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An information management approach for supply chain disruption recovery

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Abstract

Purpose – To study how supply chain decision-makers gather, process and use the available internal and external information when facing supply chain disruptions.

Methodology – The paper reviews relevant supply chain literature to build an information management model for disruption management. Afterwards, three case studies in the vehicle assembly sector, namely cars, trucks, and aircraft wings, bring the empirical insights to the information management model.

Findings – This research characterises the phases of disruption management and identifies the information companies use to recover from a variety of disruptive events. It presents an information management model to enhance supply chain visibility and support disruption management at the operational level. Moreover, it arrives at two design propositions to help companies in the redesign of their disruption discovery and recovery processes.

Originality/value – This research studies how companies manage operational disruptions. The proposed information management model allows to provide visibility to support the disruption management process. Also, based on the analysis of the disruptions occurring at the operational level we propose a conceptual model to support decision-makers in the recovery from daily disruptive events.

Keywords: Supply chain disruption management, Supply chain visibility, Information management

Paper type: Research paper

1. Introduction

With uncertainty becoming the new norm for businesses, all supply chains are susceptible to disruptions (Ambulkar et al., 2015). Studying how firms are capitalising from previous disruptions to refine mitigation strategies is an important step towards shortening the recovery time during future disruptions (Macdonald and Corsi, 2013). In doing so, we approached two complementary research streams on supply chain, namely disruption management and information management.

The informational, physical and financial flows of supply chains (Rai et al., 2006) may be disrupted in a continuum that ranges from catastrophic events, such as fire, earthquake, hurricane (Sawik, 2013) or pandemics like the COVID-19, to operations management problems, such as supplier delays, poor quality or insufficient inventory (Blackhurst et al., 2005). Although supply chain disruption (SCD) represents a highly studied topic (Blackhurst et al., 2005; Ivanov et al., 2017; Zsidisin and Wagner, 2010), researchers have so far mainly focused their attention on the response to catastrophic events as primary causes for supply chain disruptions and less on everyday operational disruptions, which are less severe, but more frequent (Marley et al., 2014). This paper addresses this important gap of lack of studies related to operational disruptions and thus contributes to broadening the picture of disruptions in supply chains. Whilst the two types of events require similar responses to deal with supply chain disruptions, the causes that generate them, the information needed to select the recovery strategy, and especially the redesign actions are different. Therefore, in this paper, we aim at filling this gap by identifying and analysing the actions taken and the information used by decision-makers during and after operational disruptive events, in order to propose a conceptual model that supports decision-makers in the recovery from disruptions.

When disruption occurs companies follow a disruption management process composed by discovery, recovery, and redesign (Macdonald and Corsi, 2013) and, in many cases, this process is supported by the previous implementation of a risk management process in the company composed by risk identification, assessment, mitigation, and monitoring (Berg, 2010; Tummala and Schoenherr, 2011). Hence, this research considers two types of strategies: (i) mitigation strategies - countermeasures that need to be preventively in place to face possible disruptive events in the future and (ii) recovery strategies - actions applied during disruption for fast recovery. 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. Consequently, there is a clear input from the redesign phase of the disruption management process for the risk management process of a company.

This paper 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 has been 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. This represents the second gap that this research aims to address by proposing an information management model tailored for supply chain disruption management, which, when implemented, can help practitioners to have the information visibility they need to effectively manage disruptions.

We tackle this problem using the information processing theory (IPT) as our lens for the analysis (Galbraith, 1973; Tushman and Nadler, 1978). This theory is used to explore the adoption of the information management model, as a proxy of the decision process, in dealing with supply chain disruptions.

To summarise, the contributions of this paper are twofold. The first contribution is the information management model that allows to provide visibility to support the disruption management process. The second contribution arrives from the analysis of disruptions occurring at operational level to submit two design propositions and a conceptual model aiming at supporting decision-makers in the recovery from daily disruptive events.

The remainder of this paper is structured as follows: Section 2 reviews the literature related to supply chain disruption together with the literature related to information management and visibility, and the motivation behind choosing the Information Processing Theory (IPT) as theoretical lens for this research. Section 3 presents the research design, while the findings are described and analysed in Section 4, and discussed in Section 5. Section 6 reflects on the presented research and discusses its implications for research and practice. Finally, we state the limitations of the study and directions for future research.

2. Theoretical Background

2.1. Supply chain disruption management

Supply chain disruption is defined as any unintended and unexpected event that occurs in the upstream supply chain, the inbound logistics network, or the downstream, that threatens the normal course of business operations of the focal firm (Bode and Macdonald, 2016; Bode et al., 2011).

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; Jüttner and Maklan, 2011). Still, the analysis of the supply chain disruption management 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 post-disruption reality for the company.

There is a broad debate on how to identify disruptive supply chain events. Some authors focus on their impact and severity, proposing a low-, medium- and high-impact scale to define the effects of disruption (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 (Ritter et al., 2007; Sawik, 2013), purposeful or accidental (Kleindorfer and Saad, 2005), 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 (Chopra and Sodhi, 2004; Park et al., 2013). In particular, we tackle these events by studying how the available information supports disruption related decisions.

The disruption management process begins with the description and discovery of the disruption, moves through the actions taken 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 and Rice Jr., 2005). Figure 1 shows the three phases of the disruption management process.

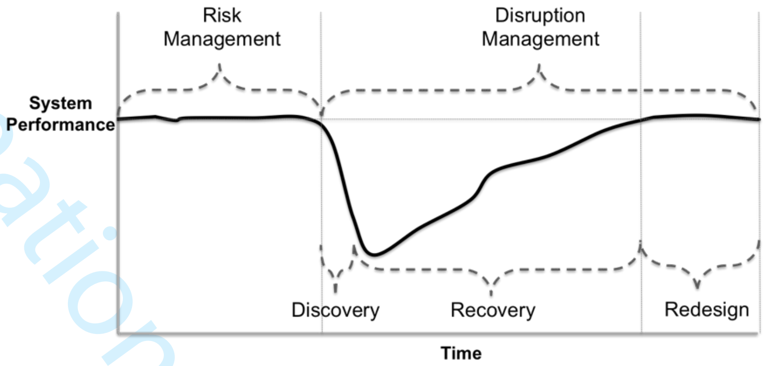


Figure 1: Disruption management process phases (adapted from Macdonald and Corsi, 2013)

Once the disruptive event is identified, 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). 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 information and thus visibility are required in all the phases of the process, for the discovery visibility is imperative. Prior research by Bode and Macdonald (2016) confirms that the discovery stage acts as a 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 on the causes that led to it, managers need to put in place actions to reduce the severity of the occurrence and to return 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, discussed in supply chain resilience literature. The first plans to build capabilities to sense threats in order to be able to manage them quickly. Collaborative relationships with partners, integration, postponement and promoting information exchange that enable quick discovery and recovery are typical examples of flexibility (Manuj and Mentzer, 2008b; Sheffi and Rice Jr., 2005). The second stream is related to strategic stock, increasing inventory, spare capacity, and maintaining multiple suppliers (Messina et al., 2016; Sheffi and Rice Jr., 2005; Zsidisin and Wagner, 2010) to achieve redundancy.

The literature analysis above suggests a strong relationship amongst the disruptive event, its causes and the recovery practices needed to cope with such disruptions. Still, more research is needed to understand the role information plays in selecting the most suited recovery practices. Consequently, we arrive at the conceptual model in Figure 2 that links these four concepts and will be further developed with the results from the empirical work in the discussion of this paper.

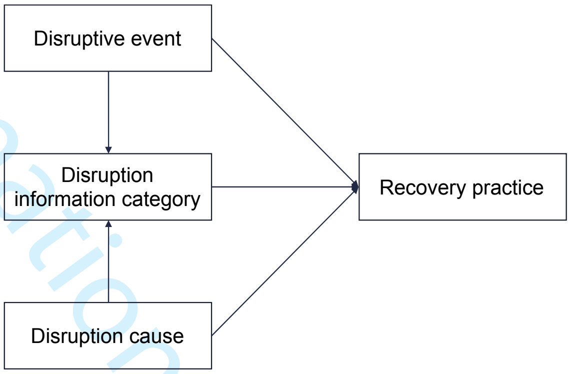


Figure 2: Conceptual model for disruption recovery phase

At the end of the recovery phase, managers need to evaluate the actions taken in order to see whether or not they were able to increase their resilience. The effects of improved resilience can be translated in terms of performance. Performance measures are related to cost, quality, service level, collaboration, and time (Christopher and Peck, 2004; Jüttner and Maklan, 2011; Tang, 2006). Through this evaluation, managers can understand and quantify their ability 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 from future occurrences (Blackhurst et al., 2005; Bode et al., 2011; Macdonald and Corsi, 2013). Although previous studies allow for a better understanding of the supply chain disruption management process, there is a consensus about the need for more empirical and theoretical insights on the subject. Additionally, researchers have so far focused on specific stages not looking at the process as a whole. The disruption management process represents the context of our research, and these phases have been analysed in our empirical work.

2.2. *Information management and visibility of the supply chain*

Information management is defined as the management of processes and systems that allow to create, acquire, organise, store, distribute, and use information (Detlor, 2010). Thus, it helps organisations to access, process and use information efficiently and effectively.

Information management, in the supply chain context, is also concerned with the identification of the types of information that are shared amongst partners (Montoya-Torres and Ortiz-Vargas, 2014). Two main groups of information can be shared to face supply chain disruption, namely internal and external. Internal information is mentioned herein as any information present at firm level or supply chain level gathered from companies' IT systems, such as Enterprise Resource Planning (ERP), Supply Chain Management (SCM) or Inventory Management systems. On the contrary, external information is defined as any information that may be captured from the supply chain or the environment, and gathered from institutional reports, stock market, public institutions, and consultancy reports (Messina et al., 2016).

Supply chain communities are fostered through the exchange of information among partners, helping to deal with supply chain disruptions and becoming more resilient (Christopher and Peck, 2004). According to several studies, managers stressed visibility as a key factor in mitigating the effects of disruptions and enhancing resilience (Blackhurst et al., 2005, 2011; Goswami et al., 2013; Johnson et al., 2013; Jüttner and Maklan, 2011; Ponis and Koronis, 2012). Members need to gain visibility over the supply chain from various perspectives, such as being able to see demand levels in real-time (Croson and Donohue, 2003), to see how much inventory a customer is holding (Fleisch and Tellkamp, 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 an informed decision-making. Supply chain visibility is achieved through proper information management models and practices (Messina et al., 2016).

In this regard, a common information management model would enable organisational connectivity (Haug, 2013), especially when partners share similar information. Such a common information management model would then be supported by information systems to operationalise the information management activities: collecting, organising, and disseminating accurately and in a timely manner the partner's shareable information (Fawcett et al., 2007).

Few publications, to the best of our knowledge, have analysed the specific problem of defining the sub-processes composing information management (Choo, 2002; Davenport, 1997; Detlor, 2010; Marchand et al., 2000). Davenport (1997), suggests looking at 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 better use of information. They also 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. The author also proposes looking at information management 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) clarifies the meaning of the term "information management", with the goal of helping organisations to reach their competitive objectives. The author identifies six predominant information processes to be managed: information creation, acquisition, organisation, storage, distribution, and use. Table 1 aggregates and synthetises the various stages considered in this literature about information management models, arriving at a total of nine steps.

Table 1: Information management models from the literature

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'		**X**		

	innovations that might impact the business; market shifts and customer demands for new products: anticipated problems with suppliers and partners.				
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

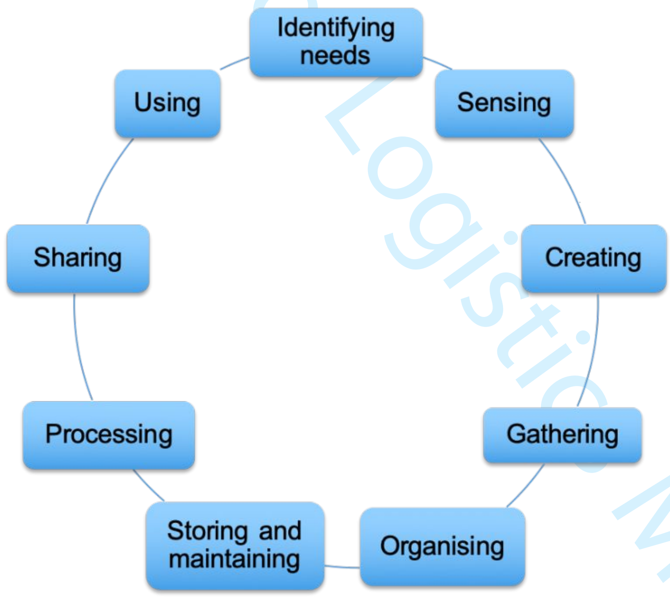


Figure 3: Information management model (life-cycle perspective)

2.3. Information processing theory for supply chain disruptions

Although the research streams presented in the previous sub-sections have generated valuable insights and have offered relevant implications for practitioners on supply chain disruptions, the theoretical foundation underlying it is still relatively thin (Bode et al., 2011). In order to advance SCD research, researchers have used and integrated theories from different academic disciplines (Sodhi et al., 2012; Tang and Musa, 2011). For this purpose, Brandon-Jones et al. (2014) utilise a contingent resource-based view theory to understand the relationship between information sharing, connectivity, visibility, and performance in terms of supply chain resilience and robustness. Golgeci and Ponomarov (2013) uses dynamic capabilities theory to investigate the relationships linking firm innovativeness, innovation magnitude, disruption severity, and supply chain resilience, in the context of SCD. Macdonald (2008) uses grounded theory to enhance the elements of a disruption management model. Bode et al. (2011) applies information processing and resource dependence theories to identify the set of strategic responses to SCD and to test a model that explains the occurrence of alternative responses. Bode and Macdonald (2016) adopted organisational information processing to bring clarity into the disruption management process using a sequence of four stages and hypotheses constraining and mediating effects of these stages. These studies contribute considerably to providing an SCD theoretical foundation, especially on the individual stages of the process. However, a theory that integrates the overall SCD process from a holistic point of view is missing. To fill this gap, based on IPT, we propose to integrate the different stages of the SCD from an information processing perspective and to understand how the information is managed to support decision-making in each of them.

Specifically, this research draws on literature that views firms as information processing systems (Galbraith, 1973; Thompson, 1967; Tushman and Nadler, 1978) that need to implement sequences of consecutive information processing activities in order to respond to external events (Bode and Macdonald, 2016; Dutton et al., 1983). As uncertainty increases due to the increased number of disruptions, firms need to increase their information processing capacity. Information processing aims at gathering, interpreting, and synthesizing information in the context of organisation decision-making (Tushman and Nadler, 1978). Consequently, this paper uses information processing theory for organisational design as a theoretical lens to tailor the nine-stage information model in Table 1 for the process of SCD management. When considering its boundary conditions we used an inside-out approach (Busse et al., 2017). With this conceptual model we want to extend IPT in order to help companies to identify the information required in a less-known context represented by the different phases of the disruption management process.

The stages of the information management model tailored for SCD management are 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 to enable fast recovery from supply chain disruptions.

This information management model for supply chain disruption management is used as a baseline to conduct the empirical work of the case research below.

3. Research method

3.1 Case research

The question guiding this research is: "How to manage information during supply chain disruptions?". Taking into account the exploratory nature of this work, case research is appropriate as research methodology (Voss et al., 2002; Yin, 2009). Case research is carried out to understand how some of the information systems solutions nowadays present in the market 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 the company. 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). Many authors have provided recommendations to enhance the 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 and 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 (section 2), and from previous studies. Design quality, validities and reliability are ensured in accordance with the data reported in Table 2. Due to the exploratory nature of this work, internal validity is not considered (Yin, 2009).

Table 2: 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 study findings	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 results	Case study protocol development to replicate the study and results

As to the research logic selection, Ketokivi and Choi (2014) propose three approaches to conduct case research: theory generation, testing and elaboration. The differences between these three logics have to do with the emphasis given to theory and practice. *Theory generation* is used in new or unfamiliar contexts in which the researcher avoids using an existing theory to reduce the risk of introducing bias. In this logic, the theory is derived from the practical observation of the context. On the other hand, in *theory testing,* the researcher selects *a priori* a theory to test through hypothesis generation. The logic here is driven by theoretical deduction. Finally, the third logic is *theoretical elaboration*. The reasoning behind this is quite similar to that of theoretical testing, but, in this case, the researcher, instead of testing a specific hypothesis, tries to extend it (Ketokivi and Choi, 2014; Voss et al., 2002). Theory elaboration is considered appropriate where a general theory exists but where the research context plays a fundamental role. Therefore, in this paper, information processing theory is used for theoretical elaboration through the development of an information management model for supply chain disruptions management.

Finally, a purposive sampling strategy has been used to select three companies in the vehicle assembly business, namely aircraft wings, trucks, and cars. The vehicle assembly context was chosen for its characteristics of global dispersion of partners, complex production, medium to long life cycle of products, and high uncertainty (Messina et al., 2016). Also, the cases under analysis 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 ran smoothly;
- Firm had suffered at least one disruption at operational level in the year prior to the interview;
- Firm required to share a conspicuous amount of different types of information, among the supply chain's and 3PL's partners, to deal with such disruption(s).

Finally, a case protocol was developed and documented, which includes the interview protocol about disruption management and the information management model at support (in Appendix A).

3.2 Data collection, analysis and validation

Data collection was carried out through semi-structured interviews, based on the description of disruptive events according to the interview protocol (in Appendix A). In total 17 interviews were conducted between April and May 2017 at company plants, which resulted in almost 17 hours of recordings. Based on the interview protocol, each participant was asked to recall two examples of disruption suffered.

As we are studying how companies use information to gain visibility over supply, demand, and product management processes (Tang, 2006a), the interviewee profiles selected included: Supply Managers, Demand or Logistics Managers, Production Managers, and Information System Managers. Involving managers who performed different company duties belonging to the internal supply chain allowed us to collect multiple views of the information management process and the 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.

To perform the data analysis, all the interviews were recorded, transcribed and then coded with the support of MAXQDA® software whose coding structures are listed in Appendix B. Also, to guarantee the construct validity, additional documents provided during the interviews, list of disruptive events, list of components with related risk levels, and procedures for spare parts checking and supplier quick alert, have been used for data triangulation. Furthermore, the transcript of the interviews was sent to the interviewees for validation.

Table 3, below, provides a summary of the main characteristics of the cases selected for this study.

Table 3: Case study data

Case Code	Sector	Year of Plant Start	Plant # of employees	SC position	Interview code and profile
Wing Co	Aircraft wings assembly	2012	400	1st Tier	A: IT Manager B: Purchasing Manager C: Avionic material planning Manager D: Non-avionic purchasing Manager and Logistic Manager
Truck Co	Trucks assembly	1964	437	OEM	E: Order and outbound logistic Manager F: Maintenance and facility Manager G: Production Manager H: Inventory Manager I: Production Planning and Outbound Logistics Manager L: Procurement Manager M: Warehouse and Internal Logistics Manager N: Supplier Manager
Car Co	Cars assembly	1995	3600	OEM	O: Supplier Manager P: Stock Manager Q: Inbound & Outbound Logistics Manager R: Critical Part Manager S: IT Key User

To increase the practical relevance of this work, design propositions were developed adopting the CIMO-logic proposed by Denyer et al. (2008). Moreover, the validation of these design propositions was made through focus groups, aiming at exploring how the experts' viewpoints are constructed and expressed during group interactions (Eriksson and Kovalainen, 2008). For each case a focus group involving the interviewees and the plant manager was carried out. Each focus group lasted about 90 minutes, in which two researchers acted as moderators. Also, additional data gathering was made immediately in the form of notes at the end of each focus group.

4. Findings

4.1 Within-case analysis

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

4.1.1 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, they have a collaborative relationship, even though hierarchical. WingCo assembles wings for two aircraft models, one based on composite alloy material and the other on metal alloy material.

The risk management process does not seem particularly well-established taking into account that not all the interviewees were aware of a formal risk management process nor of risk plans. The identification of the disruption is generally made when it occurs by querying their IT systems. The firm implements a reactive approach in dealing with this kind of events, due primarily to the scarce visibility of the information available from the system, and the lack of predefined alert systems which can warn the user about a potential disruption. Principal causes of disruption are related to the inaccuracy of the information loaded into the system, and the 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. Regarding 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 executing different operations. Other countermeasures are also applied but with greater care: such practices include machine duplication, and having multiple suppliers, generally related to non-airplane parts. WingCo evaluates the effects of disruptions in a qualitative manner.

Concerning 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 information systems supporting such activities appeared to be more oriented towards ensuring 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.

4.1.2 Case TruckCo

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

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 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 information 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 to components' delivery delays, shortage of stock, quality problems, 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, lessons learned, and proactive attitude are indicative of a strong resiliency culture. Recovery from disruptions is achieved through practices such as having multiple suppliers, multiple shipment modes, intervention of external subcontractors, and extra stock. All these practices allow TruckCo to be more robust when a disruption occurs. The interviewed managers were not able to quantify the monetary losses related to the occurrence of a disruption but translated them qualitatively in terms of delays. Such evaluation, instead, is carried out by Truck_MC1.

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

4.1.3 Case CarCo

CarCo is a large car producer, based in Europe and belongs 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 a collaborative and hierarchical relationship. CarCo is a car assembler of three different models, available in different configurations. Also, CarCo produces for Car_MC but on rare occasions also for final customers.

CarCo has an established risk management process in place. This process is continuously updated through two daily meetings in which all the area managers are involved to discuss potential risky situations for the day, and there is also a system that provides 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 disruptions, with attempts to be more proactive. Even though the system provides complete visibility over the information entered, it does not allow the level of proactivity desired by the users. Event identification is performed through a centralised IT system, and a set of auxiliary systems when needed. The system automatically identifies potential disruptions, but the operator has to query the system for greater detail. Other ways to communicate occurring or potential disruptions are by phone, e-mail, or face-to-face meetings, both internal and with stakeholders. The main cause of disruptions is related with untimely communication, which results in components delivery delays, and shortage of stock. Disruption recovery is achieved through a mix of the two recovery strategies. Practices such as a flexible process and reconfiguration of the workload allow CarCo to change the production orders or put some cars on hold to overcome most of the disruptions related to a sole supplier. Other practices such as multiple suppliers, multiple shipment modes and extra stock are also implemented. These practices allow CarCo to be flexible but at the same time robust when facing these events. As in the previous cases, the interviewees were not able to quantify the monetary losses related to the occurrence of a disruption but translated them qualitatively in terms of delays. The monetary quantification of the losses is made centrally at Car_MC.

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, provides CarCo with 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 the latter but, on the other hand, do not ensure that level of automatisation required to support decision-making. In fact, decision-makers put in place actions which rely on their experience.

4.2 Cross-case analysis

Cross-case analysis starts providing a characterisation of the main aspects of the three phases that constitute the disruption management process. Then it analyses the stages of the information management model developed and their consequences in terms of visibility.

4.2.1 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 the focus of our study, disruptive events at the operational level, this study identifies two categories of causes for disruption, namely internal and external as reported in Figure 4.

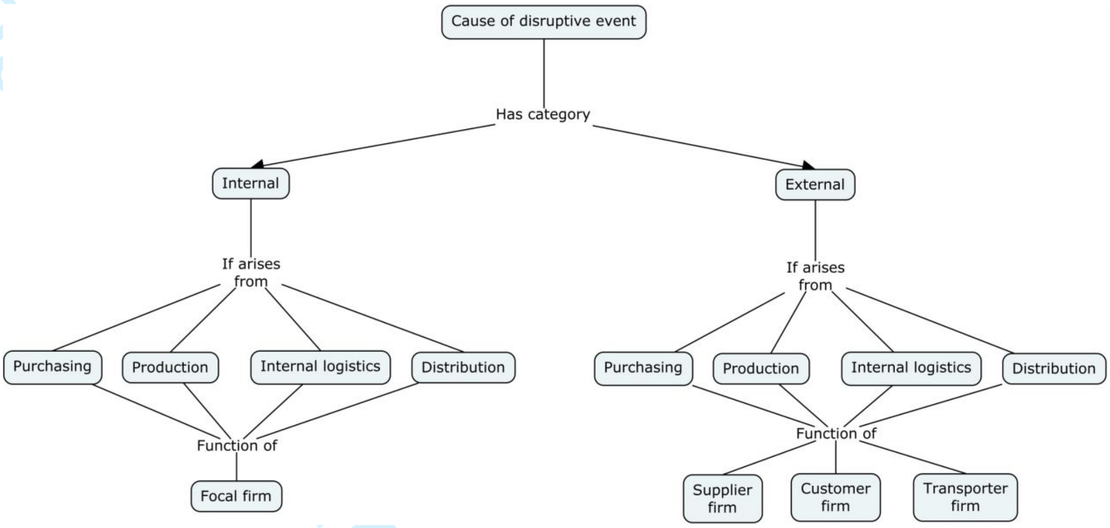


Figure 4: Disruption cause categories (adapted from Chen and Paulraj, 2004)

Table 4 provides a summary of the identified causes of disruption divided into internal and external.

Table 4: 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, Malfunction sensors	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, 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 of anomalies; the systems provided with sensors were more efficient in this aspect.

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 the recovery from disruptions, eight participants confirmed their existence, five their absence, and the other four quoted the presence of partial rules or other countermeasures as support. Table 5 provides a synthesis of this aspect.

Table 5: Presence of plans according to the interviewees

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

Amongst the eight participants confirming the presence of plans, in four cases the plans were constantly updated, even though in two of them the plans were not used to recover, 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. Also, in 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 6 shows the cases found.

Table 6: Causes and information types needed to implement the recovery strategies

Disruptive event	**Cause**	**Recovery strategy**	**Information type needed to implement the recovery strategy**
Product unavailability	Delivery delay	Speed up processes further to recover from lost time)	***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 brand	***Int:*** Order, product, demand, inventory ***Ext:*** Legal requirements
Lack of supplier's capacity	Incorrect information	Collaborative efforts with partners to align the information and Multiple shipment modes	***Int:*** Order, product, inventory ***Ext:*** 3PL, legal requirements
Machine breakdown	Maintenance team unavailable	Flexible machines	***Int:*** Product **Ext:** -
Shareholder abandonment	Supplier bankruptcy	Multiple suppliers	***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 processes further to recover for time lost	***Int:*** Product **Ext:** -
Quality problem	Supplier insolvency	Multiple suppliers 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 6 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 but none of the respondents were able to provide 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 O 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, L, R, Q, S), follow-up with problematic suppliers (M, N, O, P) and changes to improve processes or tools (A, B, C, D, E, G, H). Unexpectedly, even though interviewees Q and S stated that they did not use the existing plans to support the recovery (see Table 4), they contribute to maintain the plans updated with new occurrences. The majority of the interviewees that did not have any plans try to improve the processes to compensate for this aspect while the remaining focused more on the supplier follow-ups to overcome their problems.

4.2.2 Information management model and visibility

This section provides a characterisation of each stage of the developed information management model and the analysis of the consequences that these stages entail in terms of visibility. Also, 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.

Identifying the needs

The first stage of the information management model is the identification of the categories 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 categories were grouped in three sets: internal, external, and wanted (Table 7). The wanted category represents the need of additional information, independently if internal or external, to deal with disruption.

Table 7: 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: -
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 maintenance plan). External: 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. Wanted: More accurate information about supplier stock level, delivery time, transit time; real-time information about BOM and internal stock (level, position, integrity).
CarCo	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); Stock in house (level, position, integrity); Stock in transit (level, position); Process (sequence, entry-exit point); Advance Shipping Notice (ASN). External: Market changes; Potential supplier (price quotation, capacity, quality level, stock level); 3PL contracts. Wanted: -

The internal and external information reported in Table 7 represent a specification of the information types presented previously in Table 6. From the analysis of Table 7, 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 consequently to be proactive in managing potentially negative situations. Also, TruckCo is the only case in which the category information wanted is present. Nevertheless, information wanted in TruckCo refers to the information's characteristics, by the use of adjectives such as "more accurate" and "real-time", and not to additional information, as expected.

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 8 provides a summary of the result from environment scanning.

Table 8: Stage 2 - Sensing

WingCo	Internal: Information automatically detected by the systems, then the operator needs to share this information with the partners involved. External: -
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.
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.

TruckCo systems appear to be more "sensitive" than WingCo, and this could be related to the greater presence of sensors along the 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 9 and 10 synthesise these system features.

Table 9: Stage 3 - Creating

WingCo	Internal: New information is related to the alignment of the 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, email, excel. External: - External support systems and tools: -
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). 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, email.
CarCo	Internal: New information is related to the alignment of the 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: Email, Excel.

Table 10: 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), email, excel, and phone. External support systems and tools: email, and excel.
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, email, excel, face-to-face meeting. External support systems and tools: Web platform, EDI, share point, email, 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, email, excel, and phone. External support systems and tools: B2B platform, EDI, email.

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 tracking 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 11.

Table 11: 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 any one of the attributes that define each object within a class.
TruckCo	Different areas organise the information in a different class regarding: Internal customer; Equipment; Vehicle Identification Number; Process; Area of expertise; and Current supplier. Information retrieval can be made according to any one of the attributes that define each object within a class.
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 any one of the attributes that define each object within a class.

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 systems is equipped with interface specifics for disruptive situations. Further discussions about this aspect will follow 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 12.

Table 12: Stage 6 - Storing and maintaining

WingCo	Information stored into internal DB, and internal systems. Each manager is responsible for keeping the information they entered updated, and avoiding duplication.
TruckCo	Information stored into internal DBs, a share point, and internal systems (of the equipment). Each manager is responsible for keeping the information they entered updated, and avoiding duplication.
CarCo	Information stored into internal DB. Each manager is responsible for keeping the information they entered updated, and avoiding duplication.

Table 12 does not provide significant differences in 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´s 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 13.

Table 13: Stage 7 - Processing

WingCo	Graphics related to ticket analysis; Analysis and decision-making based on the experience.
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 a graphic and a colour code.
CarCo	String of text and KPI; Analysis and decision-making based on the experience.

Table 13 shows the features of the information systems implemented to support the decision-making. As it is possible to see, there are features that facilitate this stage, in particular the 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 14 and 15 provide a summary of the stages.

Table 14: Stage 8 - Sharing

WingCo	Internal support systems and tools: email, excel, face-to-face meeting, SFTP. External support systems and tools: email.
TruckCo	Internal support systems and tools: email, excel, face-to-face meeting, share point. External support systems and tools: web platform, share point, EDI, encrypted USB, email, and excel.
CarCo	Internal support systems and tools: Proprietary system, email, excel, face-to-face meeting. External support systems and tools: B2B platform, email, and excel.

Table 15: 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.
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 information is communicated. Wanted: Complete visibility; Would be useful having a system that automatically analyses the information related to disruptions.
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.

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 disruptions. Also, from the analysis of Table 14 it is possible to identify two categories related to the supporting systems adopted, namely internal and external. While from the analysis of Table 15 we identify three categories related to the actions entailed in 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 actions it can implement, which are 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 for 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 providing training, both internally and to suppliers. TruckCo participants required more visibility to enhance their ability to sense vulnerabilities and be 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 the weak reliability of the information within the systems. Having multiple systems, with partially overlapping information, 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.

4.2.3 Design propositions

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

The design propositions were developed adopting the CIMO-logic proposed by Denyer et al. (2008) and following the approach of Costa et al. (2020) for its application to information systems design. CIMO-logic has been used because it involves a 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 addresses the types of information shared. Table 6 shows the categories of information that companies use to face disruptions. Also, as reported when analysing Tables 6 and 7, companies that were able to integrate internal and external information showed more awareness of the context and faster disruption discovery.

From the analysis of these tables and the above described case findings, the first design proposition is derived:

Design proposition 1: During supply chain disruptions (context), information management, in particular information organisation integrating internal and external information (intervention), enhances visibility over the supply chain (mechanism) to improve disruption recovery (outcome).

Results from the validation workshops 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 proved 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 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.

The second design proposition focuses on the information organisation to enhance the decision-making processing. In particular, from the analysis of Tables 4, 5 and 10 it was possible to identify two noteworthy observations: first, the presence of risk or contingency plans as a starting point for disruptions recovery, and second the practices of organising information. Regarding the recovery and redesign phases, in this case a central role is being played by the presence of risk and contingency plans.

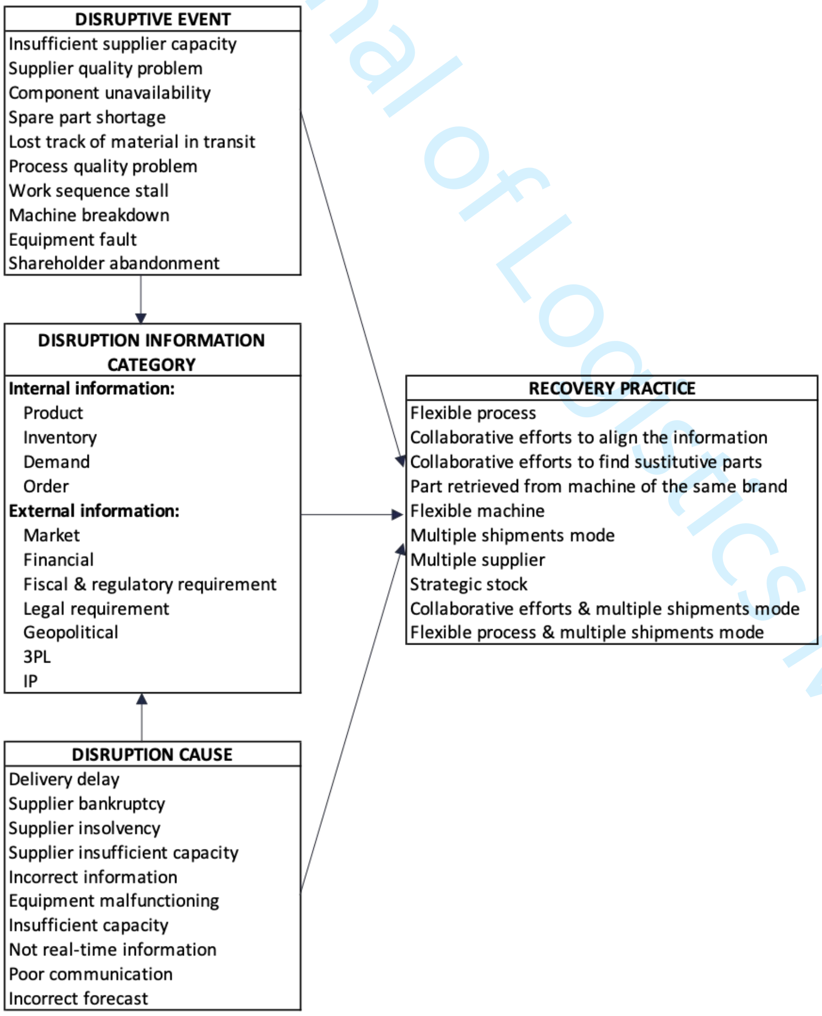
Also, past occurrences need to be recorded and overhauled in order to maintain these plans updated. As shown in the analysis, the participants of the study had their systems set to support the processes in "normal conditions", but not in a "disruption mode". This discussion lead to the final proposition:

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

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 simulating disruptions at operational level would be extremely beneficial.

In line with the result of the workshops, and based on the conceptual model in Figure 2, we propose a model that is specifically tailored to support decision-makers along the recovery process. We propose to organise the information according to the model in Figure 5, in this case filled with the information retrieved from the cases. The information organisation 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 no structured guidelines.



Text correction in box on the right: "collaborative efforts to find substitutive parts"

Figure 5: Conceptual model derived from the 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 overco 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.

5. Discussion

The description and analysis of the research findings in section 4 resulted in the design propositions (a summary is given in figure 6) and a conceptual model (see figure 5). We discuss now our findings as summarised in section 4.2.3.

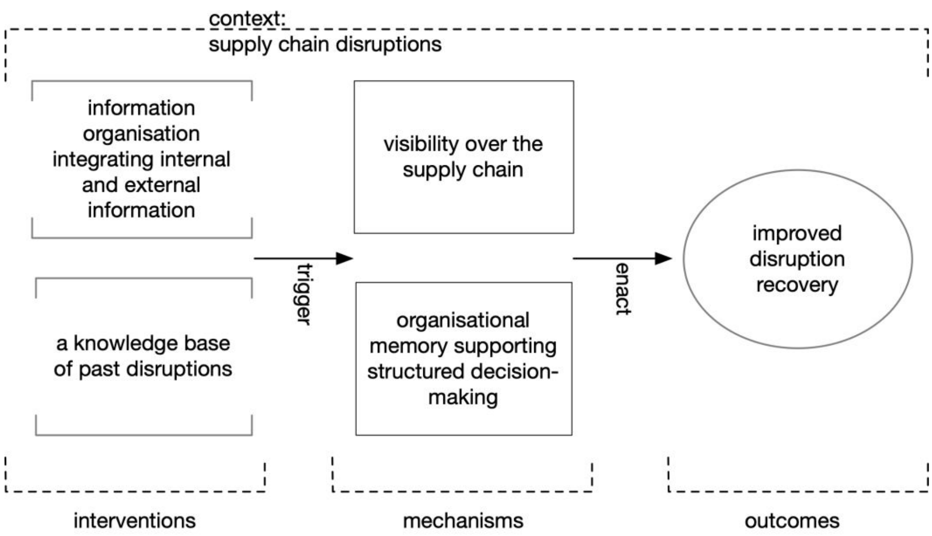


Figure 6: Summary of the design propositions

Evidence related to the need for visibility, both internal and external, to improve disruption discovery can be found in the literature (Barratt and Barratt, 2011; Bode and Macdonald, 2016). For example, Bode and Macdonald (2016) found that the integration of internal and external information positively impacts the speed and ability of decision-makers to process information in order to discover quickly the disruption and act upon it.

Also, such visibility should lead to faster disruption discovery, corroborating the results found in previous literature (Barratt and Barratt, 2011). In fact, Barratt and Barratt (2011) findings show that the visibility obtained through the integration of internal and external information allows SC players to be aware of the context in which they operate and so discover future occurrences faster. Finally, in 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. Complementing the work of Bode and Macdonald (2016), our results confirmed the relevance of discovery time but also underlined the importance of the discovery mode, an aspect that was underestimated in the extant literature. For this purpose, firms should opt for automatic disruption discovery to avoid omissions.

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 kept 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). Risk and disruption management are intertwined topics and neither of them can be examined without taking into account the other counterpart (Christopher and Peck, 2004; Messina, 2019; Tang, 2006b). Regarding this aspect we expanded the work of Bode and Macdonald (2016) by including explicitly in our research the mitigation strategies that are vital for a proficient selection and adoption of recovery strategies during disruptions.

Confirming the results obtained in previous studies (Barratt and Barratt, 2011; Jüttner and Maklan, 2011), and according to Jüttner and Maklan (2011), having knowledge about past occurrences increases supply chain network visibility and this allows the selection of those strategies positively impacting supply chain resilience.

6. Conclusion

This research began with a review of factors that were known or assumed to play a significant role in the disruption management process and has generated several important discussions for both communities of practitioners and researchers.

In the end, the paper contributes 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 theory are related to a better understanding of how firms can manage disruptions and facilitate the recovery phase. Also, the analysis of information systems in real settings 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 should support supply chain and logistics decision-makers along the information lifecycle to provide enhanced visibility, and a characterisation of each stage of the model for disruption purpose has been provided.

Finally, another contribution results from the analysis of disruptions occurring at the 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 5 represents a valuable example for supply chain managers of how to organise the information with the specific goal of enhancing the recovery phase during disruptions.

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.

7 Limitations and future research

The limitations of this study concern the limited number of cases. Nevertheless, the results may be generalised to other companies belonging to the vehicle assembly sector that consider information as crucial for facing and overcoming disruptions and, additionally, 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. Future work should focus on determining to what extent a supply chain, in terms of how many tiers both upstream and downstream, must be visible to improve the disruption management process as a whole. With this purpose, a visibility metric should be defined to assess visibility between linked nodes of the supply chain. Finally, future studies should aim at increasing the numbers of cases in order to validate these design propositions with more focused case studies.

Acknowledgements

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References

Ambulkar, S., Blackhurst, J., and Grawe, S. (2015). Firm's resilience to supply chain disruptions: Scale development and empirical examination. *Journal of Operations Management*, *33–34*, 111–122.

Barratt, M., and Barratt, R. (2011). Exploring internal and external supply chain linkages: Evidence from the field. *Journal of Operations Management*, *29*(5), 514–528.

Berg, H.-P. (2010). Risk Management: Procedures, Methods and Experiences. *RT&A*, *2*(17), 79–95.

Blackhurst, J., Craighead, C. W., Elkins, D., and Handfield, R. B. (2005). An empirically derived agenda of critical research issues for managing supply-chain disruptions. *International Journal Of*, *43*(19), 4067–4081.

Blackhurst, J., Dunn, K. S., and Craighead, C. W. (2011). An Empirically Derived Framework of Global Supply Resiliency. *Journal of Business Logistics*, *32*(4), 374–391.

Bode, C., and Macdonald, J. R. (2016). Stages of supply chain disruption response: Direct, constraining, and mediating factors for impact mitigation. *Decision Sciences*.

Bode, C., Wagner, S. M., Petersen, K. J., and Ellram, L. M. (2011). Understanding responses to supply chain disruptions: Insights from information processing and resource dependence perspectives. *Academy of Management Journal*, *54*(4), 833–856.

Brandon-Jones, E., Squire, B., Autry, C. W., and Petersen, K. J. (2014). A contingent resource-based perspective of supply chain resilience and robustness. *Journal of Supply*, *50*(3), 55–73.

Busse, C., Kach, A. P., and Wagner, S. M. (2017). Boundary Conditions: What They Are, How to Explore Them, Why We Need Them, and When to Consider Them. *Organizational Research Methods*, *20*(4), 574–609.

Choo, C. W. (2002). *Information management for the intelligent organization: the art of scanning the environment*. (I. Information Today, Ed.).

Chopra, S., and Sodhi, M. S. (2004). Managing risk to avoid supply-chain breakdown. *MIT Sloan Management Review*, *46*(1).

Chopra, S., and Sodhi, M. S. (2014). Reducing the risk of supply chain disruptions. *MIT Sloan Management Review*, *55*(3), 73.

Christopher, M., and Peck, H. (2004). Building the resilient supply chain. *The International Journal of Logistics Management*, *15*(2), 1–14.

Costa, E., Soares, A. L., and Sousa, J. P. de. (2020). Industrial business associations improving the internationalisation of SMEs with digital platforms: A design science research approach. *International Journal of Information Management*, *1*(53), 1–17.

Croson, R., and Donohue, K. (2003). Impact of POS data sharing on supply chain management: An experimental study. *Production and Operations Management*, *12*(1), 1–11.

Davenport, T. (1997). Secrets of successful knowledge management. *Knowledge Inc*, *2*(2), 1–7.

Denyer, D., Tranfield, D., and van Aken, J. E. (2008). Developing Design Propositions through Research Synthesis. *Organization Studies*, *29*(3), 393–413.

Detlor, B. (2010). Information management. *International Journal of Information Management*, *30*(2), 103–108.

Dutton, J. E., Fahey, L., and Narayanan, V. K. (1983). Toward understanding strategic issue diagnosis. *Strategic Management*, *4*(4), 307–323.

Eriksson, P., and Kovalainen, A. (2008). *Qualitative methods in business research: A practical guide to social research.* (Sage, Ed.).

Fawcett, S. E. S., Osterhaus, P., Magnan, G. M., Brau, J. C., McCarter, M. W., Croom, S., and Fawcett, S. E. S. (2007). Information sharing and supply chain performance: the role of connectivity and willingness. *Supply Chain Management: An International Journal*, *12*(5), 358–368.

Fleisch, E., and Tellkamp, C. (2005). Inventory inaccuracy and supply chain performance: a simulation study of a retail supply chain. *International Journal of Production Economics*, *95*(3), 373–385.

Galbraith, J. R. (1973). *Designing complex organizations*. Addison-Wesley Longman Publishing Co., Inc.

Goh, M., De Souza, R., Zhang, A. N., He, W., and Tan, P. S. (2009). Supply chain visibility: A decision making perspective. In *Industrial Electronics and Applications, 2009. ICIEA 2009. 4th IEEE Conference on. IEEE, 2009.* (pp. 2546–2551).

Golgeci, I., and Serhiy Y. Ponomarov. (2013). Does firm innovativeness enable effective responses to supply chain disruptions? An empirical study. *Supply Chain Management: An International Journal*, *Vol. 18*(Iss 6), 604–617.

Goswami, S., Engel, T., and Krcmar, H. (2013). A comparative analysis of information visibility in two supply chain management information systems. *Journal of Enterprise Information Management*, *26*(3), 276–294.

Haug, A. (2013). Improving the design phase through interorganisational product knowledge models. *International Journal of Production Research*, *51*(2), 626–639.

Ivanov, D., Dolgui, A., Sokolov, B., and Ivanova, M. (2017). Literature review on disruption recovery in the supply chain. *International Journal of Production Research*, *55*(20), 6158–6174.

Johnson, N., Elliott, D., and Drake, P. (2013). Exploring the role of social capital in facilitating supply chain resilience. *Supply Chain Management: An International Journal*, *18*(3), 324–336.

Jüttner, U., and Maklan, S. (2011). Supply chain resilience in the global financial crisis: an empirical study. *Supply Chain Management: An International Journal*, *16*(4), 246–259.

Ketokivi, M., and Choi, T. (2014). Renaissance of case research as a scientific method. *Journal of Operations Management*, *32*(5), 232–240.

Kleindorfer, P. R., and Saad, G. H. (2005). Managing disruption risks in supply chains. *Production and Operations Management*, *14*(1), 53–68.

Macdonald, J. R. (2008). *Supply chain disruption management: A conceptual framework and theoretical model (Doctoral dissertation).*

Macdonald, J. R., and Corsi, T. M. (2013). Supply chain disruption management: severe events, recovery, and performance. *Journal of Business Logistics*, *34*(4), 270–288.

Manuj, I., and Mentzer, J. T. (2008). Global supply chain risk management strategies. *International Journal of Physical Distribution and Logistics Management*, *38*(3), 192–223.

Marchand, D. A., Kettinger, W. J., and Rollins, J. D. (2000). Information orientation: people, technology and the bottom line. *Sloan Management Review*, *41*(4), 69–80.

Marley, K. A., Ward, P. T., and Hill, J. A. (2014). Mitigating supply chain disruptions – a normal accident perspective. *Supply Chain Management: An International Journal*, *19*(2), 142–152.

Messina, D. (2019). *Visibility in complex supply chains: an information management approach to support risk and disruption management decisions*. University of Porto.

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.

Montoya-Torres, J. R., and Ortiz-Vargas, D. A. (2014). Collaboration and information sharing in dyadic supply chains: A literature review over the period 2000–2012. *Estudios Gerenciales*, *30*(133), 343–354.

Park, Y., Hong, P., and Roh, J. J. (2013). Supply chain lessons from the catastrophic natural disaster in Japan. *Business Horizons*, *56*(1), 75–85.

Ponis, S. T., and Koronis, E. (2012). Supply chain resilience: definition of concept and its formative elements. *Journal of Applied Business Research*, *28*(5), 921.

Ponomarov, S. Y., and Holcomb, M. C. (2009). Understanding the concept of supply chain resilience. *The International Journal of Logistics Management*, *20*(1), 124–143.

Rai, A., Patnayakuni, R., and Seth, N. (2006). Firm Performance Impacts of Digitally Supply Chain Integration Capabilities1. *MIS Quarterly*, *30*(2), 225–246.

Ritter, L., Barrett, J. M., and Wilson, R. (2007). *Securing Global Transportation Networks. A Total Security Management Approach*.

Sawik, T. (2013). Selection of resilient supply portfolio under disruption risks. *Omega*, *41*(2), 259–269.

Sheffi, Y., and Rice Jr., J. B. (2005). A Supply Chain View of the Resilient Enterprise. *MIT Sloan Management Review*, *47*(1), 41–48.

Sodhi, M. S., Byung-Gak, S., and Tang, C. S. (2012). Researchers' perspectives on supply chain risk management. *Production and Operations Management*, *21*(1), 1-13.

Tang, C. S. (2006a). Perspectives in supply chain risk management. *International Journal of Production Economics*, *103*(2), 451–488.

Tang, C. S. (2006b). Robust strategies for mitigating supply chain disruptions. *International Journal of Logistics Research and Applications: A Leading Journal of Supply Chain Management*, *9*(1), 33–45.

Tang, O., and Musa, N. S. (2011). Identifying risk issues and research advancements in supply chain risk management. *International Journal of Production Economics*, *133*(1), 25–34.

Thompson, J. D. (1967). *Organizations in action: Social science bases of administrative theory*. Transaction Publishers.

Tummala, R., and Schoenherr, T. (2011). Assessing and managing risks using the Supply Chain Risk Management Process (SCRMP). *Supply Chain Management: An International Journal*, *16*(6), 474–483.

Tushman, M. L., and Nadler, D. A. (1978). Information processing as an integrating concept in organizational design. *Academy of Management Review*, *3*(3), 613–624.

Van der Zee, D.-J., and Van der Vorst, J. G. (2005). A modeling framework for supply chain simulation: opportunities for improved decision making. *Decision Sciences*, *36*(1), 65–95.

Voss, C., Tsikriktsis, N., and Frohlich, M. (2002). Case research in operations management. *International Journal of Operations & Production Management*, *22*(2), 195–219.

Yin, D. R. K. (2009). *Case Study Research: Design and Methods*. Sage Publications (CA).

Zhang, A. N., Goh, M., and Meng, F. (2011). Conceptual modelling for supply chain inventory visibility. *International Journal of Production Economics*, *133*(2), 578–585.

Zsidisin, G. A., and Wagner, S. M. (2010). Do perceptions become reality? The moderating role of supply chain resiliency on disruption occurrence. *Journal of Business Logistics*, *31*(2), 1–20.

Appendix A

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 organized 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?

Appendix B

MAXQDA® coding structures:

B-1 - 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

B-2 - 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 and tools	Formal; informal
	External support systems and tools	Formal; informal
Using	Internal	
	External	
	Wanted	

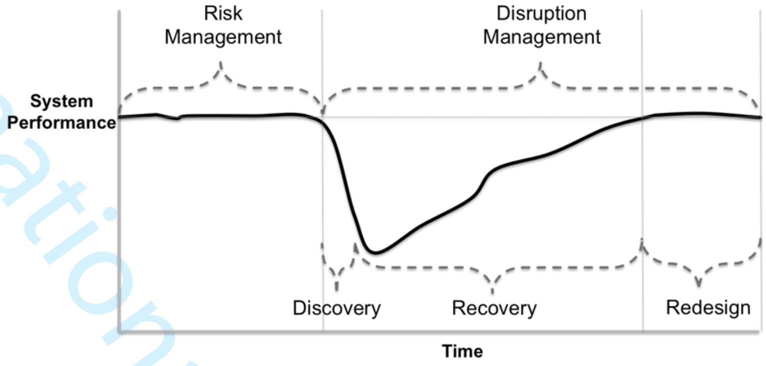


Figure 1: Disruption management process phases (adapted from Macdonald and Corsi, 2013)

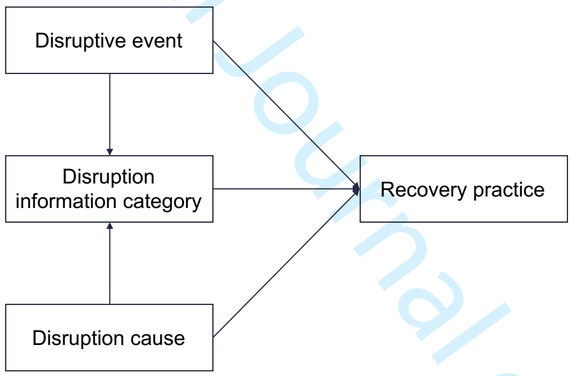


Figure 2: Conceptual model for disruption recovery phase

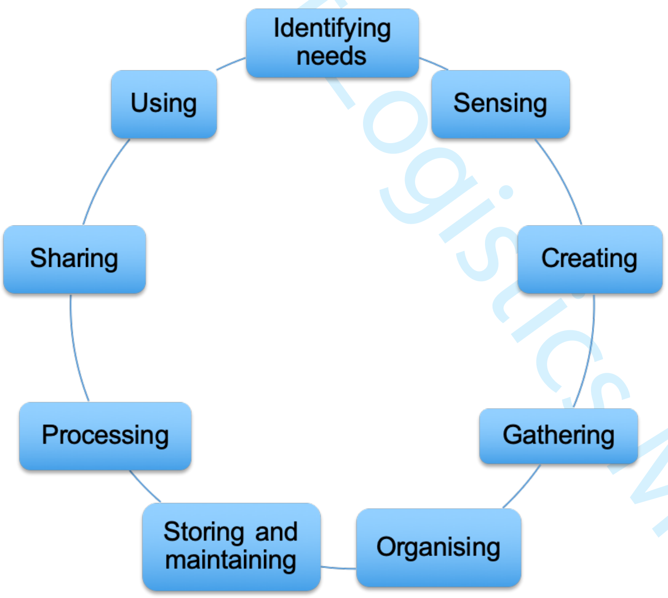


Figure 3: Information management model (life-cycle perspective)

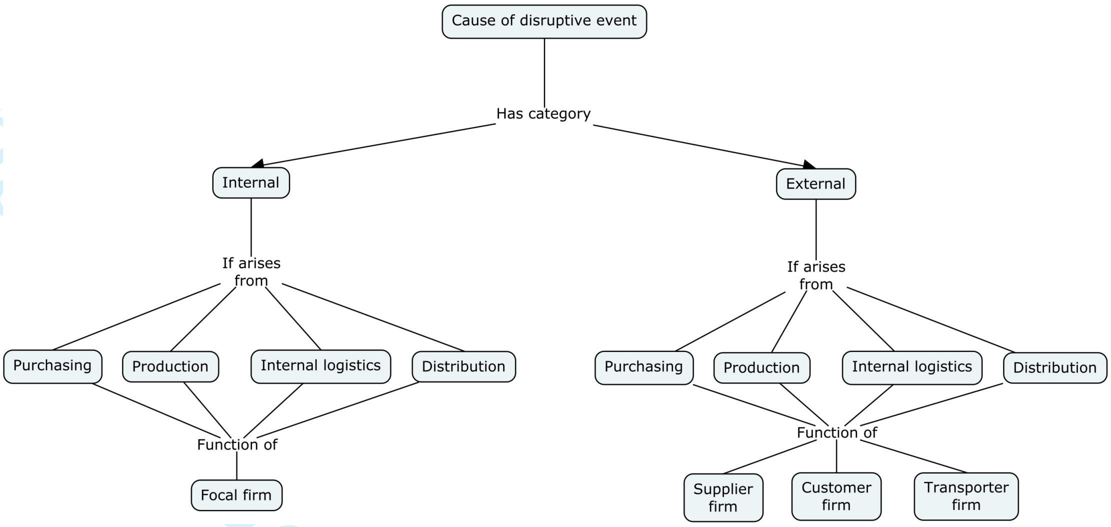


Figure 4: Disruption cause categories (adapted from Chen and Paulraj, 2004)

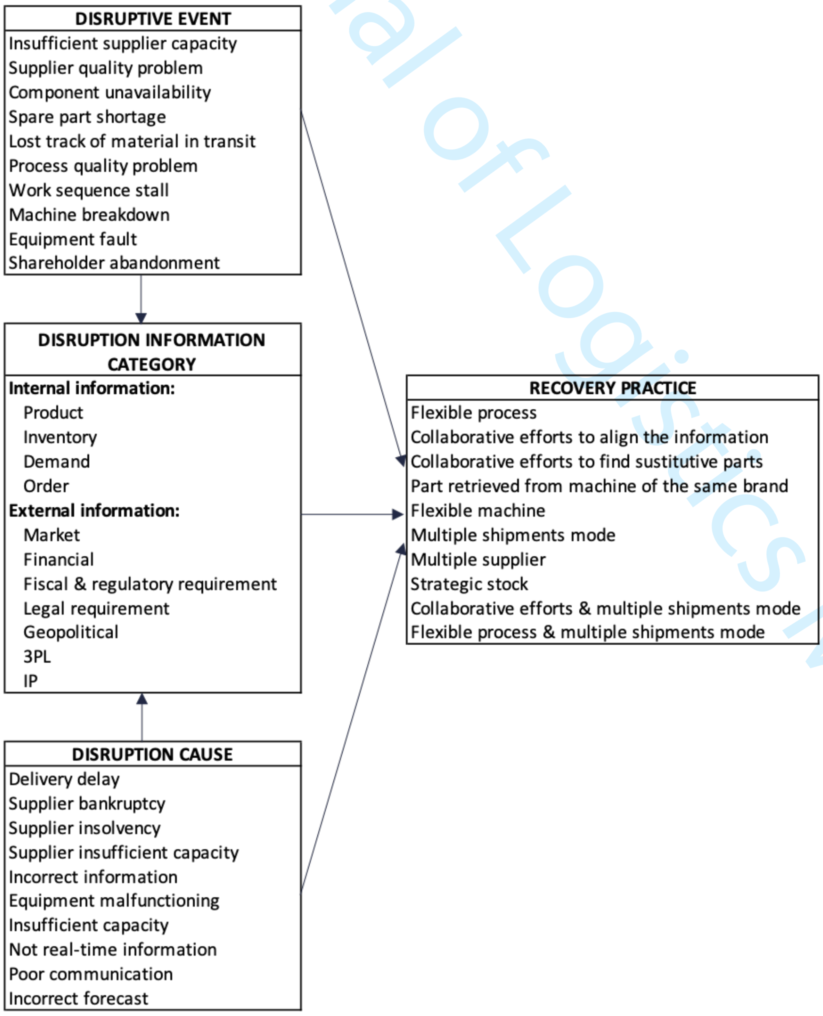


Figure 5: Conceptual model derived from the case research

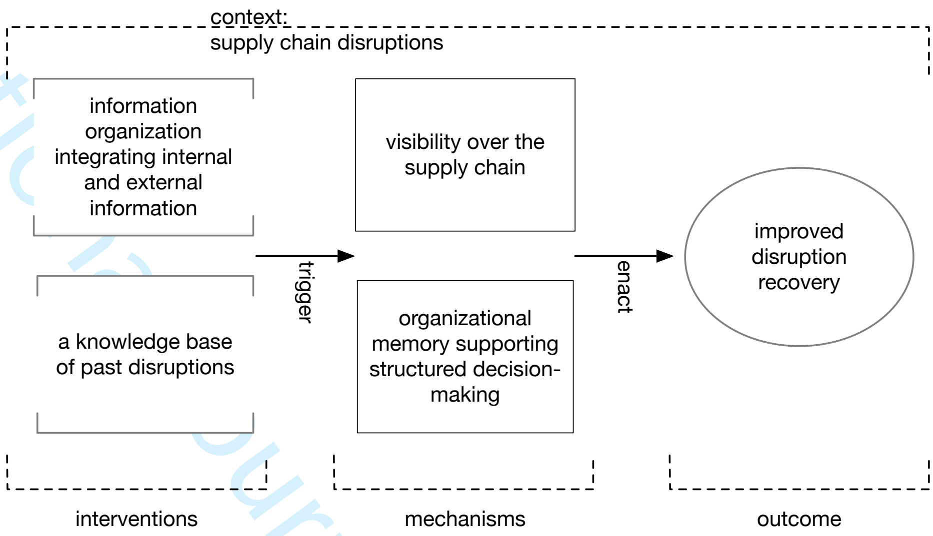


Figure 6: Summary of the design propositions

Table 1: Information management models from the literature

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**
Organizing	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, analyzing, 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**

Table 2: 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 study findings	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 results	Case study protocol development to replicate the study and results

Table 3: Case study data

Case Code	Sector	Year of Plant Start	Plant # of employees	SC position	Interview code and profile
Wing Co	Aircraft wings assembly	2012	400	1st Tier	A: IT Manager B: Purchasing Manager C: Avionic material planning Manager D: Non-avionic purchasing Manager and Logistic Manager
Truck Co	Trucks assembly	1964	437	OEM	E: Order and outbound logistic Manager F: Maintenance and facility Manager G: Production Manager H: Inventory Manager I: Production Planning and Outbound Logistics Manager L: Procurement Manager M: Warehouse and Internal Logistics Manager N: Supplier Manager
Car Co	Cars assembly	1995	3600	OEM	O: Supplier Manager P: Stock Manager Q: Inbound & Outbound Logistics Manager R: Critical Part Manager S: IT Key User

Table 4: 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, Malfunction sensors	Incorrect information, Delivery delay, Supplier insufficient capacity, Lack of communication, Incorrect forecasts, Supplier bankruptcy, Supplier insolvency, Transportation delay

Table 5: Presence of plans according to the interviewees

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

Table 6: Causes and information types needed to implement the recovery strategies

Disruptive event	Cause	Recovery strategy	Information type needed to implement the recovery strategy
Product unavailability	Delivery delay	Speed up processes further to recover for lost time)	***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 brand	***Int:*** Order, product, demand, inventory ***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 processes further 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 7: 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: -
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 maintenance plan). External: 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. Wanted: More accurate information about supplier stock level, delivery time, transit time; real-time information about BOM and internal stock (level, position, integrity).
CarCo	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); Stock in house (level, position, integrity); Stock in transit (level, position); Process (sequence, entry-exit point); Advance Shipping Notice (ASN). External: Market changes; Potential supplier (price quotation, capacity, quality level, stock level); 3PL contracts. Wanted: -

Table 8: Stage 2 - Sensing

WingCo	Internal: Information automatically detected by the systems, then the operator needs to share this information with the partners involved. External: -
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.
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.

Table 9: 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, email, excel. External: - External support systems and tools: -
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). 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, email.
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: Email, Excel.

Table 10: 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), email, excel, and phone. External support systems and tools: email, and excel.
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, centralized system within equipment, sensors, barcode reader, share point, internal DB (for supplier risk management), contingency plan, report, email, excel, face-to-face meeting. External support systems and tools: Web platform, EDI, share point, email, 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, email, excel, and phone. External support systems and tools: B2B platform, EDI, email.

Table 11: Stage 5 - Organizing

WingCo	Different areas organize 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.
TruckCo	Different areas organize 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.
CarCo	Information primarily organized 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.

Table 12: 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.
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.
CarCo	Information stored into internal DB. Each manager is responsible to keep the information they entered updated, and avoid duplication.

Table 13: Stage 7 - Processing

WingCo	Graphics related to ticket analysis; Analysis and decision-making based on the experience.
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 color code.
CarCo	String of text and KPI; Analysis and decision-making based on the experience.

Table 14: Stage 8 - Sharing

WingCo	Internal support systems and tools: email, excel, face-to-face meeting, SFTP. External support systems and tools: email.
TruckCo	Internal support systems and tools: email, excel, face-to-face meeting, share point. External support systems and tools: web platform, share point, EDI, encrypted USB, email, and excel.
CarCo	Internal support systems and tools: Proprietary system, email, excel, face-to-face meeting. External support systems and tools: B2B platform, email, and excel.

Table 15: Stage 9 - Using

WingCo	Internal: disruptions tracking in order to capitalize from past occurrences, selection of alternative suppliers for non-airplane parts, selection of flexible equipment or of the same brand. External: - Wanted: More visibility.
TruckCo	Internal: disruption tracking in order to capitalize 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 information is communicated. Wanted: Complete visibility; Would be useful having a system that automatically analyses the information related to disruptions.

CarCo	Internal: disruptions tracking in order to capitalize 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.

Appendix A

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 organized 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?

Appendix B

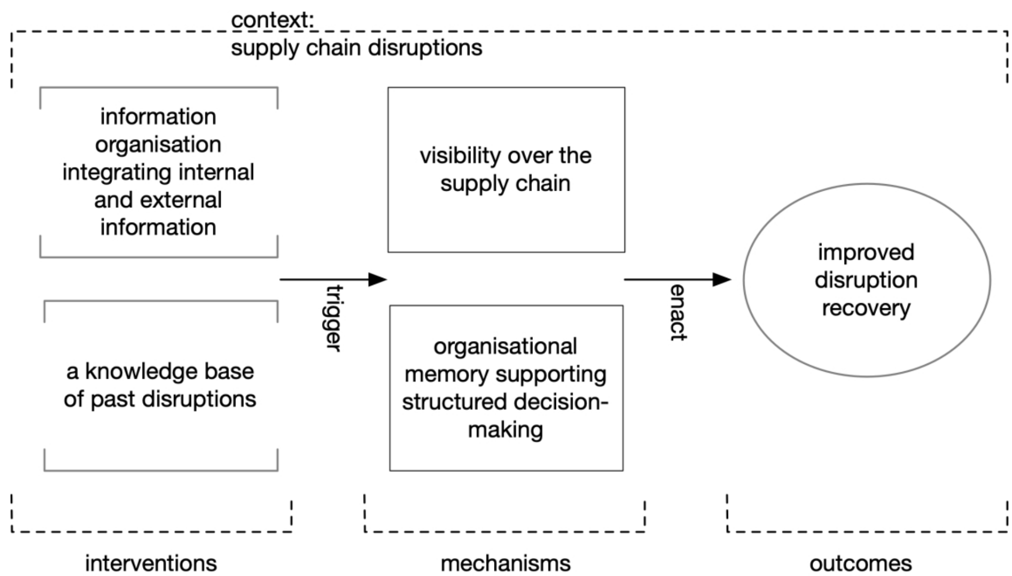
MAXQDA® coding structures:

B-1 - 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

B-2 - 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 and tools	Formal; informal
	External support systems and tools	Formal; informal
Using	Internal	
	External	
	Wanted	


context:
supply chain disruptions
information organisation integrating internal and external information
a knowledge base of past disruptions
trigger
visibility over the supply chain
organisational memory supporting structured decision-making
enact
improved disruption recovery
interventions
mechanisms
outcomes