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An assessment model to evaluate supply chain resiliency: application in the assembly industry

by

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An assessment model to evaluate supply chain resiliency: application in the assembly industry

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Abstract

In the last few years, many authors have addressed the topic of supply chain vulnerability. The main limitation of the current body of literature is its scarce use of empirical evidence. In addition, only limited attention has been paid to how companies actually respond to risk.

This work aims to further develop our understanding of how companies maintain their resiliency. Specifically, this paper will present an assessment model for evaluating the extent to which companies implement risk mitigation practices.

The development process for the model involved two steps. First, based on a literature review, a draft of the assessment model was designed and operationalised via a questionnaire. Then, to evaluate the validity of the model, five case studies were conducted.

The model allows us to evaluate the firms' ability to reduce their vulnerability and it will also allow us to identify when specific practices are most applicable.

Keywords: supply chain resiliency, supply chain risk management, risk assessment,.

1. Introduction

In the last few years, the literature related to flexibility and the supply chain has focused a great deal of attention on risk management issues. After September 11, 2001, for example, companies realised that the threat of terrorism affects their ability to operate and successfully carry on their business. Not only were several firms directly hit by the destruction of the Twin Towers, but also, almost every supply chain was affected by the grounding of the planes and the closure of the borders that immediately followed. Ford, for example, had to shut down five of its U.S. plants, partly because it could not get enough parts from suppliers in Canada. The result was a 13-percent drop in production in that quarter (Sheffi, 2001).

Within the supply chain management literature, a rich stream of studies has emerged that deals with the general issue of managing risk. Many authors have traditionally addressed the uncertainty that derives from market volatility, considering questions ranging from the amplification of fluctuations along the supply chain (Forrester, 1961) to ways of managing this kind of risk (e.g., Tsay et al., 1999).

Market uncertainty is only one of the sources of risk for the supply chain. Zsidisin (2001) reminds us that another relevant source of risk lies with suppliers and the supply market. Supply risks can significantly affect the ability of an organisation to achieve success.

A disruption in supply can affect companies a long way down the supply chain, making it essential to consider not only the risk experienced by a single company but also the risk to the many other actors in the supply network (Souter, 2000).

Companies also need suggestions regarding how to protect themselves. In particular, firms are looking for ways to increase the security of their supply chains without affecting their effectiveness. Lee and Wolfe (2003) suggest that it is possible to create strategies that both improve security and increase productivity by preventing security breaches (e.g., inspections, information protection, international standards, etc.), mitigating the consequences of disruptions and enabling prompt responses (e.g., supply network visibility, flexible sourcing, balanced inventory management, etc.).

This last group of initiatives is aligned with a relevant area of research aimed at creating resilient organisations. Coutu (2002) introduces the concept of organisational resilience, which can be defined as "the ability to bend and bounce back from hardship" (Coutu, 2002).

The goal is to shift security efforts from a source of additional costs to a source of new benefits, increasing efficiency and providing competitive advantage in line with the previously mentioned contributions (Sheffi, 2001).

The limitation of all these contributions is their scarce use of empirical evidence: some works are purely theoretical, while others are based on examples of reactions to past events, but none investigates the current corporate response. There is still no clear vision of the actual preparedness of companies for supply chain disruptions, and the previous literature has not provided a comprehensive description of the different practices that companies can adopt to increase their resiliency. Moreover, we have not developed a clear understanding of the impact of the different risk management practices on the efficiency and effectiveness of the supply chain. This work aims to move us a step forward in our understanding of how companies manage their resiliency. Specifically this work aims to develop an assessment model to evaluate the extent to which companies implement risk mitigation practices and evaluate the impact of supply chain risk management practices on performance.

The remainder of the paper is structured as follows. In the next section, the literature on supply chain risk management is analysed, with a specific focus on the design of risk assessment models. Then research objectives are defined, and the adopted methodology is described. In section 4, the designed model will be detailed, and the empirical analysis will be described. At the close of the paper, conclusions will be drawn.

2. Literature review

In this work, attention is devoted to supply chain vulnerability and supply chain risk management. Supply chains have been analysed for decades, and several definitions can be found in the current literature. Combining various definitions (e.g., Christopher, 1992; Lee and Billington, 1992; Ganeshan and Harrison, 1992; Peck, 2005; Manuj and Mentzer, 2008; Cavalieri and Pinto; 2008), we define a supply chain as a network of companies that use shared processes to generate and manage essential streams, thereby meeting the needs and expectations of the end market and achieving commonly shared goals. In the supply chain management literature, recent attention has been devoted to the concept of vulnerability. Based on previous contributions (e.g., Svensson, 2002; Juttner et al., 2003; Christopher and Peck, 2004; Tang, 2006), we define supply chain vulnerability as “the exposure of the network to different disturbances that can lead to obstruction of the flows and to breakdown of the supply chain operations”. In the scientific literature, the different disturbances affecting the network are defined as supply chain risks.

In management science, risk can be broadly defined as the chance of danger, damage, loss, injury or any other undesired consequence (Harland et al., 2003). Mitchell (1995) defines risk as “… the probability of loss and the significance of that loss to the organisation or

individual". However, Svensson (2000) has suggested that to uniquely define a specific risk, it is important to identify the sources and the triggers that can induce the negative impact. The literature includes several contributions that provide different concepts of supply chain risk by emphasising the probability, significance and sources of loss (e.g., Sheffi, 2001; Zsidisin and Lee, 2002, Juttner et al., 2003; Norrman and Lindroth, 2004; Chopra and Sodhi, 2004; Sheffy and Rise, 2005; Manuj and Mentzer, 2008). Based on these previous contributions, we can classify risk as shown in Figure 1.

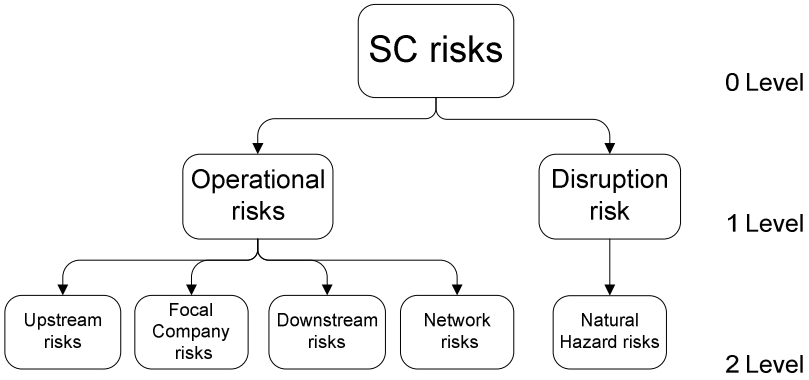

Fig 1 Supply chain risks categorization.

At the first level, we can distinguish between two classes of risk considering the dimensions P and I: operational risks (high likelihood, low impact) and disruption risks (low likelihood, high-impact) (e.g., Finch, 2004; Chopra and Sodhi, 2004, 2005; Norman and Jansson, 2005; Kleindorfer and Saad, 2005; Tang, 2006).

Operational risk is related to the uncertainty that characterises processes and material/information flows in the supply chain. This kind of risk arises more frequently and causes inefficiency, reductions in the network's operative and economic performance, and (in the worst case scenario) the breakdown of supply chain operations. The probability of operational uncertainty is very difficult to quantify (Milliken, 1987), but it is strictly related to the way in which business is managed and the strategic and tactical plans implemented by the supply chain partners. For this reason, these risks are managed by leveraging practices that influence both the probability of occurrence and the impact, thus contributing to the creation of a resilient network.

Disruption risks depend on natural hazard, the unpredictability of the social, political, economic and environmental context in which partners work. This kind of risk is characterised by a low probability of occurrence and high negative impact on the performance

of supply chain operations. With this kind of risks, there is no opportunity to influence the probability of occurrence because natural hazards cannot be influenced (or at least influencing them is very complex). Thus, they must be managed in a proactive manner (through avoidance, insurance or hedging) (e.g., Ermoliev et al., 1999; Chambers and Jacobs, 2007; Knemeyer et al., 2008; Trkman and McCormack, 2009).

In this paper, our attention will mainly be focused on operational risk. Within operational risk, it is possible to distinguish four classes of risk or risk sources:

1. Upstream risk. Purchasing organisations are exposed to numerous supply risks associated with their supply network and the uncertainty that characterises suppliers' delivery performance (Svennson, 2000, 2002), vendors reliability (Zsidisin et al., 2003, 2004) as well as the extra costs of supply due to the fluctuations in exchange rates and raw material prices (Speackman and Davis, 2004; Kleindorfer and Saad, 2005). In this category, we can also include intellectual property risk related to the difficulty of protecting the intellectual property that goods represent during outsourcing (Chopra and Sodhi, 2004; Chandler and Fung, 2006; Ordish, 2008).
2. Focal company risks. In this class, we include the risk factors that characterise the decision processes and internal operations of the focal firm, including the risk of errors in the optimisation of internal processes, relationships with plants that are not necessarily reliable, IT problems, the possibility of developing inappropriate business strategies, etc. (Cavinato, 2004; Peck, 2005).
3. Downstream risks. We assign to this class all risks that are tied to the distribution network, including demand risks arising from uncertainty regarding the volume and mix of customer demand, poor and distorted information flow from the downstream network, and problems related to relationships with downstream partners. These risks lead to increased network inefficiency and increase out-of-stock and over-stock situations throughout the supply chain (Chopra and Sodhi, 2004).
4. Network risks. These risks have to do with the increasing complexity of networks, reducing supply chain visibility and generating a lack of coherence between the strategies adopted by supply chain partners. Limited visibility reduces the confidence of each supply chain partner and thus the performance of the network. In this class, we can also include all problems related to the design of the supply chain in terms of network design (e.g., supplier selection, location of manufacturing facilities, location of distribution centres and warehouses, transportation) and responsibilities (e.g., the role of the plants,

product responsibility, coordinated production planning) (Juttner et al., 2004; Sheffy and Rice, 2005).

To cope with risk in the supply chain, in recent years attention has been devoted to supply chain risk management (SCRM). SCRM can be defined as the management of supply chain risk through coordination or collaboration among supply chain partners so as to ensure profitability and continuity (Tang, 2006).

This discipline aims to develop mechanisms that help to reduce the probability of adverse events and simultaneously improve network resilience and ability to react so as to reduce the impacts of risk. Thus, the goal is to improve supply chain operations through the design of a strong and efficient network. Toward this end, companies need to implement a structured SCRM process that generally includes three steps (Peck, 2006; Manuj and Mentzer, 2008):

1. Risk identification

   First, risk factors must be identified, and the risk profile of the focal firm or network must be defined by linking elements of supply chain risk, risk sources, and performance that can be influenced. Several methodologies have been designed to provide support at this stage. Value Focus Process Engineering (VFPE) is a methodology that combines process-based and objective-based business modelling approaches into a model that enables the holistic representation of the business (Neiger et al., 2003, 2004, 2006, 2007). This tool links risks, risk sources and objectives and thus is very helpful for risk analysis. However, its complexity significantly limits its applications.

   Flow charts are also recommended because they allow to identify the critical risks that are connected to the most important streams of the supply chain (e.g., Svennson, 2000, 2004; Juttner et al., 2003; Kiser and Cantrell, 2007). This methodology is easier to develop, but it is rather general and is not associated with performance evaluation.

2. Risk evaluation

   When risks are identified, they have to be evaluated to assess which are critical for the supply chain and the focal company. Thus, it is necessary to conduct evaluation analysis to quantify the areas of vulnerability. To achieve this goal, many qualitative and quantitative risk assessment methodologies have been developed. The qualitative methodologies that are usually suggested are brainstorming, the Delphi model and other models based on expert opinion (e.g., Bookmaster, 1997; Norman and Janson, 2004; Manuj and Mentzer, 2008). Quantitative models have also been recommended; they include reliability

simulations, Monte Carlo simulations, chance constrained programming, data envelopment analysis, multiple objective programming, discrete event dynamic systems and fuzzy-variable models (e.g., Swartz, 1989; Fischer et al., 2002; Ruiz-Torres and Mahmoodi, 2005; Wu and Olson, 2008; Klimov and Merkuryve, 2008).

3. Selection and development of SCRM practices.

   Ultimately, it is important to select the right SCRM strategies to reduce the potential effect of risks that are evaluated as critical. Indeed, if the goal is to maximise performance and minimise risk, it is necessary to implement only those strategies that effectively reduce vulnerability so to obtain the best benefit/cost ratio.

The literature has indicated several SCRM practices that usually refer to specific sources of risks. Table 1 shows the main categories of practices based on an extensive literature review.

Supply Chain Risks	SCRM Strategic Plans	Tactical Plans
Upstream risks	Supply Management	Supplier selection, Supplier Order Allocation, Contracts, Supplier Development and Integration.
Focal Company risks	Product Variety Flexible manufacturing	Product portfolio management, Postponement, Buffer-Based practices, Operations Management.
Downstream risks	Demand management	Demand Shifting, Price Postponement, Contracts.
Network risks	SC Visibility and Information Management	Information Sharing, Collaborative Forecasting, VMI, Quick Response, Contracts, Network Design.
Natural hazard risks	Proactive Planning	Avoidance, Hedging, Insurance.

Table 1 Framework SC risks - SCRM best practices

As reported in Table 1, supply chain risk can be managed via many different practices that contribute to generating alignment, adaptability and agility (Lee, 2004), but some direct connections between risk sources and SCRM practices exist (Tang, 2006). For example, supply risk can be mitigated through strategic supply relationships (e.g., Kraljic, 1983; Tang, 1999; Helper, 1999; Torres and Mahmoodi, 2005), by implementing a structured vendor selection process (e.g., Ellram, 1990; Swift, 1995; Boer et al., 2001; Micheli et al., 2009) or by optimising order allocation and properly defining contracts (e.g., Cohen and Agrawal, 1999; Shin et al., 2000). These practices allow a firm to identify those of its supply relationships that add value, determine which of its suppliers provide the best delivery capabilities, and enable flexible, shifting supply order quantities across vendors and time (Tsay and Lovejoy, 1999).

The SCRM process points out the importance of risk assessment. The models used during this stage can enable the decision-maker to quantify the probability of occurrence and the impact associated with a specific risk. Additionally, these methodologies are used to measure improvements in resilience after SCRM practices have been implemented. Assessment models usually need to take into account the trade-off between usability and accuracy: qualitative models, for example, can be used to evaluate many types of risk in many situations but do not yield very reliable results because they tend to be based on subjective evaluations and affected by bias. On the contrary, quantitative tools are usually more accurate but tend to be more complex and thus are usually developed for specific risks, networks or contexts; they tend to be less useful when an overall assessment of risk is required.

For this reason, risk assessment is certainly an area where further scientific contributions are needed to provide companies with effective assessment models that allow them to identify where risks are most likely to occur.

3. Objectives and methodology

Based on the literature review, this work aims to provide a risk assessment model that companies can directly use to evaluate their risk resiliency. However, because resiliency is of a contingent nature, this model also aims to evaluate the relevance of risk for particular companies. From this point of view, we assume that risk management is of a contingent nature. Thus, we do not expect that all companies need to pay critical attention to this issue; instead, we find that risk management may have a different importance in different contexts.

For this reason, the conceptual model that we use in this work considers three kinds of variables.

1. First, we consider resilient capabilities, which are practices that are usually related to superior control of risk sources and potential impacts. Thus, companies that implement rating programs for vendors, for example, have better resilient capability than companies that do not monitor suppliers at all.
2. Second, we have risk conditions. Different scenarios will be associated with different risks that, according to the specific context, may or may not be critical.
3. Lastly, we have Contingent Variables, thus specific characteristics of the industrial context where companies operate.

This work addresses the first two kinds of variables because our goal is to develop an assessment model that future research will be able to apply to different contexts to test its descriptive capabilities.

The development of the model was based on two sequential steps. First, we reviewed the literature regarding supply chain risk management to identify practices related to supply chain resiliency. Almost 170 articles were identified that provide some evidence of how risk can be managed in a supply chain context. Table 2 shows the distribution of these articles over time and among particular journals. Much of the literature on the topic has been published in the last ten years.

Journal	Until 1989	from 1990 to 1999	from 2000 to 2009	Tot
Decision Sciences Institute	0	0	2	**2**
Decision Support Systems	0	0	2	**2**
European Journal of Operational Research	0	3	8	**11**
Handbooks in Operations Research and Management Science	0	0	2	**2**
Harvard Business Review	0	1	1	**2**
IIE Transactions	1	4	2	**7**
Int. Journal of Logistics Management	0	0	2	**2**
Int. Journal of Logistics: Research and application	0	0	2	**2**
Int. Journal of Operations and Production Management	0	1	1	**2**
Int. Journal of Physical Distribution and Logistics Management	0	0	4	**4**
Int. Journal of Production Economics	0	1	17	**18**
Journal of Business Logistics	0	1	2	**3**
Journal of Operations Management	0	2	8	**10**
Journal of Purchasing & Supply Management	0	0	4	**4**
Management Science	2	17	17	**36**
Manufacturing and Service Operations Management	0	2	3	**5**
Operations Research	0	7	2	**9**
Production and Operations Management	0	1	3	**4**
Sloan Management Review	1	2	2	**5**
Supply Chain Management: An International Journal	0	0	3	**3**
Transportation Research Part E	0	0	2	**2**
Others	2	8	23	**33**
Total	**6**	**50**	**112**	**168**

Table 2 Literature review

Based on this literature review, a first draft version of the assessment model was designed and operationalised using a questionnaire.

To determine the validity of the model and the discriminant ability of the questionnaire, the model was tested using five case studies. Table 3 provides a brief description of the cases and their characteristics.

Cases	Employees	Total Sales	$\frac{\text{RM}}{\text{Total Sales}}$ [1]	ATECO and product description
Firm A	398	65 mln €	42%	ATECO 28490 Produces circular saw blades and other accessories.
Firm B	326	91 mln €	62%	ATECO 28000 Produces various type of injection molding machine.
Firm C	361	177 mln €	61%	ATECO 28140 Produces various type of hydraulic valve.
Firm D	392	88 mln €	57%	ATECO 22290 Produces plastic components for automotive batteries.
Firm E	221	104 mln €	66%	ATECO 28130 Produces various type of compressors and pumps.

Table 3 Case Studies

The goal of the case study analysis is mainly to refine the operational model and to verify its thoroughness. The selection of the five cases studies follows Voss et al. (2002). Moreover, the selection of a multiple case study approach rather than a retrospective or longitudinal approach is coherent with the goals of the analysis. The cases were chosen as a convenience sample of a population of companies according to the following criteria:

1) Medium-sized companies. We decided to limit our selection to medium-sized companies to limit the complexity of the organisations being evaluated.
2) Manufacturing companies. We considered companies in manufacturing industries. Most of these companies belong to the machinery manufacturing industry.
3) Supply chain relevance. Companies were chosen based on the importance of the supply chain to their operations. The selections were made based on the purchasing costs.

The selected cases show a level of dissimilarity that helps us in limiting the risk of selection bias.

The case studies were conducted by means of interviews with the purchasing managers of the selected firms. The interviews were conducted according to the designed questionnaire, which constituted the core of the interview protocol. In appendix the designed questionnaire is provided.

4. Model description

The risk assessment model allows one to measure the extent to which SCRM practices are implemented and compare this evaluation with the degree of criticality and turbulence that characterises the context in which the focal firm operates. The model includes two parts: one

[1] RM/Total Sales: incidence of the purchase cost of raw material on the total revenue of the firm.

analysing companies' practices to evaluate their resiliency and another focusing on the evaluation of the potential risks that the focal company is facing. The variables constituting the two parts of the model are described respectively in Tables 4 and 5.

Resiliency can be evaluated according to four main groups of practices: strategic sourcing, vendor rating, supplier portfolio management, postponement (Table 4).

Practice	References
1. Strategic Sourcing	e.g., Kraljic, 1983; Cohen and Agrawal, 1999; Torres and Mahmoodi, 2005; Tang, 2006.
2. Vendor Rating	e.g., Swift, 1995; Choi and Hartley, 1996; Boer et al., 2001; Micheli et al., 2009.
3. Supplier portfolio management	e.g., Olsen and Ellram, 1997; Trkman and McCormack 2009.
4. Postponement	e.g., Bucklin, 1995; Lee and Tang 1997; Aviv and Federgruen, 2001; Lee, 2003; Yang et al., 2004.

Table 4 Practices developers of resilient capabilities

Strategic Sourcing. This preventive practice allows a firm to identify critical purchases and properly define sourcing strategies to improve supply performance and reduce the supplier's risk of failure (e.g., Kraljic, 1983; Cohen and Agrawal, 1999; Torres and Mahmoodi, 2005; Tang, 2006). The model evaluates to what extent the features of the purchased goods (specificity, complexity, contribution to competitive differentials and value) and the peculiarities of supply markets (concentration, capacity constraints, accessibility, uncertainty and competitiveness) are considered by the focal firm classifying its supplies. Additionally, the model measures the ability of the focal firm to select the right sourcing strategy according to the degree of criticality of each of his purchases.

Supplier selection. The literature has devoted fairly significant attention to the vendor rating process and the importance of the criteria according to which suppliers are evaluated. The more globalised the business, the shorter the product lifecycle, and the greater the complexity of the components and work associated with each project, the more important it is to use structured and complete vendor rating methodologies to reduce the risk of adverse selection (e.g., Swift, 1995; Choi and Hartley, 1996; Boer et al., 2001; Micheli et al., 2009). Considering the importance of this preventive practice, the risk assessment model takes into account how the firm collects the data, how the selection process is articulated and which selection criteria are considered.

Supplier portfolio management. Measuring the economic and operative performance of vendors allows one to control for the coherence between the degree of

collaboration/cooperation involved in the relationships developed and the degree of supplier attractiveness. These qualities are important to effective vendor management and to reducing exposure to failure risk on the part of the supplier (Olsen and Ellram, 1997). The model measures how the focal firm controls its supplier portfolio and evaluates the potential performance of its supply relationships.

Postponement. Postponement is a robust strategy able to enhance flexibility and efficiency, reduce operational uncertainty and improve the ability of the firm to respond to adverse events (e.g., Bucklin, 1995; Lee and Tang, 1997; Aviv and Federgruen, 1998; Yang et al., 2004). The literature provides evidence of how postponement can be achieved via concurrent engineering, the standardisation of components and sub-assembly processes, modular design and the re-sequencing of operations (Swaminathan and Lee, 2003; Yang et al., 2004; Hopkins, 2005). Postponement can also facilitate recovery from disruption events. The model measures the commitment of the focal company to implementing these proactive practices.

The riskiness of the context in which the company operates is evaluated based on four main kinds of variables. When a firm is characterised by market and technological turbulence, high levels of business complexity, a high proportion of critical components, a great propensity toward single sourcing and a highly developed level of cooperation with suppliers, it is exposed to a greater risk of supplier failure, and such failures will have a more significant impact (e.g., Tang, 1999, 2006; Juttner et al., 2004; Chapman and Ward, 2003; Micheli et al., 2009). Table 5 shows the variables and measures used in the model to evaluate the risk conditions.

Variable	Measures	References
Market and Technological turbulence	- Market competition evaluated by the purchasing manager of the selected firm; - frequency of technological changes; - Rate of product obsolescence;	e.g., Wagner and Bode, 2006; Trkman and McCormack, 2009.
Business Complexity	- Type of Business (MTS, ATO, MTO, ETO) - Globalization degree; - Number of product family;	e.g., Stock et al., 2000; Norrman and Jansson, 2004; Zsidisin et al., 2005;Wagner and Bode 2006; Micheli et al., 2009.
Criticality of Purchases Portfolio	- Total cost of purchases; - Proportion of purchases that are classified as critical;	e.g., Kraljic, 1983; Vonderembse et al. 2006.
Riskiness of sourcing strategies	- Propensity to single sourcing; - Degree of cooperation usually developed in supply relationships.	e.g., Kraljic, 1983; Chopra and Sodhi, 2004; Wagner and Bode 2006.

Table 5 Variables and measures characterizing the risk conditions

Market and Technological Turbulence: Following earlier authors (e.g., Wagner and Bode, 2006; Trkman and McCormack, 2009), specific measures are proposed for addressing market and technological turbulence: competitive pressure, frequent technological changes and degree of product obsolescence. If these elements are present to a great extent, the relevance of delivery and quality problems in the supply network will be high.

Business Complexity: Having an engineering-to-order environment, a supply chain that is geographically dispersed and a great number of product families increases the complexity of the business and its exposure to supply risks by increasing operational uncertainty and reducing the visibility of the network (e.g., Stock et al., 2000; Norrman and Jansson, 2004; Zsidisin et al., 2005; Wagner and Bode 2006; Micheli et al., 2009). In other words, the greater the complexity of the business, the more necessary the implementation of SCRM practices becomes to increase network confidence and reduce exposure to operational risks.

Criticality of Purchases Portfolio: The importance of the procured materials to the focal company is great, but the greater the cost and specificity of purchases are, the greater the dependency of the focal firm on its suppliers will be (Kraljic, 1983). Thus, when the purchase portfolio is highly critical, the relevance of supply risks is greater (Vonderembse et al., 2006).

Riskiness of sourcing strategy: A relatively unreliable single sourcing supplier poses a considerably greater risk than does a multiple sourcing scenario (Trkman and McCormack, 2009). Consequently, it is possible to say that the greater the propensity of the firm toward single sourcing and the effort spent on supplier integration and development strategies, the greater the potential loss will be from supplier failure.

Based on the analysis of the case studies, the described model was tested and verified. The cases studies also allowed us to analyse the descriptive capabilities of the model via a comparison of the different cases.

Figure 2 shows the distribution of the five cases developed to test the model according to their specific resilient capabilities and risk conditions.

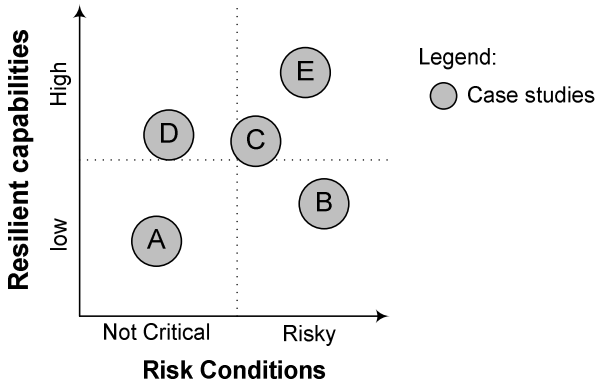

Fig 2 resilient capabilities and risk conditions distribution of the considered case studies

Company A is characterised by a low level of SCRM practice adoption and by low risk. This sort of firm can be considered robust and efficient because the extent to which the SCRM strategies are implemented is coherent with the risk conditions characterising the context. The area in which company D is located is a context in which the firm's resiliency is greater than is probably necessary, making the firm highly robust. However, we can't take into account the cost/benefit ratio associated with this extensive implementation because the model is not able to measure the operative and economic performance of firms. Companies C and E can be considered robust and efficient because their organisational resilience is coherent with the riskiness of the context. Finally, the situation in which firm B finds itself could be defined as risky because its adoption of SCRM practices is not adequate for it to manage the critical nature of some issues associated with the business.

Different comparisons can be made among the different companies. The following two comparisons (each between two different companies) are presented because they allow us to compare two different contexts. First, we see a situation in which companies use different practices even though the context appears to be similar from a risk perspective. Then, we examine a second situation in which two companies use similar practices with a rather different risk context.

Company E vs. Company B:

This first comparison provides greater evidence of why E is evaluated as robust while B as vulnerable. Indeed, although both are characterised by similar business complexity and equal criticality of portfolio purchases, the degree of implementation of SCRM practices for these companies is different:

- Strategic sourcing: Unlike company E, company B defines its sourcing strategy without considering all of the product characteristics involved and peculiarities of the supply

market for his purchases. This could lead company B to develop inappropriate purchasing strategies and increase the relevance of supply risks (e.g., Kraljic, 1983; Wagner et al., 2008; Trkman and McCormack, 2009);

- Supplier's selection: Company B rarely analyses the delivery capabilities and financial performance of its vendors. If the company doesn't consider these aspects in developing its vendor rating process, the probability of adverse selection is higher (Swift, 1995; Gulen, 2007, Dabhilkar et al., 2009, Micheli, et al., 2009);
- Supplier portfolio management and postponement: companies show similarly resilient capabilities.

Company B vs. Company A

This second comparison can be used to show the differences between context characteristics that lead to the creation of very different risk conditions.

- Market and technology turbulence: For company B, the rate of product obsolescence and the frequency of technological changes are higher. Based on these aspects of the firm context, it is feasible to say that the endogenous uncertainty to which company B is exposed is greater (Trkman and McCormack, 2009);
- Business complexity: Company A conducts production based on a make-to-stock system, while company B manufactures its products using a make-to-order process. Unlike company A, company B has foreign production plants and many relationships with foreign suppliers. In considering these aspects, it is possible to say that the risk to which company B is exposed is higher as a result of the complexity that it must manage (Micheli et al., 2009; Wagnar and Bode, 2009);
- Criticality of purchase portfolio: Company A enjoys low supply cost (30% of total sales), and the goods that it purchases are not classified as critical (15% of purchases are categorised as critical), while company B must pay higher supply costs (60% of total sales), and its purchases are more critical (40% of purchases are categorised in this way); unlike the components purchased by company A, those purchased by company B are very specific and numerous. By considering these differences it becomes feasible to say that company B is more exposed to supply risks (Ellis et al., 2009) ;
- Riskiness of sourcing strategies: Coherently with of the nature of its purchase portfolio, company B has developed a larger number of partnerships. This typology of sourcing relations absorbs a great deal of effort and brings with it greater supply and moral hazards risks (Ruiz-Torres and Mahmoodi, 2005; Yu et al., 2008).

Considering lack of resilience of company B and the risk conditions characterising the environment in which it operates, the model evaluates company B as vulnerable to supplier failure risk.

5. Conclusion

A firm that desires to achieve success and reduce the vulnerability of its supply chain must consider the importance of SCRM. The number of papers on this subject has significantly increased in the last 10 years, providing evidence of the importance of this discipline.

In analysing the SCRM process, one can identify risk evaluation as an area in which research is needed. In fact, risk assessment is critical because it becomes necessary for a firm to cope with the trade-off between the usability and accuracy of evaluation.

This paper has provided original insight and extended the reach of the SCRM literature specifically to the risk assessment area. The assessment model evaluates the SCRM practices adopted by the focal firm and defines the resilient capabilities of companies on the basis of early contributions that have demonstrated the effectiveness of these strategies. By considering the contingency nature of vulnerability, the model also evaluates the characteristics of the context in which these companies operate. By measuring both resilience and risk conditions, the proposed methodology is able to provide a complete assessment of firm robustness and identify the area in which each company needs to invest to reduce its vulnerability.

Based on our empirical analyses, we were also able to test the theoretical and operationalised model. Using the model, a company can analyse its practices and we can collect information about the managerial habits of manufacturing companies, evaluating what SCRM practices are usually implemented by the firm, which SCRM practices have more influence on vulnerability, and which should be implemented in a specific context.

In the end, we would like to highlight some limitations and areas of future development. First, the study considered only a specific area of SCRM. This scope could be extended to include other SCRM practices (e.g., contracts, buffer-based strategies, information-sharing) to allow a more complete assessment. Secondly, the empirical evidence, even if sufficient to provide an assessment of the quality of the model, does not allow us to analyse the relationships among SCRM practices, performance and context variables. Future studies should collect more data and evaluate the relationship between the mentioned variables.

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Appendix A

1.When defining the sourcing strategy of direct purchases for production, how relevant are considered the following dimensions?

Characteristics of the product	never				always
Value of the purchased good	1	2	3	4	5
Degree of personalization of the purchased good	1	2	3	4	5
Complexity of the purchased good (e.g. Number of shares, Number of interfaces with the finished goods, technological level)	1	2	3	4	5
Contribution to the quality of the finished product	1	2	3	4	5
Contribution to the availability and the performance of the finished product	1	2	3	4	5
Characteristic of the supply market:	never				always
Concentration of supply markets	1	2	3	4	5
Suppliers' capacity utilization and suppliers' breakeven stability	1	2	3	4	5
Markets access (e.g. nearness of suppliers)	1	2	3	4	5
Maturity of the supply markets	1	2	3	4	5
Rate of technological innovation characterizing the supply market	1	2	3	4	5

2. Please consider the most critical purchase in your portfolio; describe the product characteristics, the supply market characteristic and the sourcing strategy.

Characteristics of the product	low				High
Value of the purchased good	1	2	3	4	5
Degree of personalization for the purchased good	1	2	3	4	5
Complexity of the purchased good (e.g. Number of shares, Number of interfaces with the finished goods, Technological level)	1	2	3	4	5
Contribution to the quality of the finished product	1	2	3	4	5
Contribution to the availability and the performance of the finished	1	2	3	4	5
Characteristic of the supply market:	low				high
Concentration of supply market	1	2	3	4	5
Suppliers' capacity utilization and suppliers' breakeven stability	1	2	3	4	5
Markets access (e.g. nearness of supplier)	1	2	3	4	5
Maturity of the supply market	1	2	3	4	5
Rate of technological innovation characterizing the supply market	1	2	3	4	5

Implemented strategy	☐ Single Sourcing	☐ Dual/Parallel Sourcing	☐ Multiple Sourcing

Suppliers' selection process

3. Indicate the frequency with which your firm adopts the following actions in implementing vendor rating processes.

	never	rarely	only for the critical purchases	For the critical purchases but also for others	always
Market research with the goal of identifying new suppliers	1	2	3	4	5
Collection of public information	1	2	3	4	5
Visits at the supplier's production sites	1	2	3	4	5

Request of sample supplies	1	2	3	4	5
Collection of reputational information	1	2	3	4	5
Development of analysis with the aim of assessing the supplier's attractiveness	1	2	3	4	5
Development of analysis with the aim of comparing the suppliers and selecting the best one	1	2	3	4	5

4. Indicate the frequency with which your firm evaluates the following selection criteria in implementing vendor rating process:

Selection criteria	never	rarely	only for the critical purchases	For the critical purchases but also for others	always
Geographic extension of supplier's business	1	2	3	4	5
Criticality of the economic, politic and environmental context in which the supplier operates.	1	2	3	4	5
General characteristic of the supplier's market (e.g. concentration, maturity, Suppliers' capacity utilization and suppliers' breakeven stability etc.)	1	2	3	4	5
Formalization of the supplier's organization (e.g. Number of employed, typology of organizational structure, etc.)	1	2	3	4	5
Operational parameters characterizing the supplier(e.g. capacity, lead time, etc.)	1	2	3	4	5
Quality certifications of the supplier	1	2	3	4	5
Technological degree characterizing the supplier's plants	1	2	3	4	5
Attention to the maintenance characterizing the supplier	1	2	3	4	5
Attention to the safety aspects of the operations characterizing the supplier	1	2	3	4	5
Performance and reliability of the vendor's supply network	1	2	3	4	5
Degree of involvement and motivation of the management of the supplier	1	2	3	4	5
Problem solving skills of the management of supplier	1	2	3	4	5
Propensity of the supplier's organization to share information	1	2	3	4	5
Propensity to innovate (e.g. R&D investment, patents number) characterizing the supplier	1	2	3	4	5
Supplier's economic performance trend	1	2	3	4	5
Market share of the supplier	1	2	3	4	5
Financial Soundness Indicators of the supplier	1	2	3	4	5
Offer Price of the supplier	1	2	3	4	5
Total cost of ownership (total cost to establish and manage the relation with the supplier)	1	2	3	4	5

Supplier portfolio management

5. Indicate the frequency with which your firm implement the following actions in order to check the quality of your supplier's portfolio.

never	Less than once a year	At least once a years	Several time a year	Continuously	For none	For some vendors	Only for strategic suppliers	For strategic supplier and for single sourcing relations	For all suppliers

1	2	3	4	5	Recording of the delivery performance of the supplier (e.g. punctuality, quality, cost, conformity)	1	2	3	4	5
1	2	3	4	5	Evaluation of the track record of the delivery performance of the supplier	1	2	3	4	5
1	2	3	4	5	Re-evaluation of the selection criteria characterizing the suppliers	1	2	3	4	5
1	2	3	4	5	Re-evaluation of the condition of the market in which the supplier operates	1	2	3	4	5
1	2	3	4	5	Periodic redefinition of the supplier's attractiveness	1	2	3	4	5
1	2	3	4	5	Comparison between the supplier's attractiveness and the commitment spent by your firm in developing the supply relationship	1	2	3	4	5
1	2	3	4	5	Feed-back to your suppliers (e.g. communication of the evaluation results to the interested suppliers)	1	2	3	4	5

Postponement

6. How much do you agree with the following claims?

Dynamic Teaming	Strongly disagree				Strongly agree
Production teams that can be reorganized are used in our plant	1	2	3	4	5
Production teams can be reorganized in response to production/process changes	1	2	3	4	5
Production teams can be reassigned to different production tasks	1	2	3	4	5
Production teams are not permanently linked to a certain production task	1	2	3	4	5
Production team members can be reassigned to different teams	1	2	3	4	5
Production team members are capable of working on different teams	1	2	3	4	5
Production teams have no difficulty accessing necessary resources	1	2	3	4	5
Product Modularity	Strongly disagree				Strongly agree
Our products used modularized design	1	2	3	4	5
Our products share common modules	1	2	3	4	5
Our product features are designed around a standard base unit	1	2	3	4	5
Our products can be customized by adding feature modules as requested	1	2	3	4	5
Product modules can be reassembled into different forms	1	2	3	4	5
Product feature modules can be added to a standard base unit	1	2	3	4	5
Product modules can be rearranged by end users to suit their needs					
Process Modularity	Strongly disagree				Strongly agree
Our product process is designed as adjustable modules	1	2	3	4	5
Our production process can be adjusted by adding new process modules	1	2	3	4	5
Production process modules can be adjusted for changing production needs	1	2	3	4	5
Our product process can be broken down into standard subprocess that produce standard base units and customization subprocess that further customize the base units	1	2	3	4	5
Production process modules can be rearranged so that customization subprocess occur last	1	2	3	4	5

Production process modules can be rearranged so that customization subprocess cab be carried out later at distribution centers	1	2	3	4	5