Cambridge, UK.
- **Messina, D.**, Barros, A. C. A. C., and Soares, A. L. (2016). An Information Management Perspective of Supplier Selection Process in Manufacturing Networks. In *Working Conference on Virtual Enterprises* (Vol. 480). Springer International Publishing. https://doi.org/10.1007/978-3-319-45390-3_16
- **Messina, D.**, Santos, C., Barros, A. C., and Matopoulos, A. (2015). Who monitors the supply chain? An arm-wrestle between OEM and first-tier supplier. In *22nd International Annual EurOMA conference, Neuchâtel, Switzerland.* (pp. 1–9). Neuchâtel, Switzerland.

6.3 Limitations and future work

As any empirical research, this dissertation is not without limitations. Therefore, in this section we want to provide future research directions in order to overcome them. The main limitation of this work is related to the exiguous number of cases we were able to conduct in both studies, which restricted the generalisation of the results obtained. Data collection was very challenging especially in the beginning of this work. Some aspects that motivated this difficulty can be traced to the characteristics of the sector under analysis. In fact, vehicle assembly is a conservative sector for what concerns data accessibility, mainly due to information sensitivity and to partnership with government departments. Future researches and studies should focus on both increasing the numbers of cases and determining to what extent supply chain visibility is necessary for improving supply chain disruption management process.

Some limitations can be pointed out regarding the design and test of the artefacts. In addition to the difficulty of accessing data, as explained above, time restrictions further hindered our ability to exploit the full potential of our artefacts. Regarding the information management model, despite being able test its multi-perspective property, we were not able to fully test its multi-viewpoint property. Thus, future research should aim firstly at including the missing viewpoints, namely lowest tier suppliers and customer(s), and conduct tests in a supply chain including all the main partners.

For what concerns the conceptual model, compared to the original plans, we were not able to associate any data regarding the financial impact of the different disruptions, nor those related to the extra-cost required to implement the different recovery practices. Further research in this direction should contribute to provide a more complete picture about the adoption of the model in order to support decision makers in the “static mode”. At this point, researchers in the area of data science or company’s developers could implement and train the model in order to provide disruption recovery aggregator and meta-search engine, such as the one developed for the selection of hotels and flights, which could support decision makers in the “dynamic mode”.

Finally, the main limitation of the quantitative approach is the lack of weight for partner differentiation. Moreover, this aspect does not allow us to take into account critical situations, such as the absence of an alternative partner or of a substitute product. Further studies should point in these directions to increase the robustness of the proposed approach.

Despite these limitations, we are confident about the quality of the cases selected to conduct this work and we believe that this doctoral thesis has generated several contributions for academics and practitioners interested in solving risk and disruption related problem through a more effective information management.

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Appendix A

Informed consent and interview protocol:

A-1 - Informed consent (in Portuguese):

Título do estudo: An information management approach for supply chain disruption recovery

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Objetivo
Pretende-se estudar como a gestão da informação pode levar a uma visibilidade alargada sobre os processos da cadeia de abastecimento de uma empresa de forma a melhorar a tomada de decisão relativa à gestão de disrupções operacionais.

Procedimentos
A recolha de informação para este estudo será realizada através de entrevistas com gestores de empresas de montagem de veículos.

As entrevistas terão uma duração de 30-45 minutos, e serão realizadas nas instalações onde os entrevistados desempenham a sua função ou via software de videoconferência. No início da entrevista, será solicitado aos entrevistados que (1) assinem o seguinte formulário de consentimento, que demonstra o seu conhecimento sobre os objetivos do estudo, e (2) confirmem a sua permissão para gravação da entrevista de forma a garantir maior precisão das informações divulgadas. Os entrevistados serão informados que eles tem o direito de solicitar a interrupção da gravação da entrevista a qualquer momento para fazer uma declaração que não conste nos arquivos.
As entrevistas serão transcritas e codificadas de forma a extrair-se informações relevantes para a investigação. Apenas os membros da equipa de investigação terão acesso às gravações.

Perfil dos Entrevistados
Gestores de compras, vendas, produto e sistemas de informação de empresas de montagem de veículos.

Confidencialidade
Ao participar deste estudo, compreende e concorda que a sua confidencialidade será mantida da seguinte forma:

Os seus dados e o formulário de consentimento serão mantidos em separado. O seu

consentimento será mantido em um local fechado nas propriedades do INESC TEC e não será divulgado a terceiros. Ao participar do estudo, compreende e concorda que os dados e informações recolhidos durante o estudo poderão ser usados pelo INESC TEC para publicações e/ou divulgados pelo INESC TEC a terceiros. No entanto, o seu nome, morada, contactos e outras informações pessoais descritas no seu formulário de consentimento não serão mencionados pelo INESC TEC em qualquer publicação ou material de disseminação da investigação e/ou seus resultados.
Os investigadores seguirão as seguintes medidas para proteger as identidades dos participantes deste estudo: (1) será atribuído um número ou código a cada participante; (2) os investigadores guardarão todos os dados recolhidos durante o estudo por número ou código, não por nome; (3) todas as gravações originais e ficheiros de dados serão armazenados num local seguro, com acesso restrito apenas aos investigadores autorizados.

Permissão Opcional
Concordo que os investigadores procedam à gravação da entrevista para garantir maior precisão das informações divulgadas.
Por favor rubricar aqui: _______ SIM ________NÃO

Direitos
A sua participação é voluntária. Poderá interromper a sua participação a qualquer momento. A sua recusa em participar ou a revogação do seu consentimento ou participação descontinuada no estudo não resultará em qualquer penalidade ou perda dos benefícios ou direitos a que teria direito.
Caso tenha alguma dúvida sobre o estudo, tem a abertura para fazer as perguntas neste momento. Caso venha a ter alguma dúvida mais tarde ou desejar mais informações, por favor contacte o Investigador líder de acordo com as informações de contato listadas na primeira página deste consentimento.

Consentimento voluntário
Ao assinar no campo abaixo, concorda que as informações descritas acima lhe foram explicadas e todas as suas perguntas foram respondidas e que aceita participar neste estudo.

_______________________________________ _____________________________

ASSINATURA DO PARTICIPANTE DATA

Eu certifico que expliquei a natureza e o propósito deste estudo de investigação e discuti potenciais benefícios ou riscos inerentes à participação no estudo. Qualquer questão colocada pelo participante foi respondida e questões futuras acerca do estudo serão igualmente esclarecidas pelos investigadores.

_______________________________________ _____________________________

ASSINATURA DO INVESTIGADOR DATA

A-2 - Interview protocol:
Information management model for disruption recovery:

- How do you define a disruption?
- Could you describe to us two examples of severe disruptions that your company experienced?
    - What happened?
    - Please describe the possible causes of this disruption.
    - How did it affect your organization (in terms of costs, time, relationship with your SC partners)?
    - How did you find out that you were facing a disruption? What was the time lag between disruption starts and its discovery?
- What types of information did you use to manage the disruption? What information would have been useful if available?
- Did your system have access to this information automatically (sensing)?
- How was this information generated/created?
    - From internal sources?
    - From external sources?
- How was this information loaded into the system?
- How is this information structured and organised within the system in order to be easily retrieved (from different partners)?
- Where and how do you store the information gathered? Once entered in the system who is the responsible to maintain this information?
- How is this information presented to the user?
- How is the information shared within the company and among key partners? Who has access to it?
- What actions were taken to recover from the disruption? (Do you keep a "procedure" register? Who is in charge to maintain it updated?) What types of information did you need to select the recovery practice? What information would have been useful if available?
- What changes have been implemented after the recovery to reduce the risk of happening again?

- Do you use a risk management process? Can you describe it for us, please?
- Do you have any information system to support this process?

A-3 - Interview guidelines (general):

Guidelines		
Target interviewee: **Interview duration:**		
Introductory questions:		
Date of interview Interviewee's role Interviewee's role description		
Main questions to interviewee	**Categories and sub-categories**	**Answers**
Information Management Model		
1. What types of information did you use to manage the disruption? What information would have been useful if available?		
2. Did your system have access to this information automatically (sensing)?		
3. How was this information generated/created? • From internal sources? • From external sources?		
4. How was this information loaded into the system?		
5. How is this information structured and organised within the system in order to be easily retrieved (from different partners)?		
6. Where and how do you store the information gathered? Once entered in the system who is the responsible to maintain this information?		
7. How is this information presented to the user?		
8. How is the information shared within the company and among key partners? Who has access to it?		

9. What types of information did you need to select the recovery practice? What information would have been useful if available?		
Supply Chain Risk and Disruption Management		
10. How do you define a disruption?		
11. Could you describe to us two examples of severe disruptions that your company experienced?		
• What happened?		
• Please describe the possible causes of this disruption.		
• How did it affect your organization (in terms of costs, time, relationship with your SC partners)?		
• How did you find out that you were facing a disruption? What was the time lag between disruption starts and its discovery?		
12. What actions were taken to recover from the disruption? (Do you keep a "procedure" register? Who is in charge to maintain it updated?)		
13. What changes have been implemented after the recovery to reduce the risk of happening again?		
14. Do you use a risk management process? Can you describe it for us, please?		
15. Do you have any information system to support this process?		
Request for information		
Additional documents at support		

A-4 - Interview guidelines with excerpts retrieved from WingCo's interviews:

Guidelines		
Target interviewee: IT Manager, Purchasing Manager, Avionic Material Planning Manager, Non-avionic Purchasing Manager and Logistic Manager **Interview duration:** 43-49 minutes		
Introductory questions:		
Date of interview: 12th of April 2017 Interviewee's role Interviewee's role description		
Main questions to interviewee	**Categories and sub-categories**	**Answers**
Information Management Model		
1. What types of information did you use to manage the disruption? What information would have been useful if available?	Internal • Order External • 3PL	*SAP has all the information related to a [supplier delivery] delay that can affect the production or the assembly;* [...] *I am responsible for all the contracts with suppliers and service providers;* *We do not need additional information aside the one in the systems*
2. Did your system have access to this information automatically (sensing)?	Internal • Automatic	*Yes, the system detects automatically the [internal] information, and then I share it with partners;* *MC is responsible for all the external information*
3. How was this information generated/created? • From internal sources? • From external sources?	Internal • Product • Inventory Internal support systems and tools • Formal	*New information is created to align production plans and inventory;* *I use [internally] primarily the ticket platform;* *We do not have any system that allows us*

		to manage the information coming from external sources […] MC is deputed to manage such information [from external sources]
4. How was this information loaded into the system?	Mother company role Internal support systems and tools • Formal External support systems and tools • Informal	*Wing_MC is responsible for the information entered into our systems;* *Purchasing order comes through ERP, with purchase requisition for the buyer;* *[External] information reaches my own account. I verify the information, then I have to put it in an excel file and load it into the system*
5. How is this information structured and organised within the system in order to be easily retrieved (from different partners)?	Information organisation Information retrieval	*The information is classified and retrieved by purchasing order*
6. Where and how do you store the information gathered? Once entered in the system who is the responsible to maintain this information?	Information storage Information maintenance	*The information is internally stored. The manager is also responsible to maintain it updated*
7. How is this information presented to the user?	Information system features Decision-making based on experience	*The information is processed through graphics related to the analysis of the tickets;* *We are so in rush that the management of the different tasks we are involved happens based on the experience*
8. How is the information	Internal support systems	*Internally the*

shared within the company and among key partners? Who has access to it?	and tools • Informal External support systems and tools • Informal	*information is shared informally [chat and e-mail] among colleagues. No external communication aside with MC through e-mail*
9. What types of information did you need to select the recovery practice? What information would have been useful if available?	Internal Wanted	*We have multiple suppliers for the same [non-airplane] parts;* *I would like to have more visibility over the information available*
Supply Chain Risk and Disruption Management		
10. How do you define a disruption?		*What can lead to a disruption in my work is the lack of a spare part or the unavailability of a machine that is under maintenance*
11. Could you describe to us two examples of severe disruptions that your company experienced?		
• What happened?	Disruptive event	*The production line was on hold for the lack of spear parts*
• Please describe the possible causes of this disruption.	Internal	*The information loaded into the system was incorrect*
• How did it affect your organization (in terms of costs, time, relationship with your SC partners)?	Qualitative assessment	*We evaluate disruption's impact in a qualitative manner*
• How did you find out that you were facing a disruption? What was the time lag between disruption starts and its discovery?	Automatic • Completely • Partially Manual	*The system alerts me of the presence of a disruption but then I have to query the system for more details*
12. What actions were	Flexible practices	*I had to retrieve the*

taken to recover from the disruption? (Do you keep a “procedure” register? Who is in charge to maintain it updated?)	• Postponement;	*missing part from another machine. At this purpose, we generally use machine of the same brand*
13. What changes have been implemented after the recovery to reduce the risk of happening again?	Action • Update of existing plans • Follow-up with problematic suppliers • Changes to improve processes or tools	*I try to put in place actions to improve the problematic processes*
14. Do you use a risk management process? Can you describe it for us, please?	Absent	*We do not have a formal risk management process*
15. Do you have any information system to support this process?	Internal support systems and tools	*I am not sure, Wing_MC is responsible for risk management process*
Request for information		
Additional documents at support: Two interviewees showed us how their systems work		

A-5 - Interview guidelines with excerpts retrieved from TruckCo's interviews:

Guidelines		
Target interviewee: Order and Outbound Logistic Manager, Maintenance and Facility Manager, Production Manager, Inventory Manager, Production Planning and Outbound Logistic Manager, Procurement Manager, Warehouse and Internal Logistic Manager, Supplier Manager **Interview duration:** 51-64 minutes		
Introductory questions:		
Date of interview: 17th – 18th of April 2017 Interviewee's role Interviewee's role description		
Main questions to interviewee	**Categories and sub-categories**	**Answers**
Information Management Model		
1. What types of information did you use to manage the disruption? What information would have been useful if available?	Internal External • Market	*I need all the information about the equipment and related maintenance plans, it means preventive, predictive and corrective, but also about contingency plans;* *I monitor the [external] information related to market changes that can affect my work;* *It would be useful to have the information related to the bill of material (BOM), and the difference between physical and virtual level of stock 100% reliable*
2. Did your system have access to this information automatically (sensing)?	Internal • Manual External • Automatic	*Truck_MC1 provides a system that detects disruptions, but the user needs to look for it, it is not automatically alerted;* *We are also developing tools that allow to take into account global situation (such*

		as level of risk of the country in which the supplier is installed, financial stability, partnerships etc.)
3. How was this information generated/created? • From internal sources? • From external sources?	Internal • Product Internal support system and tools • Formal External External support systems and tools • Formal • Informal	*IBM AS/400 system supports the production process (production plan, entry/exit point, and all the information related to product);* *External information is created when forecasts are updated;* *Once the problem is identified, we have the support of an external subcontractor to verify our physical stock;* *External support is provided via e-mail, and EDI*
4. How was this information loaded into the system?	Mother company role Internal support system and tools • Formal External support systems and tools • Formal	*Truck_MC1 is responsible for the information [present in the system] related to EU market while Truck_MC2 is responsible for the information about non-EU market;* *[…] We have also an internal DB to support the analysis of risks related to our suppliers;* *The information reaches the system through EDI or is loaded manually*
5. How is this information structured and organised within the system in	Information organisation Information retrieval	*The information is organised by ID number, part name,*

order to be easily retrieved (from different partners)?		*month of production, remarks, and risk level. The retrieval can be made accordingly*
6. Where and how do you store the information gathered? Once entered in the system who is the responsible to maintain this information?	Information storage Information maintenance	*The information is stored into an internal DB. The direct responsible is in charge to maintain it updated*
7. How is this information presented to the user?	Information system features Decision-making based on experience	[*The information is processed] through graphics and colour codes, the information is clear represented and facilitate the decision-making process*
8. How is the information shared within the company and among key partners? Who has access to it?	Internal support system and tools • Informal External support systems and tools • Informal	*Internally the information is shared to all the interested parties with informal means such as e-mails and excel [spread]sheets;* *I use primarily e-mails to share [externally] the information*
9. What types of information did you need to select the recovery practice? What information would have been useful if available?	Internal External Wanted	*We were able to find an alternative supplier, thanks also to the conjoint effort of other departments;* *We audit our supplier and provide training to avoid the same situation;* *I would like to have complete visibility over the information*
Supply Chain Risk and Disruption Management		
10. How do you define a disruption?		*Lack of component or the result of any failure on a machine or process that lead to a stop on the*

		production line
11. Could you describe to us two examples of severe disruptions that your company experienced?		
• What happened?	Disruptive event	*A shareholder abandoned the organisation*
• Please describe the possible causes of this disruption.	External	*We later discovered that the supplier was bankrupt*
• How did it affect your organization (in terms of costs, time, relationship with your SC partners)?	Qualitative assessment	*Disruption led to delays on the delivery of the final product*
• How did you find out that you were facing a disruption? What was the time lag between disruption starts and its discovery?	Manual	*The CEO of the firm sent us an e-mail to communicate his decision, a couple of days after the disruption occurred*
12. What actions were taken to recover from the disruption? (Do you keep a “procedure” register? Who is in charge to maintain it updated?)	Redundant practices • Multiple supplier	*We were able to find an alternative supplier, thanks also to the conjoint effort of other departments*
13. What changes have been implemented after the recovery to reduce the risk of happening again?	Action • Update of existing plans • Follow-up with problematic suppliers • Changes to improve processes or tools	*We make frequent small changes to improve our tools*
14. Do you use a risk management process? Can you describe it for us, please?	Present • Used • Updated	*Yes, we have a formal risk management process due to certification process. Every time a new risk occurs I have to rely on the risk management process and update it with the new entry*

15. Do you have any information system to support this process?	Internal support system and tools • Formal • Informal	*The information system partially supports the identification of potential risks and critical points but the other stages are made manually or with other tools internally developed*
Request for information		
Additional documents at support: All the interviewees showed us how their systems work, also three of them provide us, respectively, the “Partial-parts shortage checking” (equivalent to risk management process for such parts) and a “Partial list of pieces wit related risk levels”, copy of a “Defect card” (front and back), and a copy of the “Supplier quick-alert”. We cannot show these additional documents due to the confidentiality clause in the informed consent.		

A-6 - Interview guidelines with excerpts retrieved from CarCo's interviews:

Guidelines		
Target interviewee: Supplier Manager, Stock Manager, Inbound and Outbound Logistics Manager, Critical Part Manager, IT Key User **Interview duration:** 70-77 minutes		
Introductory questions:		
Date of interview: 27th – 28th of July 2017 Interviewee's role Interviewee's role description		
Main questions to interviewee	**Categories and sub-categories**	**Answers**
Information Management Model		
1. What types of information did you use to manage the disruption? What information would have been useful if available?	Internal • Inventory External	*We need information about the level, position, and integrity of stock at our plant;* *External information is related to the price, capacity, quality and level of stock of potential suppliers;* *We do not need more information we need better communication!*
2. Did your system have access to this information automatically (sensing)?	Internal • Automatic External • Automatic	*The information related to the difference, between pieces requested and pieces delivered, is provided automatically by the system;* *Externally one of our department [marketing] monitor changes about the market and communicate them to us*
3. How was this information generated/created? • From internal sources? • From external	Internal • Product Internal support system and tools • Formal External	*New information is related to problems with product delivered by suppliers or its quality;* *Additional systems are*

sources?	External support systems and tools • Informal	*used when the information on the platform is not enough;* *Order updates need to be communicated immediately to our [external] partners;* *Excel spreadsheet and e-mail are used for some information about our suppliers*
4. How was this information loaded into the system?	Mother company role Internal support system and tools • Informal External support systems and tools • Formal	*Car_MC provides the information to our main system;* *Sometimes I use excel and e-mail for additional information to put in the [main] system;* *I use EDI that are linked to our system*
5. How is this information structured and organised within the system in order to be easily retrieved (from different partners)?	Information organisation Information retrieval	*95% of the information (quantity, delivery date, ID supplier and so on) is organised by supplier;* *If needed I can go into details to retrieve the information. For example, I can see the type of transportation used, the usage rate of a piece, the stock level etc.*
6. Where and how do you store the information gathered? Once entered in the system who is the responsible to maintain this information?	Information storage Information maintenance	*All the information about the order is stored into our system, and I am responsible to maintain it updated*
7. How is this information presented to the user?	Information system features Decision-making based on experience	*The information is presented as alphanumerical strings;* *In my department we have too many*

		systems so, most of the time, I make my decision based on experience
8. How is the information shared within the company and among key partners? Who has access to it?	Internal support system and tools • Formal External support systems and tools • Formal	*[Internally and externally] The information is shared primarily via our system, and only the information within the system is valid. Once the information is in the system it's completely visible, according to clearance*
9. What types of information did you need to select the recovery practice? What information would have been useful if available?	External	*In case of disruption we make the follow up of the worst suppliers involved, and we try to make a task force in order to solve the problem. Sometimes we train their workers too;* *I would like to have better communication among partners*
Supply Chain Risk and Disruption Management		
10. How do you define a disruption?		*Anything that stuck my production process, both in terms of information or material, leads to disruption*
11. Could you describe to us two examples of severe disruptions that your company experienced?		
• What happened?	Disruptive event	*Lack of supplier's capacity*
• Please describe the possible causes of this disruption.	Internal External	*The information into the system was incorrect*
• How did it affect your organization (in terms of costs, time,	Qualitative assessment	*The impact of a disruption is assessed [qualitatively] in*

relationship with your SC partners)?		*terms of day(s) of delay. Also, extra costs […] that in a second period will be charged to the supplier. Our SLA establishes precise conditions for such problems*
• How did you find out that you were facing a disruption? What was the time lag between disruption starts and its discovery?	Automatic • Partially	*The disruption was detected automatically by the system. The detection occurred, almost, in real-time then I had to query the system for greater details*
12. What actions were taken to recover from the disruption? (Do you keep a "procedure" register? Who is in charge to maintain it updated?)	Mix practices • Mixed	*We had to collaborate with our partners to align the information and then opt for a faster shipment mode*
13. What changes have been implemented after the recovery to reduce the risk of happening again?	Action • Update of existing plans	*[In our department] we take trace of all our past occurrences and maintain the plans updated;*
14. Do you use a risk management process? Can you describe it for us, please?	Present • Not used • Updated	*We have a formalised risk management process, and even if I do not use it often I have to maintain it updated when new events occur*
15. Do you have any information system to support this process?	Internal support system and tools • Formal	*Our system is already parameterised to identify the risks but I have to analyse it*
Request for information		
Additional documents at support: All the interviewees showed us how their systems work thoroughly		

A-7 - MAXQDA® categories and sub-categories related to supply chain risk and disruption management:

Subject	Categories	Sub-categories
Supply Chain Risk and Disruption Management		
Disruptive event	Disruptive event	
Disruption cause	Internal	
	External	
Discovery	Automatic	Completely; partially
	Manual	
Recovery	Flexible practices	Collaborative relationship; integration; postponement; information exchange
	Redundant practices	Strategic stock; increasing inventory; spare capacity; multiple suppliers
	Mix practices	Mixed
Disruption impact	Qualitative assessment	
Redesign	Action	Update of existing plans; follow-up with problematic suppliers; changes to improve processes or tools
Risk and contingency plan	Present	Used; not used; updated; not updated; plan maintenance
	Absent	
	Presence of partial rules/countermeasures	
IT system supporting risk management process	Internal support systems and tools	Formal; informal
	External support systems and tools	Formal; informal

A-8 - MAXQDA® categories and sub-categories related to the information management model:

Subject	Categories	Sub-categories
Information Management Model		
Identifying needs	Internal	Product; inventory; demand; order
	External	Market; financial; fiscal and regulatory requirement; legal requirement; geopolitical; 3PL; IP
	Wanted	
Sensing	Internal	Automatic; manual
	External	Automatic; manual
Creating	Internal	Product; inventory; demand; order
	Internal support systems and tools	Formal; informal
	External	Market; financial; Fiscal and regulatory requirement; legal requirement; geopolitical; 3PL; IP
	External support systems and tools	Formal; informal
Gathering	Mother company role	
	Internal support systems and tools	Formal; informal
	External support systems and tools	Formal; informal
Organising	Information organisation	
	Information retrieval	
Storing and maintaining	Information storage	
	Information maintenance	
Processing	Information system features	
	Decision-making based on experience	
Sharing	Internal support systems	Formal; informal

	and tools	
	External support systems and tools	Formal; informal
Using	Internal	
	External	
	Wanted	

Appendix B

Visibility assessment tools:

		Supplier side (this represent only 1 of your supplier)								
		Available capacity	Production process	Stock level	Supplier order	Alternative supplier	Geopolitical constraints	Supplier contract	Track & trace	Logistics service provider contracts
Accessibility	Our firm has access to the following type of information from supplier **(Y/N)**									
Note: ONLY the accessible information (Y) should be evaluated (with a X in correspondence to the more appropriate option) according to the following dimensions										
Quantity	**Amount of information shared among SC partners**									
1	Unsatisfactory									
2	Most of the time we ask for more information from supplier									
3	In some case we ask for more information from supplier									
4	Satisfactory									
Timeliness	**Information is available on-time**									
1	Unsatisfactory									
2	Information is updated only upon request									
3	Information is updated most of the time without request									
4	Real time									
Accuracy	**Information is correct and precise**									
1	Only in few occasions									
2	Sometimes									
3	Most of the time									
4	Always									

Note: This worksheet refer only to one actor. Add new worksheets on the left or right, of the internal side, if you have several suppliers and/or customers rispectively

Figure B-1 Visibility assessment tool for supplier side

		Internal side						
		Available capacity	**Production process**	**Stock level**	**Production order**	**Geopolitical constraints**	**Track & trace**	**Logistics service provider contracts**
Accessibility	Our internal functions have access to the following type of information **(Y/N)**							
Note: ONLY the accessible information should be evaluated (with a X in correspondence to the more appropriate option) according to the following dimensions								
Quantity	**Amount of information shared among SC partners**							
1	Unsatisfactory							
2	Most of the time we ask for more information from supplier							
3	In some case we ask for more information from supplier							
4	Satisfactory							
Timeliness	**Information is available on-time**							
1	Unsatisfactory							
2	Information is updated only upon request							
3	Information is updated most of the time without request							
4	Real time							
Accuracy	**Information is correct and precise**							
1	Only in few occasions							
2	Sometimes							
3	Most of the time							
4	Always							

Figure B-2 Visibility assessment tool for internal side

		Customer side (this represent only 1 customer)								
		Available capacity	Production process	Stock level	Customer order	Market changes	Geopolitical constraints	Customer contract	Track & trace	Logistics service provider contracts
Accessibility	Our firm has access to the following type of information from customer **(Y/N)**									
Note: ONLY the accessible information should be evaluated (with a X in correspondence to the more appropriate option) according to the following dimensions										
Quantity	**Amount of information shared among SC partners**									
1	Unsatisfactory									
2	Most of the time we ask for more information from supplier									
3	In some case we ask for more information from supplier									
4	Satisfactory									
Timeliness	**Information is available on-time**									
1	Unsatisfactory									
2	Information is updated only upon request									
3	Information is updated most of the time without request									
4	Real time									
Accuracy	**Information is correct and precise**									
1	Only in few occasions									
2	Sometimes									
3	Most of the time									
4	Always									

Note: This worksheet refer only to one actor. Add new worksheets on the left or right, of the internal side, if you have several suppliers and/or customers rispectively

Figure B-3 Visibility assessment tool for customer side