COVID-19 pandemic disruption: A matter of building companies' internal and external resilience

Abstract

This paper develops an integrated methodology aimed at diagnosing supply chain resilience in terms of (1) internal dynamic capabilities of an enterprise, and (2) resilience of its suppliers. In addition, unlike other research, it integrates the suppliers' resilience evaluation into the order size allocation plan. Multi-attribute decision making (MADM) algorithms were employed to quantify the relative importance to evaluate the internal and external resilience of an enterprise. Furthermore, the MADM output was combined with a multi-objective programming model formulated to solve the order size problem considering economic and resilience objectives. The applicability of the developed methodology is demonstrated via a dairy manufacturing enterprise that suffered from disruptions attributed to COVID-19. The results translate the enterprise's non-viable manufacturing due to its poor external and internal resilience profiles. It is emphasized that if an enterprise fails to develop internal capabilities such as readiness and sensing, the enterprise could also fail in managing external resilience. A resilient supply chain requires a blend of internal and external resilience. This work represents the first quantitative attempt to provide a unified methodology for identifying and measuring internal and external resilience. Furthermore, the integration between suppliers' resilience performance and the order allocation process into decision makers' opinions for order size assignment is another unique contribution of this work.

Keywords: *Supply chain resilience; Dynamic capability; Supply chain risk; Optimization; Order size*

1. Introduction

Because of the global pandemic of COVID-19, several nations decided to close their borders, which, in turn, blocked shipments of parts and materials worldwide. This blockage created a massive disruption in global supply chains due to shortages of supplies. The Institute of Supply Management (ISM), for instance, reported that 75% of companies expect a decreased revenue at an average of 5.6% due to COVID-19 disruptions (Bridget McCrea, 2020). Similarly, Fortune magazine reported that 940 Fortune companies judged the COVID-19 pandemic as a supply chain (SC) disruption event (Fortune, 2020). By and large, the COVID-19 pandemic challenged the SC adaptations strategies (Ivanov, 2021).

Supply chain processes are prone to unexpected events. In SC context, Svensson (2001) describes these events as "*unplanned events that may occur in the supply chain which might affect the normal or expected flow of materials and components"*. However, the wide-ranging extent of COVID-19 disruptions proved that many organizations are still not totally aware of the possible significant risks of a pandemic's disruptions on their global SC relationships (Ivanov and Das, 2020). In other words, many enterprises have failed to recognize the requirement for a resilient SC as a significant part of their ultimate awareness of SC risk management (Jain, et al., 2020).

The resilience concept has been studied from different perspectives, including psychology, engineering, and business management; thus, its definition is varied according to the applied subject. From the business management perspective, SC resilience refers to "*the ability of a [supply chain] to return to its original state or move to a new, more desirable state after being disturbed*" (Christopher and Peck, 2004).

SC resilience must include suppliers' profile to mitigate external threats and to accordingly reinforce the backbone of SC resilience (Kamalahmadi and Parast, 2016; Namdar et al., 2018; Giannoccaro and Iftikhar, 2020; Saputro et al., 2020; Burgos and Ivanov, 2021). On the other hand, an enterprise that is externally resilient to supply disruptions but lacks the internal resilience to work together with those resilient suppliers will not be capable of handling unexpected disruptions. Internal resilience is represented by the enterprise's dynamic capabilities that help to withstand the extrinsic disruptions towards business continuity. The concept of dynamic capability infers the capacity of an enterprise to defy unexpected disasters (Sheffi, 2005).

In other words, managers should identify and analyze supplier resilience (external) and the dynamic capabilities (internal) to regulate their SC resilience against disruptive events. This is based on the fact that the concerns from supplier risk encourage SC managers towards further integration of internal capabilities to achieve higher resilience (Brusset and Teller, 2017). After highlighting internal and external resilience, SC resilience can be tailored to this research as "*the existence of dynamic capabilities of an enterprise and resilience of suppliers to absorb unexpected disruptions towards the normal work prior to disruptions."*

Generally speaking, "*you cannot improve what you cannot measure."* Therefore, a quantitative diagnostic tool to gauge a firm's healthiness for internal dynamic capabilities and suppliers' resilience is a paramount need (Wenzel et al., 2020). It helps to evaluate and analyze the current resilience health of a SC, and such a tool would identify the key parameters in which improvements are required. Although resilient supplier selection has been heavily studied, only a scarce number of literature resources are found that explore the role of dynamic capabilities (Brusset and Teller, 2017; Juan and Lin, 2019), and the linkages among supplier selection, dynamic capabilities, and SC resilience.

With the aforementioned motivation, this work presents the following objectives:

- To identify and quantify the internal (dynamic capabilities) and external (supplier capabilities) enablers required to build a resilient SC into a holistic framework.
- To develop a decision-making tool to quantify SC resilience internally and externally.
- To guide purchasing management teams to get a cost-effective and resilient supply of materials considering suppliers' profiles.
- To debate managerial and practical implications of the research to industries that have been hit by COVID-19 pandemic.

Towards these objectives, a hybrid integrated MADM-multi-objective programming model (MOPM)-based methodology towards a resilient SC is developed. It aims at diagnosing external resilience (i.e., resilience of suppliers) and internal resilience (i.e., dynamic capabilities of an enterprise). The developed methodology firstly presents a holistic framework that identifies, in addition to traditional criteria (TC), resilient sourcing enablers (RSEs) and dynamic capabilities enablers (DCEs) of an enterprise based on literature and experts' opinions. Following this, the relative importance of the enablers for supplier resilience and dynamic capabilities were quantified using rough set theory (RST) and analytical hierarchy process (AHP) algorithms, respectively. Then, these enablers were used in diagnosing resilience healthiness of suppliers and enterprises (i.e., its dynamic capabilities) using the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) algorithm. Next, the RST and VIKOR outputs were integrated into the MOPM. This integration further supports purchasing teams in having a cost-effective and resilient allocation of order sizes among suppliers. Furthermore, the model was implemented four times under different demand scenarios to cope with possible demand uncertainty. Despite the application of the proposed methodology on a food SC, the internal and external resilience metrics could be generalized on other SCs, for instance, a pharmaceutical SC.

This research contributes to the area of SC resilience by presenting an integrated methodology aimed at diagnosing SC resilience in terms of (1) internal dynamic capabilities of an enterprise, and (2) resilience of suppliers. In addition, unlike other research, it integrates the suppliers' resilience evaluation into the order allocation plan. The developed methodology is expected to help managers (e.g., purchasing managers, and production and engineering managers) in measuring and analyzing the weaknesses in their businesses and, subsequently, directing their efforts towards a better SC resilience. Also, this work poses some recommendations for the case analyzed to redevelop its strategies towards SC resilience based on research outcomes. In addition, it proposes general recommendations for other case studies that might have different SC resilience profiles.

This work represents the first quantitative attempt to provide a unified methodology for identifying and measuring internal and external resilience. To the best of our knowledge, no such endeavor has been discovered in related literature.

The next sections are presented as follows: In section 2, a state-of-the-art analysis is presented to position this study. In section 3, the phases and algorithms used for creating the SC resilience methodology are detailed. In section 4, this methodology is operated and examined on a case of a dairy sector. Finally, section 5 closes this research with conclusions, limitations, and future research avenues.

2. State-of-the-art analysis

In this research, the following literature topics were analyzed: SC risk management, the need for resilient suppliers and dynamic capabilities, and research contributions.

2.1 Supply chain risk management

Since the 1950s, research on risk management has been explored in the business context. Recently, researchers and practitioners have given a growing interest to managing SC risk due to the recent massive disruptions caused by disasters (e.g., floods, tsunamis, protests, pandemics, etc.) on business (Hosseini et al., 2020; Ivanov, 2020; Heydari et al., 2019; Gupta et al., 2016; Dasaklis et al., 2012; Thun et al., 2011; Dolgui and Ivanov, 2021; Ivanov and Dolgui, 2021a).

Generally, risk management requires highlighting, analyzing, overcoming, and controlling risks. Within the mindset of SC integration, managing global SCs risks should be performed throughout the entire SC. Risks have vital consequences on SCs, that might face disruptions, generating severe performance lags due to poorly executed risk management tools (Namdar et al., 2018; Ye et al., 2019; Christopher et al., 2011). Poor risk management can negatively affect product quality, forecasting, business reputation, turnover, and issues among companies' stakeholders (DuHadway et al., 2019; Louis and Pagell, 2019; Sawik, 2018 and 2020). Hence, companies are encouraged to have SC risk management in place to overcome these consequences (Manuj and Mentzer, 2008; Sokolov et al., 2016; Zsidisin and Henke, 2019; DuHadway et al., 2019).

Ivanov and Dolgui (2020) presented an analysis of literature on SC disruptions, mainly on its propagation (i.e., ripple effects); they proposed a methodical taxonomy in addition to theoretical avenues for handling disruptions caused by COVID-19-like pandemics. In the ripple effect context, Li et al. (2020) presented a simulation study to explore such a propagation through companies in SC networks. The propagation effects of supplier disruptions were quantified via a new measurement model presented by Kinra et al. (2020). Queiroz et al. (2020) presented a review study exploring the impact of COVID-19 pandemic on SCs. The authors concluded that influenza was the most impactful disruption-cause diagnosed, and they found that optimization of allocating resources was the most common theme. Fahimnia et al. (2015) and Snyder et al. (2016) conducted a review research on quantitative approaches used for managing SC disruptions. Similar approaches were studied previously by Heckmann et al. (2015), focusing on the definition of SC risks and associated theories. Chopra, Reinhardt, and Mohan (2007) argued that it is paramount to consider risks associated with both supply and disruption in SC risk management. Ivanov et al. (2017) reviewed research on designing and planning of SCs considering possible disruptions and recovery policies.

Generally, SC disruption risks can be categorized as internal risks (e.g., control and process) and external risks (e.g., demand and supply) (Christopher and Peck, 2004). Based on the tailored definition of SC resilience (see section 1), this research pursues its interest in coping with supply risks (external risks) and internal risks. Arguably, all companies are subject to these risks to a particular extent. In fact, SCs with a global influence embody a more complicated supply and demand chain and work under uncertain environments (Zsidisin and Henke, 2019). Therefore, these global influencing companies pose a greater extent of risks because of possible incidents, shutdowns, or stoppages, the political atmosphere, and bankruptcies. Accordingly, there is a paramount need to adopt instruments towards an efficient management of these risks.

2.2 Need for resilient suppliers

Kochan and Nowicki (2018), Ali et al. (2017), Ribeiro and Barbosa-Povoa (2017), Saenz et al. (2015), and Tukamuhabwa et al. (2015) presented review studies on SC resilience. Also, several research studies were conducted, primarily on resilient supplier selection considering the significant role of the sourcing process in SC management (Pereira et al., 2014; Cavalcante, 2019; Hoseini et al., 2019; Mohammed, 2019; Yoon, Talluri, and Rosales, 2020; Mohammed et al., 2020 and 2019). Most recently, Davoudabadi et al. (2020) developed a combined method that includes first aggregation and last aggregation to evaluate and rank suppliers based on resilience performance such as responsiveness and investment in building buffer capacity. Ghadikolaei and Parkouhi (2017) worked on examining a SC resilience status considering supplier performance in terms of buyer-supplier relationships, supply restrictions, collaborative development, and flexibility. Rao et al. (2017) presented supplier evaluation research based on the multi-attribute auction method considering supply risks. Pramanik et al. (2016) proposed a fuzzy MADM-based seeking the selection of resilient suppliers. The authors assessed resilience based on criteria of buffer capacity, critical nodes, responsiveness, re-engineering, and adaptive capability. Kamalahmadi and Mellat-Parast (2016) focused on the flexibility capability of sourcing to absorb disruptions. Adtiya et al. (2014) presented a TOPSIS-based supplier evaluation approach considering flexibility, multiple sourcing, and strategic stock as resilient sourcing criteria.

The literature proved that resilient suppliers represent a paramount arena in building SC resilience (Kamalahmadi and Mellat-Parast, 2016; Hosseini et al., 2019; Mohammed et al., 2020 and 2021). However, it revealed that resilience enablers are not well defined. Ponomarov and Holcomb (2009) argued that the main resilience pillars include reduction of uncertainty, agility, visibility, integration, structure and knowledge, flexibility/redundancy, complexity, re-engineering collaboration, transparency, and operational capabilities. However, Carvalho et al. (2012) selected redundancy and flexibility (Tomlin, 2006) as resilience criteria or enablers.

In this article, four resilience enablers: robustness, agility, leanness, and flexibility (RALF) that were presented by Purvis et al. (2016) are considered to evaluate the resilience performance of suppliers. In addition, visibility (V) is added to RALF to become V-RALF where the V is proposed by this research team. We hereby argue that higher visibility among SC companies would improve their agility in reacting to disruptions and building more flexibility in terms of preparedness.

2.3 Need for internal resilience (resilience of companies)

Recently, managers have redirected their organizational strategy from an emphasis on value and profit towards the incorporation of resilience due to continuously volatile marketplace. Hence, the literature experienced an increasing number of research studies on resilience in companies (Han et al. 2020; Macdonald et al., 2018). However, definitions, conceptualizations, and approaches on this topic (so-called internal resilience in this research) remain scarce in the literature. Ambulkar et al. (2015) defined internal resilience of a company as "*the capability of a firm to be alert to, adapt to, and quickly respond to changes brought by a supply chain disruption.*"

The majority of literature dedicated to SC resilience (Pettit et al., 2019; Li et al., 2020; Pettit et al., 2010; Scholten et al., 2020), and systems' resilience (Legido-Quigley et al., 2020; Guo et al., 2020; Norris et al., 2007) lacking the crucial consideration of internal resilience (Parker and Ameen, 2018; Conz and Magnani, 2020; Battisti et al., 2019). Very recently, Conz and Magnani (2020) presented a review analysis on internal resilience literature towards a definition and conceptualization. Based on their study, two main paths for explaining organizational resilience (i.e., absorptive resilience and adaptive resilience paths) are presented. Conz and Magnani (2020)'s proposal highlighted the dynamic nature of internal resilience conceptualization. Also, the study identified the crucial needs for a set of capabilities (e.g., readiness and persistence) within the two resilience paths.

Prior to that, Linnenluecke (2017) conducted a review analysis on internal resilience of companies. Billington et al. (2016) presented an exploratory study on internal resilience in four production companies located in four different areas. The research presented an internal resilience framework consolidating three elements: the contextual, the cognitive, and the behavioral. Poor infrastructure performance was recognized as a critical internal resilience aspect in responding to SC disruption (Romme et al., 2010; Ambulkar et al., 2015). The authors concluded that this cause has led to many failed companies. Parker and Ameen (2018) listed several measurements towards internal resilience, including: investment in risk-averting infrastructure, proactive risk management, resource reconfiguration, firm resilience, disruption impact, and company size. However, it can be observed that these measures might be interrelated where, for instance, company resilience is related to disruption impact and proactive risk management. Ambulkar et al. (2015) argued that building and reconfiguration of companies' resources play an important role in responding and then surviving from SC disruptions. They argued that this reconfiguration would enable companies to embed and evolve capabilities that help in absorbing the negative impact of external disruption risks. Pal et al. (2014) argued that readiness is the main player in building and managing internal resilience of companies.

It can be inferred that existing studies present several capabilities that need dynamic considerations. In particular, due to the characteristics of the COVID 19 pandemic, dynamically adaptable capabilities for assessing resilience in SCs are necessary (Ruel et al., 2021; Ivanov and Dolgui, 2021b). Thus, this research, we highlight the need for dynamic capabilities to understand the internal capability of a firm, as follows.

2.4 Need for dynamic capabilities

The concept of dynamic capability was first presented by Teece (1997). It focuses on analyzing how enterprises can attain a competitive and sustained business in dynamic markets (Eisenhardt and Martin, 2000; Teece et al., 1997). The dynamic capability was partially created as an advancement development of the resource-based view (RBV) lens; it arguably consisted of a number of resources (Wernerfelt, 1984; Barney, 1991). An enterprise can attain a sustained competitive advantage if some of these resources are valuable and robust. Notwithstanding, there is a limited body of knowledge to identify, evaluate, and improve these resources or securing enablers to attain a competitive and resilient business from which the dynamic capability concept emerges (Brusset and Teller, 2017; Juan and Lin, 2019; Ponomarov, 2012; Pal et al., 2014).

An enterprise's internal capabilities have been recognized as a crucial aspect towards sustainable competitive advantages (Jabbarzadeh et al., 2018; Naguib et al., 2017; Schreyogg and Kliesch-Eberl, 2007). The dynamic capabilities of an enterprise are aimed at rapidly building event-explicit capability based on the deviation of situation dynamism (Eisenhardt and Martin, 2000). Nonetheless, whether dynamic capabilities can boost a long-term or short-term competitive advantage for an enterprise is still under debate (Kuo et al., 2017; Banerjee et al., 2018; Eisenhardt and Martin, 2000). In the sense of this research, the dynamic capabilities are expected to bring a long-term competitive and sustained business for an enterprise upon the experience of COVID-19 pandemic disruptions.

For a company, the ultimate accomplishment of its dynamic capabilities lies in (1) identifying what are the main enablers for dynamic capabilities, and (2) diagnosing the current dynamic capabilities and then improving them while remaining dynamic for disruptions. A fluctuated research spectrum on dynamic capabilities has been presented in the literature considering different perspectives: e.g., an enterprise's preference, SC managers' points of view, study sectors, and so forth. Arguably, enablers of dynamic capabilities are not unified in the literature. Only limited review studies are presented on dynamic capabilities (Barreto, 2010; Piening, 2013; Schilke et al., 2018).

Ponomarov and Holcomb (2009) identified three enablers of dynamic capabilities called readiness, response, and recovery. This was also supported by a review study by Hohenstein et al. (2015). These authors identified another enabler of growth. Teece (2007) argued that dynamic capabilities of an enterprise depend on "sensing opportunities, seizing them, and reconfiguring itself around them".

Based on the aforementioned studies, for this study, the enablers components of dynamic capabilities are sensing (S), readiness (R), response (R), recovery (R) and growth (G) (SRRRG). Then, dynamic capabilities can now be defined as "*enterprises must have the sense of potential disruptions and accordingly be structured to consolidate readiness for disruptions and response effectively, aiming at recovering its normal state, and then growing to a more robust state, to cope with unexpected disruptions*".

2.5 Research contributions

The literature review highlights a substantial contribution in SC resilience, but it is limited in terms of dynamic capabilities (Brusset and Teller, 2017; Juan and Lin, 2019). Remarkably, limited studies have addressed the resilience aspect using quantitative approaches in terms of assessing and analyzing SC resilience problems (Mohammed, 2020; Mzougui et al., 2020; Mohammed et al., 2020; Hohenstein et al., 2015; Ghadikolaei and Parkouhi, 2017). This is the first study that: (i) discusses, analyzes, and presents the enablers of supplier resilience (V-RALF) and enterprise's internal dynamic capabilities (SRRRG) into a unified and holistic framework towards a resilient SC; (ii) integrates the relative weight of V-RALF, revealed via

MADM algorithms, into a multi-objective programming model modelled to handle an order size task and (iii) not only assesses suppliers' resilience performance, unlike other research studies, but also explores the internal dynamic capabilities of enterprises towards SC resilience.

In other words, this work represents the first quantitative attempt to provide a unified methodology for identifying and measuring SC resilience via an enterprise's internal and external resilience. In this context, Table 1 presents a review on internal and external resilience metrics found in the literature. In addition, this research presents two new definitions for SC resilience and internal dynamic capabilities. The latter was newly consolidated considering five enablers (SRRRG).

Table 1. Resilience metrics found in the literature

Study	Resilience metrics	Internal	External
Ambulkar et al. (2015)	Alertness, adaptation, and response	*	
McPhee (2014)	Surviving - Capacity to survive disruptions.	*	
Conz and Magnani (2020)	Readiness and persistence	*	
Teece (2007)	Sensing opportunities, seizing them, and reconfiguring itself around them	*	
Mohammed et al. (2020) and (2018), and Purvis et al. (2016)	Robustness, agility, leanness and flexibility		*
Romme et al. (2010)	Readiness of company infrastructure	*	
Ponomarov and Holcomb (2009)	Reduction of uncertainty, agility, visibility, integration, structure and knowledge, flexibility/redundancy, complexity, re-engineering collaboration, transparency, and operational capabilities		*
Parker and Ameen (2018)	Investment in risk-averting infrastructure, proactive risk management, resource reconfiguration, firm resilience, disruption impact, company size	*	
Acquaah et al. (2011)	Persistence withstanding	*	
Carvalho et al. (2012)	Redundancy and flexibility		*
This work	V-RALF (External) and SRRRG (Internal)	*	*

3. Research methodology

The unprecedented COVID-19 pandemic resulted in massive disruptions in the manufacturing sector due to the blockage of materials and the movement of people. New understanding and adaptive strategies and practices are necessary to build up SC resilience.

A manufacturing process for a dairy enterprise (henceforth called Company D) was disrupted due to shortages of milk and packaging materials. These shortages stemmed from border closures after the rapid spread of COVID-19 in March 2020. This research is motivated by Company D's need for a resilient SC.

The enterprise's objective was to improve suppliers' performance either by improving current suppliers' profile or by seeking new resilient suppliers. The research team argued that having resilient suppliers plays a significant role. However, this step should be initiated in conjunction with improving the enterprise's internal resilience in terms of having the dynamic capabilities to internally cope with unexpected disruptions (e.g., preparedness of backup local suppliers). This research complies with the argument to enable the case enterprise in evaluating the resilience performance of current suppliers and diagnosing its internal resilience (i.e., dynamic capabilities). To this end, the internal and external SC resilience methodology was developed from the following six points:

1. Identify traditional criteria (TC), resilience enablers (RSEs), and dynamic capabilities enablers (DCEs) as shown in Figure 1. These TC, RSEs, and DCEs were identified based on the literature and from this research team and experts' perspectives. Table 2 presents definitions of resilience enablers and dynamic capabilities enablers (Ponomarov and Holcomb, 2009; Teece, 2007; Purvis et al., 2016; Hohenstein et al., 2015).
2. Quantify the degree of importance for TC and RSEs by using RST from decision makers' perspectives.
3. Evaluate and rank suppliers vis-à-vis resilience and traditional performance by using VIKOR.
4. Allocate an optimal order size among suppliers considering economic and resilience aspects using the developed MADM-MOPM and incorporating the weights from phases 2 and 3.
5. Quantify the degree of importance for DCEs (i.e., SRRRG) by using AHP from the enterprise and academic perspectives. The academic perspective is hereby involved because the concept of dynamic capabilities has been newly presented to the enterprise under study.
6. Measure the degree of healthiness for the enterprise's internal resilience status vis-à-vis SRRRG by using VIKOR.

Figure 2 shows a framework for obtaining the proposed SC resilience methodology.

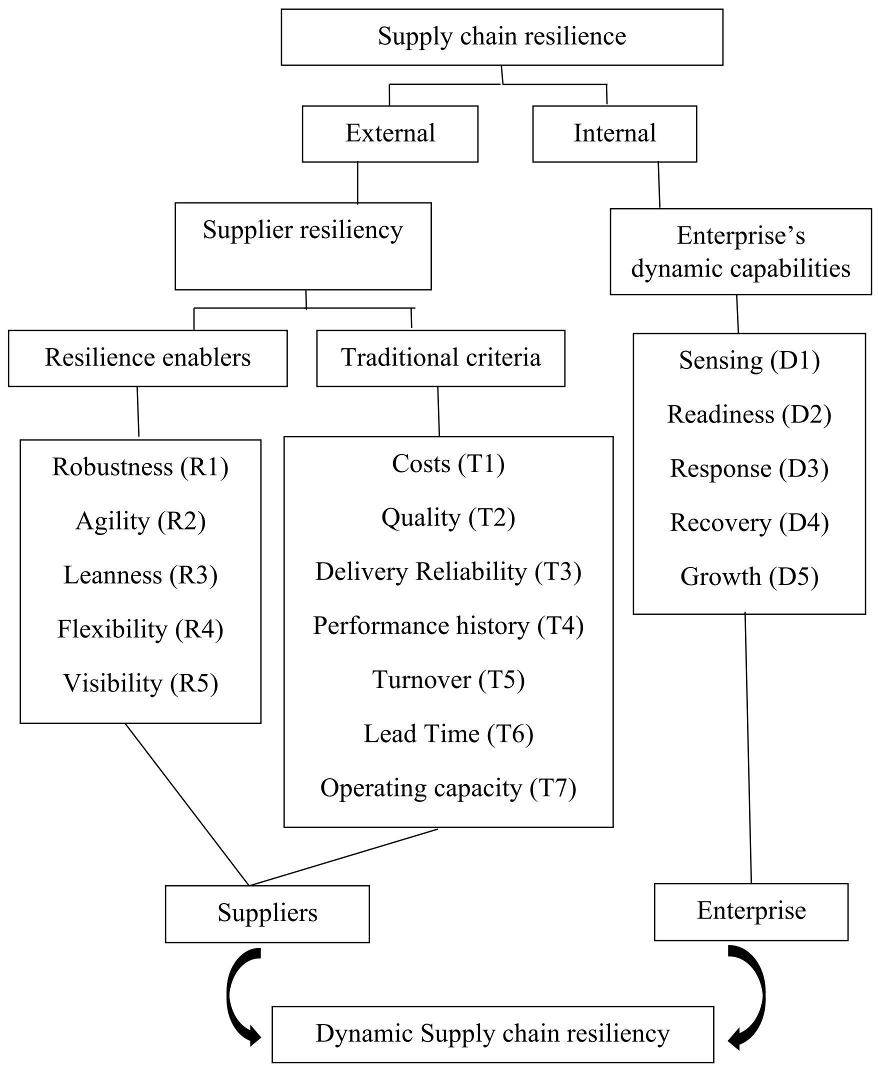

Figure 1. Criteria and enablers towards internal and external resilient SC.

Table 2. Definitions related to RSEs and DCEs

Enabler	Definition
Sensing	Detecting and evaluating opportunities of disruptions outside your enterprise.
Readiness	The degree of preparedness in terms of resources, suppliers and plans for the sensed potential disruptions.
Respond	Measuring the effectively and efficiency of and enterprise to timely response to a disruption based on its resources and degree of readiness.
Recovery	The capability of an enterprise to return to its traditional position.
Growth	Not only return to an original state upon a disruption but growing to an improved state. Also, it describes the possibility of an enterprise to learn and merge new approaches in response to risk events.
Robustness	Measures the ability to withstand disruptions to elements within the supply network, either through the immediate availability of alternative suppliers or being capable of quickly planning the incorporation of new suppliers.
Agility	Evaluates the ability to respond in a quick and well-coordinated manner to comparatively small market opportunities, through having a partner able to handle unexpected / volatile demand.
Leanness	Assesses the absence of excess / waste and hence the ability to fulfil predictable, baseline, demand in an efficient manner.
Flexibility	Gauges the ability to respond easily to disturbances in the supply network, whilst maintaining control of costs and lead-times. This involves having processes in place that enable effective response when disturbances in the supply chain are sensed.

Visibility	Sharing relevant information which would improve sensing of unexpected orders and fulling them. In other words, it is the ability of suppliers to see the light at the end of tunnel and run towards it based on their flexibility and agility.

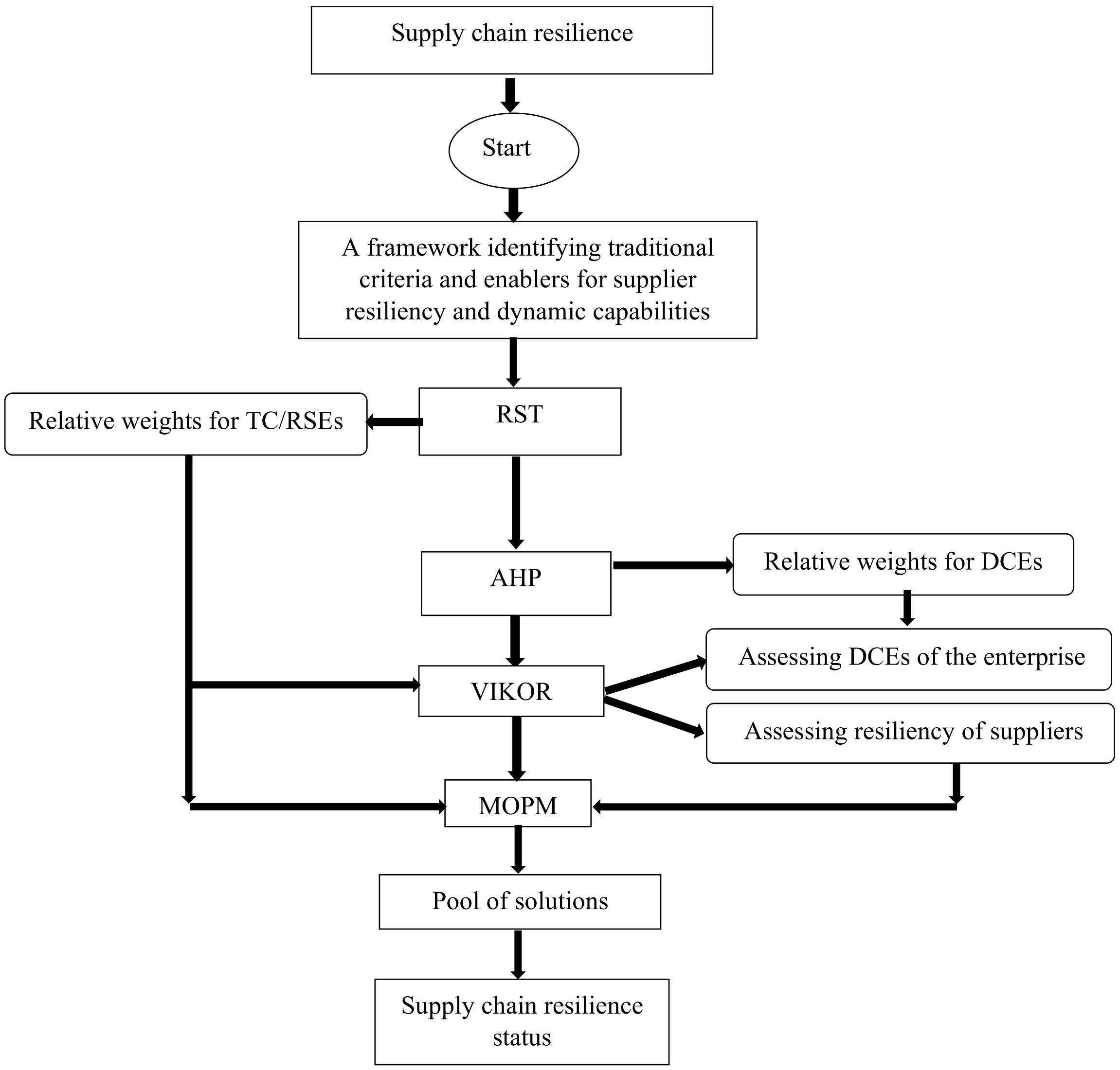

Figure 2. A framework for the dynamic SC resilience.

3.1 Methods: RST/AHP/VIKOR

3.1.1 Weighting traditional criteria and resilience enablers: RST

RST was introduced as a MADM algorithm to cope with shortages in data such as inconsistent data (Pawlak, 1997). As an MADM algorithm, RST performs well in inconsistent evaluation environments (Magnani, 2003). In RST, the datasets are signified in two forms: information content and decision tables. For further details on Rough Set Theory, readers are referred to Nowicki (2019); Zhang et al. (2016). The RST application steps towards TC/RSEs weight are as follows:

Step 1: Ask experts – from the case company – to evaluate the traditional and resilience performances of alternatives to be evaluated and ranked.

Step 2: Build the aggregated decision matrix by calculating the average mean for experts' evaluation obtained from step 1.

Step 3: Identify the numbers of suppliers that are given the same scale in step 2.

Step 4: Calculate the level of information (I) content related to the traditional criteria and resilient sourcing enablers by using Formula 1.

$$I(T\,\&\,R) = 1 - \frac{1}{\left|U^2\right|}\sum_{t\in T}\left|X_t^{C\&R}\right|^2 \qquad (1)$$

Where U refers to alternatives and $\left|X_t^{C\&R}\right|$ refers to alternatives that fall under the same scale.

Step 5: Quantify the relative importance of traditional criteria and resilient sourcing enablers by using Formula 2.

$$w(T\,\&\,R) = \frac{I(T\,\&\,R)}{\sum_{i\in J} I(T\,\&\,R)} \qquad (2)$$

3.1.2 Weighting dynamic capabilities enablers (SRRRG): AHP

AHP is the most popular MADM method originally created by Saaty (Saaty, 1980) for hierarchical decision-making analysis encountering both qualitative and quantitative criteria. It performs decision-evaluation analysis via pairwise comparisons among criteria using the evaluation scales. It has been applied in a wide range of application sectors such as engineering and SCS (Ho and Ma, 2018; Darko et al., 2019; Dos Santos et al., 2019; Majumdar et al., 2020). In the current research, this method was employed to calculate weights for DCEs. The application steps for the AHP method can be found in Saaty, 1980; Luthra et al., 2016; Mohammed et al., 2020; Wu et al., 2021).

3.1.3 Evaluating suppliers and dynamic capabilities: VIKOR

The VIKOR algorithm, developed by Serafim Opricovic (Opricovic, 2011), is one of the most commonly employed MCDM in the SC context (Govindan et al., 2015; Rashidi et al., 2020). VIKOR helps in choosing the best alternative in the existence of a contradicted set of evaluation criteria. It encounters the distance to ideal and worst solutions to rank alternatives using the evaluation scale (Opricovic and Tzeng 2007; Opricovic, 2011). The literature proved VIKOR's output efficiency via its application in several SC decision-making problems (Rashidi et al., 2020; Ikram et al., 2020; Rostamzadeh et al., 2015). In the current study, VIKOR was applied for two evaluation tasks: suppliers' performance vis-à-vis TC/RSEs and the case enterprise's current resiliency healthiness in terms of the dynamic capabilities. Steps for applying the VIKOR algorithm can be found in Luthra et al., 2016 and Rostamzadeh et al., 2015.

3.2 The hybrid MADM-MOPM

This section presents the solution for the order size problem, modelled using the multi-objective optimization. Table 3 presents symbols used in the MADM-MOPM. This modelling guides the purchasing team to set an orders size incorporating economic and resilience aspects. Two objective functions are modelled, including:

1. Minimization of related costs presented as Min RC, and
2. Maximization of value of resilience purchasing presented as Max Res.

Table 3. Symbols used in the MADM-MOPM modelling

I	set of suppliers, $i = 1,\dots, I$	IW^t	importance weight of traditional criteria revealed via RST
C_i^p	purchasing cost per unit of product ordered from supplier i	IW^r	importance weight of resilience criteria revealed via RST
C_{ij}^t	unit transportation cost per mile from supplier i	iw_i^t	importance weight of supplier i revealed via VIKOR towards traditional performance
C_i^a	administration cost per order of supplier i	iw_i^r	importance weight of supplier i revealed via VIKOR towards resilience performance
d_i	transportation distance (mile) of product from supplier i	D_i	quantity (units) of product to be ordered from supplier i
TC	transportation capacity (units) per lorry	C_i	supply capacity (units) of supplier i
q_i	quantity of products ordered from supplier i		

Objective function 1 (*RC*): Formula 3 refers to the modelling of minimum costs including purchasing cost per item, transportation cost per item/mile, and administration cost per item. Also, the first term aims at modelling the minimization of low traditional supplier performance by incorporating weights of TC and suppliers retrieved from RST and VIKOR, respectively. This objective function is modelled as follows:

$$Min \;\; RC = Min\left(IW^t \left(\sum_{i \in I} iw_i^t q_i \right) \right) + \sum_{i \in I} C_i^p q_i + \sum_{i \in I} C_i^a q_i + \sum_{i \in I} C_i^t \left\lceil \frac{q_i}{TC} \right\rceil \; d \tag{3}$$

Objective function 2 (*Res*): Formula 4 refers to the modelling of maximum resilient purchasing value. To this desire, weight for RSEs obtained by RST in addition to the suppliers' weight obtained by the VIKOR method are incorporated in this formula considering the order size decision variable. This objective function is modelled as follows:

$$Max \ \mathrm{Re}s = IW^r \sum_{i \in I} q_i iw_i^r \tag{4}$$

These two objective functions are limited by supply and demand constraints as follows:

Formula 5 limits the order size by the supply capacity for all suppliers.

$$\sum_{i \in I} q_i \leq C_i \, s_i \tag{5}$$

Formula 6 enforces the fulfilment of orders by selected suppliers.

$$\sum_{i \in I} q_i \geq \mathrm{D}_i \tag{6}$$

Non-negativity for the order size variable is limited by Formula 7.

$$q_i \quad \geq 0 \quad \forall i \tag{7}$$

3.2.1 Pareto solutions: ε-constraint

The multi-objective optimization models can be solved by transforming them to a mono-objective model using the traditional multi-objective solving approach. In this work, one of the most popular used approaches, called the ε-constraint approach, was applied to transform the MOPM into a mono-objective model by moving the second objective function to the constraint set (Ehrgott, 2005; Nujoom et al., 2019; Mohammed et al., 2019a and 2017). Accordingly, the current model can be represented as follows:

$$Min \ RC = IW^t \left(\sum_{i \in I} iw_i^t q_i \right) + \sum_{i \in I} C_i^p q_i + \sum_{i \in I} C_i^a q_i + \sum_{i \in I} C_i^t \left\lceil \frac{q_i}{TC} \right\rceil d_i \tag{8}$$

This objective function is limited by Formulas 9 and 10 in addition to 5-7.

$$Max \ \mathrm{Re}s \geq \varepsilon \tag{9}$$

$$[\mathrm{Re}s]^{\min} \leq \varepsilon \leq [\mathrm{Re}s]^{\max} \tag{10}$$

4. Application: a real case study

To explore the applicability and effectiveness of the developed methodology, it was applied on a manufacturing enterprise in the dairy industry. The case enterprise produces various dairy products (e.g., fresh milk, cheese, infant products, etc.) that are distributed nationally via several collaborated retailers. The purchasing team utilizes geographically distant suppliers to supply some of their production needs for milk, flavors, and packing materials. However, they source part of these materials and items from local suppliers. The SC manager clarified that they intend to nearshore due to a lack of sufficient local suppliers that comply with their quality requirements. In late March 2020, the border was closed with the nearshoring countries to battle the rapid spread of the COVID-19 pandemic. Obviously, this closure interrupted their SC and resulted in shortages of manufacturing and packaging materials after only three weeks. In fact, for highly perishable products like milk, serious disruptions occurred even more quickly. Very recently, Company D initiated an ultimate plan towards establishing a resilient SC. They asked why could they not efficiently sustain manufacturing? How could their enterprise be viable against the next disruption and sustain a long-term stable future? These questions, formed by the research team, describe concerns highlighted by managers of the case enterprise.

Within these questions, a research collaboration was established to support Company D in building its SC resilience. Therefore, this work presents the internal and external SC resilience methodology. This helps the purchasing team to improve their sourcing strategy towards resilience; the objective is to develop a resilient supplier selection approach based on traditional criteria and resilience enablers (see Figure 2). However, it was discussed that resilient suppliers would not withstand a disruption unless the case enterprise is resilient. Thus, this work also helps managers to build up the internal resilience by incorporating dynamic capabilities (SRRRG) into their SC risk management strategy.

It should be noted that re-applicability of this methodology in another case study would need a re-approval of the selected internal and external SC resilience metrics and traditional criteria with the relevant manager in that case study.

Three decision makers were invited to participate in the evaluation steps of the internal resilience (i.e., DCEs). These decision makers are an academic expert in SC risk management, a SC manager, and the head of operations and engineering department at the case enterprise. Also, three members (i.e., M1, M2, and M3) from the purchasing department participated in the supplier's evaluation vis-à-vis TC/RSEs. The three members are a senior buyer and two buyers. A meeting was held with the three members individually to conduct the evaluation process. The purchasing team has nominated five of its current packaging materials suppliers for the validation purposes.

4.1 Quantifying relative importance of TC/RSEs: RST

This sub-section presents steps for calculating the weight of traditional criteria and resilient sourcing enablers by implementing the RST algorithm as follows:

Step 1: The traditional and resilience performances of the five selected suppliers were evaluated by the three members (M1, M2, and M3). Table 4 lists the aggregated matrix by taking the average mean for the three evaluations. The opinions of M1, M2, and M3 were given the same weight.

Step 2: The numbers of suppliers evaluated in a similar scale are identified. For instance, for traditional criterion 1 (T1), two suppliers were evaluated of scale 5, two suppliers were evaluated of scale 7, and one supplier was evaluated of scale 9. Also, with regard to resilience enabler 5 (R5), four suppliers were evaluated of scale 3 and one supplier of scale 5.

Step 3: The level of information (I) content related to the traditional criteria and resilient sourcing enablers were calculated by using formula 1 (see section 3.1.1). Table 4 lists the Information content values. For instance, the information content for T1 was determined as follows:

$$I(T1) = 1 - \left(\frac{1}{(5\wedge 2)} * (2\wedge 2 + 2\wedge 2 + 1\wedge 2)\right) = 0.64 \tag{10}$$

Step 4: The relative weights of traditional criteria and resilient sourcing enablers were determined (see Table 5) by applying formula 2 (see section 3.1.1). For instance, relative weight of traditional criterion one (T1) was revealed as follows:

$w(T1) = \frac{0.64}{3.84} = 0.166667$, where 3.84 refers to the summation of information contents of traditional criteria.

Table 4. The aggregated matrix related to RST

Suppliers\Criteria	T1	T2	T3	T4	T5	T6	T7	R1	R2	R3	R4	R5
S1	7	3	5	1	7	5	7	3	5	5	7	3
S2	7	5	5	3	3	7	5	3	5	5	5	3
S3	5	5	5	5	5	5	5	7	5	5	3	3
S4	5	7	7	5	3	5	5	5	7	7	7	5
S5	5	5	5	5	3	5	5	5	5	5	5	3

Table 5. Relative weights of TC/RSEs revealed via RST

	Criteria/enablers	Information content	Weight
TC	**T1**	**0.64**	0.1667
	T2	0.56	0.1458
	T3	0.56	0.1458
	T4	0.56	0.1458
	T5	0.64	0.1667
	T6	0.32	0.1458
	T7	**0.56**	0.0833
RSEs	R1	0.56	0.2500
	R2	0.32	0.1429
	R3	0.32	0.1429
	R4	**0.72**	0.3214
	R5	0.32	0.1429

As shown in Table 5, the highest importance (0.1667) is given similarly to the cost and turnover while the operating capacity turned out the lowest one (0.0833). Also, flexibility is the most importance resilience criterion (0.3214) while criteria of the agility, leanness, and visibility achieved the least importance (0.1429). This echoes the concerns shared during the interviews by two members regarding some suppliers who do not react smoothly to disruptions in supply, failing to maintain a reasonable purchasing cost.

It is noteworthy that the SC manager mentioned that the enterprise currently gives more importance to resilience enablers rather than to traditional criteria. Considering this bias, we have not determined the global relative weight of traditional and resilience aspects as it would be obvious that resilience aspect is more important.

4.2 Evaluating suppliers' resilience performance: VIKOR

After the relative weights for the traditional criteria and resilience enablers were revealed via RST, the VIKOR algorithm was implemented to evaluate suppliers according to their traditional and resilience profiles. This helps the purchasing team to know which supplier needs either performance improvement or replacement. The VIKOR algorithm was implemented as follows:

Step 1: Table 6 presents the normalized matrix that is based on the aggregated matrix. Then, the weighted normalized decision matrix was built by multiplying the sub-criteria weights obtained by RST with the normalized matrix as shown in Table 7.

Step 2: Values of (f+)-fij and w*(((f+)-fij)/(f+)-(f-)) were determined as shown in Table 7.

Step 3: Values related to Si, Ri and Qi were determined as reported in Table 8.

Table 6. Normalized and weighted normalized decision matrices

Supplier	T1	T2	T3	T4	T5	T6	T7	R1	R2	R3	R4	R5
S1	0.532	0.260	0.410	0.109	0.697	0.410	0.574	0.277	0.410	0.410	0.559	0.384
S2	0.532	0.434	0.410	0.325	0.299	0.574	0.410	0.277	0.410	0.410	0.399	0.384
S3	0.380	0.434	0.410	0.542	0.498	0.410	0.410	0.647	0.410	0.410	0.239	0.384
S4	0.380	0.607	0.574	0.542	0.299	0.410	0.410	0.462	0.574	0.574	0.559	0.640
S5	0.380	0.434	0.410	0.542	0.299	0.410	0.410	0.462	0.410	0.410	0.399	0.384

Weighted normalized decision matrix

Weight (TC/RSEs)	0.090	0.104	0.060	0.104	0.104	0.060	0.059	0.119	0.060	0.060	0.119	0.060
Supplier\TC/RSEs	T1	T2	T3	T4	T5	T6	T7	R1	R2	R3	R4	R5
S1	0.048	0.027	0.025	0.011	0.073	0.025	0.034	0.033	0.025	0.025	0.067	0.023
S2	0.048	0.045	0.025	0.034	0.031	0.034	0.025	0.033	0.025	0.025	0.048	0.023
S3	0.034	0.045	0.025	0.057	0.052	0.025	0.025	0.077	0.025	0.025	0.029	0.023
S4	0.034	0.063	0.034	0.057	0.031	0.025	0.025	0.055	0.034	0.034	0.067	0.038
S5	0.034	0.045	0.025	0.057	0.031	0.025	0.025	0.055	0.025	0.025	0.048	0.023
Min	0.034	0.027	0.025	0.011	0.031	0.025	0.025	0.033	0.025	0.025	0.029	0.023
Max	0.048	0.063	0.034	0.057	0.073	0.034	0.034	0.077	0.034	0.034	0.067	0.038
f+	0.048	0.063	0.034	0.057	0.073	0.034	0.034	0.077	0.034	0.034	0.067	0.038
f-	0.034	0.027	0.025	0.011	0.031	0.025	0.025	0.033	0.025	0.025	0.029	0.023
(f+)-(f-)	0.014	0.036	0.010	0.045	0.042	0.010	0.010	0.044	0.010	0.010	0.038	0.015

Table 7. VIKOR related output

Supplier	TC/RSEs											
	T1	T2	T3	T4	T5	T6	T7	R1	R2	R3	R4	R5
S1	0.000	0.036	0.010	0.045	0.000	0.010	0.000	0.044	0.010	0.010	0.000	0.015
S2	0.000	0.018	0.010	0.023	0.042	0.000	0.010	0.044	0.010	0.010	0.019	0.015
S3	0.014	0.018	0.010	0.000	0.021	0.010	0.010	0.000	0.010	0.010	0.038	0.015
S4	0.014	0.000	0.000	0.000	0.042	0.010	0.010	0.022	0.000	0.000	0.000	0.000
S5	0.014	0.018	0.010	0.000	0.042	0.010	0.010	0.022	0.010	0.010	0.019	0.015
	w*(((f+)-fij)/(f+)-(f-))											
Weight (TC/RSEs)	0.090	0.104	0.060	0.104	0.104	0.060	0.059	0.119	0.060	0.060	0.119	0.060
Suppliers\TC/RSEs	T1	T2	T3	T4	T5	T6	T7	R1	R2	R3	R4	R5
S1	0.000	0.105	0.060	0.105	0.000	0.060	0.000	0.119	0.060	0.060	0.000	0.060
S2	0.000	0.052	0.060	0.052	0.105	0.000	0.060	0.119	0.060	0.060	0.060	0.060
S3	0.090	0.052	0.060	0.000	0.052	0.060	0.060	0.000	0.060	0.060	0.119	0.060
S4	0.090	0.000	0.000	0.000	0.105	0.060	0.060	0.060	0.000	0.000	0.000	0.000
S5	0.090	0.052	0.060	0.000	0.105	0.060	0.060	0.060	0.060	0.060	0.060	0.060

Table 8. Si, Ri, and Qi values related to suppliers

	Si	Ri	Qi	Global weight (Si+Ri+Qi) (between 0 and 3)	Rank
S1	0.5771	0.1194	0.8987	1.7640	1/5
S2	0.6915	0.1045	0.8889	1.6849	2/4
S3	0.5522	0.1194	0.8767	1.3794	4/2
S4	0.1269	0.0522	0.0000	0.1791	5/1
S5	0.6244	0.1045	0.8294	1.3894	3/3

With respect to the value of Ri representing the distance between the suppliers' performance and the ideal performance, S4 reveals the closest distance (0.0522), followed by S5=S2 and S3=S1. As shown in Table 8, the global weight obtained via the summation of the three values, S4 also proved its superiority over other suppliers revealing the lowest value of 0.1791 followed by S3 (1.3794), S5 (1.3894), S2 (1.6849), and S1 as the worst suppliers with the furthest distance to the ideal solution (1.7640). The suppliers' performance could be categorized into two clusters: low performance (the global weight > 1) and high performance (the global weight < 1); towards a clear linguistic description. Arguably, most of suppliers, for the case company, revealed very close low performance.

Hence, it was recommended that the buyers should start (1) working with suppliers to improve their resilience performance where possible, and (2) finding new alternative sources. Also, the purchasing team was advised to conduct this recommendation on critical parts and materials as priority. Furthermore, the purchasing team was notified to evaluate performance of tier-two suppliers, if applicable, once direct suppliers' performance is improved considering the important role of tier-two, and onwards, suppliers (Villena and Gioia, 2018; Arroyo-López et al., 2012). For a long-term realignment of their purchasing strategy, they might consider the evaluation for suppliers on all tiers. Also, this might include a regular formal check (e.g., twice per year) for the supplier performance via a collaborative agreement. A poor output for this regular check would be considered an early alarm for SC resilience deterioration.

It can be inferred that this output clarifies, partially, that the case company was hit by COVID-19 disruptions due to the low performance of suppliers. The SC manager said that SC resilience has not been given the desired interest as this disruption has not been experienced before.

4.3 Resilient and cost-effective order size allocation: The hybrid MADM-MOPM

After assessing suppliers' performance vis-à-vis TC/RSEs, the three members (generally, the purchasing team) in Company D were also asked to identify the optimal order size that should be requested from suppliers. Buyers allocate this randomly regardless of the performance profile. They consider the purchasing discounts as the primary consideration. This research proposes to allocate the order size among suppliers according to (1) their resilience performance and (2) the possible minimum related costs (e.g., purchasing cost). Hence, the hybrid MADM-MOPM model (see section 3.2) was developed to set the order size's decision variable from the five suppliers towards the minimization of related cost and maximization of value of resilience purchasing. The latter incorporates the relative weights obtained via RST (weight of RSEs, see Table 5) and VIKOR (global weight of suppliers, see Table 8). This further expresses the suppliers' performance and the importance of resilience, from the decision makers' perspective, into the purchasing process. Table 9 lists input data that was provided by the SC manager. It also includes data related to the weights for TC/RSEs obtained by RST and suppliers' global weights obtained by VIKOR. It should be noted that these weights were amplified 100 times to be in a closer mathematical environment to the order size.

Table 9. Data for the case enterprise

	S1	S2	S3	S4	S5
C_i^p £/unit	40	45	42	39	40
C_i^t £/mile	1.5	1.5	1.5	1.5	1.5
C_i^a *£/unit*	1.2	1.2	1.2	1.2	1.2
d_i *mile*	150	13	122	82	133
TC unit	100	100	100	100	100
S_i unit	9500	7000	4000	3000	2500
D			8820		
CO_{2i} *g/m*	260	260	260	260	260
IW^t	41.9	41.9	41.9	41.9	41.9
IW^r	58.1	58.1	58.1	58.1	58.1
iw_i^t	7.58	7.38	7.51	8.6	7.13
iw_i^r	41.9	41.9	41.9	41.9	41.9

The two objective functions were optimized by applying the ε-constraint method. In this work, it was decided to keep cost minimization objective function (formula 8) and move the maximization of value of resilience purchasing to the ε-based constraint (formula 9). Objective function two (*Max Res*) was optimized independently to derive its best and worst values aiming to allocate ε values (see formula 10). Hence, the values between the two extremes were split to 10 values. The latter values were set separately to the ε parameter shown in formula 9.

Table 10 presents a pool of 10 Pareto solutions obtained by optimizing the hybrid MADM-MOPM model. Also, there is an order size correlated with each of these 10 solutions. For instance, Table 10 also lists the order size correlated with solution number 2. This solution setting requires minimum costs of 433,284.67 and gives a maximum value of resilience purchasing of 4,091.84. This order size is split among three suppliers: 2, 4, and 5 (0 1 0 1 1) in which 5496, 3000, and 324 are assigned to these suppliers, respectively.

Table 10. Pareto solutions

Objective functions solutions				
#	ε value	*Min RC*	*Max Res*	Selected Supplier
1	2,824.61	400,411.94	3,059.07	0 1 0 1 0
2	3,491.64	433,284.67	4,091.84	0 1 0 1 1
3	4,158.67	514,832.66	4,158.85	0 1 0 1 1
4	4,825.70	605,628.40	4,825.95	0 1 0 1 1
5	5,492.73	696,429.54	5,492.84	1 1 1 1 1
6	6,159.76	787,273.49	6,159.84	0 1 1 1 1
7	6,826.79	878,118.81	6,826.85	1 1 1 1 1
8	7,493.82	968,962.76	7,493.85	1 1 1 1 1
9	8,160.85	105,980,8.29	8,160.86	1 1 1 1 1
10	8,827.88	115,065,3.83	8,827.88	0 1 0 1 1

Assigning of order size number 2					
	1	2	3	4	5
1	0	7000	0	1820	0
2	0	5496	0	3000	324
3	0	4494	0	3000	1326
4	0	3491	0	3000	2329
5	1	2564	898	3000	2499
6	0	1848	1961	3000	2500
7	1	1133	3022	3000	2500
8	68	437	4000	3000	2500
9	1037	1	3841	3000	2500
10	0	5100	0	3000	2500

Now, the buyers should select one solution based on personal preferences to get the final order size allocation. In this application, it was agreed to select the order size based on solution 4. However, it was clarified to the participants that they can select any solution that its objective values comply with their favorites. The nominated solution costs (*Min RC*) 605,628 and leads to resilience purchasing value (*Max Res*) of 4825. Solution 4 splits the order size among suppliers 2, 4, and 5 recommending an orders size of 3491, 3000, and 2329 units from recommended suppliers, respectively. It is noticed that most solutions tend to split the orders among three suppliers. This eases the purchasing team task in handling three suppliers rather than five.

The SC managers mentioned that this approach could be applicable in normal cases where borders are not closed as two of these suppliers are in near-distance countries. Therefore, it was proposed that the purchasing team should encourage current local suppliers to scale up their supply capacity in addition to their resilience performance. For instance, this could include their agility performance by rapidly responding to urgent supply requests, either by increasing their supply capacity or by having the ability to collaborate with other suppliers to fulfil the extra demand. Generally, the SC managers are encouraged to reshore most of their sourcing to local suppliers as part of the enterprise's SC risk management strategy. This could include the ability to keep the nearshoring towards competitive advantages, but with the ability to switch all sourcing locally in case of disruptions. It was argued that a shorter SC would (1) boost SC resilience and (2) lead to cheaper transportation costs. The boost in SC resilience would be in:

1. Having more response suppliers (i.e., local) compared to distant ones,
2. Building further collaboration and joint growth via frequent "supplier visits" by the purchasing team that would not be easy for distant ones,
3. Enhancing the visibility aspect of SC resilience as face-to-face discussion would improve information sharing, and
4. Conducting more frequent supplier audits and checks.

4.3.1 Capturing the volatile marketplace

The marketplace tends to be highly uncertain in several sectors (e.g., food, electronics, and fashion), and this uncertainty results from several factors (e.g., economic or safety) or occasions (retailers' closures, curfew, etc.). Managers within but players need to adjust their decisions regarding, for instance, sourcing, production planning, and labor force according to the predicted demand size. Hence, demand uncertainty was highlighted as a source of SC disruption risk (Christopher and Peck, 2004). In this work, the possible uncertain demand is captured by considering four demand alteration periods. This includes a 10% and 20% increase or decrease in demand. To this end, the MADM-MOPM model was applied four times considering these four demand sizes. Table 11 presents the objectives values for the four demand periods (i.e., periods 1-4 referring to 10% and 20% increase or decrease, respectively). It can be observed that demand volatility has a great impact on the total cost in addition to the resilient purchasing value. This demonstrates the importance of modelling purchasing resilience objectives considering the supply quantity that eventually depends on demand forecast. These four scenarios would present more realistic supply and demand setting for the SC manager, production manager, and warehouse manager who may consider other decisions (e.g., capacity planning, labor force, and inventory planning) accordingly. It is worth mentioning that increasing order size – based on predicted higher demand – might lead to offset related cost value by gaining, for instance, free shipping, bulk production, or bulk purchase discount.

Table 11. Solutions based on four demand periods

		Objective functions solutions	
Period	#	*Min RC*	*Max Res*
1	1	440,428.14	3339.98
	2	476,535.14	3763.02
	3	566,233.93	4492.74
	4	666,132.24	5249.55
	5	766,044.50	6014.12
	6	865,962.84	6737.82
	7	965,910.69	7489.54
	8	106,578,9.04	8173.24
	9	116,573,3.12	8920.95
	10	126,566,4.21	9655.67
2	1	360,330.75	2713.16
	2	389,888.20	3074.66
	3	463,283.40	3676.97
	4	545,037.56	4315.36
	5	626,751.59	4908.56
	6	708,493.14	5490.86
	7	790,262.93	6100.17
	8	872,027.49	6705.47
	9	953,763.46	7280.77
	10	103,552,2.44	7879.09
3	1	480,419.33	3595.88
	2	519,920.61	4169.21
	3	617,752.20	4943.62
	4	726,677.08	5714.14
	5	835,661.45	6537.41
	6	944,643.19	7306.81
	7	105,370,0.57	8150.22
	8	116,269,5.32	8932.62
	9	127,171,4.95	9738.03
	10	138,070,2.59	10511.46
4	1	320,245.55	2363.26
	2	346,564.74	2730.47
	3	411,823.13	3284.08
	4	484,461.72	3819.76
	5	557,087.63	4338.27
	6	629,744.79	4853.87
	7	702,456.05	5422.48

8	775,146.21	5971.08
9	847,773.64	6455.69
10	920,485.06	7024.30

4.4 Diagnosing internal dynamic capabilities (SRRRG): AHP and VIKOR

Realizing that having a resilient supplier will not be enough to cope with unexpected disruptions, the enterprise would also need to be resilient to handle it. This section diagnoses the internal resilience healthiness of the case enterprise and its readiness to cope internally with an unexpected disruption.

The identified dynamic capabilities enablers (see Figure 1) were presented, discussed, and approved by the SC manager and head of the production and engineering department. The research team hereby went with both managers along every DCE to make sure it is perceived properly prior to the evaluation process. The latter includes two steps: quantification of DCEs (via AHP) and evaluation of dynamic capabilities (via VIKOR) of the case enterprise. To this end, the AHP steps were implemented to quantify the weight of the dynamic capabilities enablers as follows:

a) Three decision makers, including an academic who is an expert in SC risk management, a SC manager, and the head of operations and engineering department, were invited to evaluate SRRRG based on the AHP evaluation scale. Table 12 shows the aggregated pairwise decision matrix developed by taking the average mean for all their opinions.

b) Table 14 shows the obtained relative weights of dynamic capabilities enablers. As presented in Table 13, the DCE of sensing revealed the greatest weight based on experts' opinions compared to recovery which achieved the lowest importance. There was a common argument among the three evaluators that sensing represents the core towards dynamic capabilities. They argued that this enabler would lead to develop others. Note that readiness attains the second-most important enabler.

Table 12. Aggregated pairwise comparison matrix related to dynamic capabilities enablers

	D1	D2	D3	D4	D5
D1	0.5128	0.7759	0.3158	0.3077	0.4545
D2	0.0855	0.1293	0.4211	0.3846	0.2727
D3	0.1709	0.0259	0.1053	0.1538	0.0909
D4	0.1282	0.0259	0.0526	0.0769	0.0909
D5	0.1026	0.0431	0.1053	0.0769	0.0909

Table 13. Weights of dynamic capabilities enablers via AHP

SRRRG	Weight
D1	**0.4733**
D2	0.2586
D3	0.1094
D4	0.0749
D5	0.0838

After quantifying the relative weight of SRRRG, the VIOKR algorithm was applied, again, to assess the internal resilience healthiness of Company D based on its distance from the ideal resilience healthiness represented by the global weight (between 0 and 3). The resilience healthiness is clustered into three outputs:

1. 0 - 0.99 " healthy" ➔ No actions required
2. 1 - 1.99 " not healthy" ➔ Actions required
3. 2 - 3 " dying" ➔ Urgent actions required

However, managers might consider further detailed clustering, given such five clusters. Table 14 shows the obtained values related to VIKOR output for the case enterprise (see Eqs. 4-10).

Table 14. Si, Ri, and Qi values related to the case enterprise

	Si	Ri	Qi	Global weight (Si+Ri+Qi)	Status
Company D	0.8666	0.3201	0.9445	2.1312	"Dying"

As shown in Table 14, the global weight turned out to be 2.1312, so its resilience healthiness falls in the worst cluster of "Dying." In other words, Company D, in case of a disruption, would not be able to sustain its manufacturing properly regardless of having a resilient supplier. This translates the experienced disruption as the approach of dynamic capabilities was not on the SC risk management agenda. Hence, it was recommended to the head of operations and engineering department and SC manager to embed enablers of dynamic capabilities into the SC risk management strategy.

After analyzing enablers of both internal and external resilience within the case study, it was noted that SC managers should pay attention to sensing and readiness internal capabilities in order to have a balance between internal and external resilience. Thus, the following roadmap is suggested as a means of dealing with lack of DCE, which is the case of 'dying' resilience healthiness mentioned above.

a) To assess the level of sensing of a firm, which means the degree of being able to detect opportunities of disruption. In order to improve such degree, firms should gather information from the market environment in terms of, for instance, volatility of prices of materials, changes in consumers' patterns or in market regulations, economic and political turbulences, and so on. Therefore, keeping close links with organizations, such as trade unions, customers, regulatory bodies, financial sectors that may share information with regard to the market environment is very important because such links can help firms to detect opportunities of disruptions outside of it.

b) To check the degree of readiness of the firm, which is related to a preparedness level in terms of resources and supply plans. SC managers should have backup plans already developed with suppliers to deal with potential risks of disruptions. Such backup plans could work with certain levels of inventory slack, onshore suppliers, and strategies of delivering workshops. Further, conducting in person visits at suppliers' facilities would assist in developing a visibility of the SC which would nurture a culture of anticipation and agility in response to disruptions.

4.5 Recommendations for other internal and external resilience healthiness states

This work aimed at proposing a methodology for evaluating and measuring SC resilience by means of internal and external resilience of companies. Externally, suppliers' performance is clustered as high performance and low performance. The latter was the evaluation for the case company's suppliers in which the VIKOR global weight is greater than 1 (out of 3) for most suppliers. Internally, three resilience healthiness clusters (i.e., healthy, not healthy and dying) are proposed in which the case company revealed a "Dying" state. Towards generalization of the proposed research methodology, we pose managerial recommendations for other internal and external resilience healthiness states that could be applicable for other companies.

For "healthy" and "not healthy" states for the internal resilience healthiness, we propose:

1. "Healthy": This state would demonstrate a trustful internal resilience achieved via the serious consideration of building dynamic capabilities at a strategic level. However, managers may focus on the "growth" enabler to embed the continues improvement mindset in other dynamic capabilities enablers - based on lessoned learned from experienced disruptions - towards continuous improvement. For instance, speedy recovery and responsiveness, and wider sensing channels. Also, the continuous growth, in the internal resilience state, should consider a deeper consideration of people who represents a key-pillar for any business. This argument might include empowering and trusting laborers, providing the required tools (e.g., training on simulation software and analytical algorithms) and enhancing communication at all levels within an organization. In the people level, senior managers might consider establishing the resilience team – similar to the risk assessment team in some companies. These would be sufficient elements in leading people to recommend resilience solutions that will sustain an organization today and tomorrow. Last, but not the least, managers might consider revisiting their current contracts, with SC patterns, seeking growth in terms of potential risks such as penalties for cancellation, delay, and termination.

2. "Not healthy": This state might demonstrate the partial consideration of internal resilience at a tactical level rather than organizational. Managers are expected to take gradual actions to elevate the evaluation to the "healthy" state. This should start by shaping the organizational culture that shapes strategies. This includes the incorporation of business resilience within the vision and mission that will then help in embedding

resilience elements into the organizational strategy. Senior manager might reshape these aspects considering the consequences of COVID-19 disruptions on the business. Once this culture is embraced, managers should spread it via clear messages throughout the organization. From a practical perspective, this state could be elevated to “healthy” by reviewing all dynamic capabilities enablers embedding missing ones and improving those exist at a strategic level and as part of their SC risk management. Once all DCEs are embedded, managers might consider recommendations listed for the “healthy” state. Senior managers might consider establishing a team to explore and filling missing enablers at all levels (e.g., planning and operations).

From an external resilience perspective, this work proposes recommendations for companies evaluated with “high performance” suppliers (i.e., the global weight > 1.5) as follows:

- Support and encourage suppliers in continuously reviewing their resilience performance vis-à-vis the resilient sourcing enablers. This could be achieved via frequent workshops or visits, mainly, with key suppliers.
- Work with suppliers to continuously identify potential risk vulnerabilities and cooperatively pose mitigations practices and actions.
- Engage the purchasing department team in regular discussions regarding practices or actions taken to safeguard the business.
- Guide the purchasing team to gradually build a pool of back up suppliers – in addition to the existing ones - that includes their performance evaluation. The purchasing team hereby might need considering advanced and modern evaluation techniques such machine learning that helps in boosting the evaluation process (Cavalcante et al., 2019).

In addition to suppliers, managers should work on sharing messages consistently with all external stakeholders and customers that spread the confidence in the business resilience state.

5. Conclusions

The COVID-19 pandemic has revealed unprecedented disruptions among global SCs. Sustaining manufacturing has become a major concern for managers during the COVID-19 pandemic. This research is inspired by the need to build SC resilience for a manufacturing enterprise affected by the outbreak of COVID-19, with the objective of strategically planning for future disruptive instances.

To build SC resilience, enterprises need to first understand its main key aspects by evaluating their current state and, finally, building them for greater success. This study presents a hybrid integrated MADM-MOPM methodology towards resilient SC. It aims at diagnosing external resilience (i.e., resilience of suppliers) and internal resilience (i.e., dynamic capabilities of the enterprise). In addition, four demand scenarios were considered to handle the potential uncertain demand. To this aim, the developed methodology firstly presented a holistic framework identifying, in addition to traditional criteria, enablers of resilient sourcing (i.e., V-RALF) and dynamic capabilities (i.e., SRRRG) of an enterprise based on thorough literature review and academic and professional perspectives. Then, the relative importance of traditional criteria, V-RALF and SRRRG, were measured by using the RST and AHP algorithms, respectively. Next, the healthiness of suppliers and the case enterprise from a resilience perspective was diagnosed via VIKOR. In addition to the evaluation, this study also supported the purchasing team of the case studied in allocating an optimal orders size among suppliers merging traditional economic and resilience aspects. The relative importance of resilience enablers (obtained via RST) and suppliers' resilience performance (obtained via VIKOR) were integrated into the programming model to reflect the importance of resilience enablers and suppliers' resilience performance.

5.1 Academic Contributions

This is the first study that discusses, analyzes, and presents the enablers of supplier resilience (V-RALF) and enterprise's internal dynamic capabilities (SRRRG) into a unified and holistic framework towards a resilient SC. The literature reviewed highlighted a substantial contribution in SC resilience topic, but it is limited in terms of dynamic capabilities. So, this study extends the current body of knowledge regarding the use of dynamic capabilities for enhancing SC resilience. In addition, this proposed variables to assess firms' internal and external resilience by means of SRRRG and V-RALF, respectively. Remarkably, limited studies have addressed the resilience aspect using quantitative approaches in terms of assessing and analyzing SC resilience problems and this study applied MADM-MOPM methodology.

5.2 Managerial Implications

The research outcome leads managers to embed the concept of internal dynamic capabilities (i.e., SRRRG) into their SC risk management strategy. It highlights that if an enterprise fails in developing internal capabilities such as readiness and sensing, the enterprise could also fail in managing external resilience. It hereby guides managers to not only consider resilient sourcing, but also to establish an internal resilience business.

The research outcome proved the paramount need for not merely seeking resilient sourcing, but also internal resilience. The case studied falls in the worst cluster of resilience healthiness revealed by the proposed diagnosing internal dynamic capabilities (SRRRG) approach. Company D has excellent resilient suppliers, but with such a weak internal resilience status, the company would face business disruption as a result. This enlightens the need for dynamic capabilities consideration that is underexplored in the literature, as shown in section 2 (Table 1). Companies with similar internal resilience status would need to include this point within their organizational strategy spreading its objectives and building pillars throughout related departments (e.g., purchasing, warehousing, and production). A fully resilient SC requires a blend of internal and external resilience. In addition, the study shows that external resilience can be built based on encouraging current local suppliers to scale up their supply capacity. A certain level of reshoring would be a solution to achieve external resilience.

SC managers should foresee and pay attention to both internal and external (suppliers' side) sources of resilience to minimize or avoid disruptions in SCs. Internally, SC managers should focus priority on sensing capability, which means keeping close links with organizations, such as trade unions, customers, regulatory bodies, and financial sectors that can share information regarding the market environment, then helping those firms to detect opportunities of disruptions outside of it. In addition, readiness is another internal capability to be worked out. This capability has close relation with external sources of resilience (suppliers' side). Thus, such capability should be reinforced. In this sense, SC managers should have backup plans with suppliers to deal with potential risks of disruptions. Such plans should consider certain levels of inventory slack, onshore suppliers, and strategies of delivering workshops. In addition, in person visits at suppliers' facilities would help to develop a visibility of the SC that would nurture a culture of anticipation and agility in response to disruptions.

Furthermore, the SC, warehouse, and production managers should meet frequently to enact plans to protect the business from demand variations that are considered external disruption risks. This might include potential backup-inventory scenarios for a possible increase in demand. However, this consideration would cover the total costs in which extra inventory costs might be offset using bulk purchases or potentially avoiding shortage costs. Thus, members of the purchasing team might need further discussion regarding new agreements with suppliers to consider these requirements.

From a sourcing perspective, the results demonstrate the ability to optimize the two objective functions (i.e., minimization of related costs and maximization of resilient purchasing value) towards an optimal order allocation among suppliers via the proposed integrated MADM-MOPM model.

5.3 Future Research

Arguments and studies on the concept of SC resilience are still growing, along with trials of addressing questions of how to identify and measure a supply chain's resilience performance. Arguably, the current work could be a promising step in establishing a quantitative basis for future avenues in the field of SC risk management. However, the presented SC resilience methodology (e.g., enablers and criteria) has been conceptualized via various qualitative and quantitative studies whereas not all of them, so far, have been fully empirically validated. It will be interesting to further develop this methodology to investigate the need, complementarities, and relationships among presented enablers and the others presented in the literature (see Table 1). Also, this includes recommendations, strategies, or detailed plans on the embedding or improvement approaches for these enablers.

As a matter of fact, the COVID-19 pandemic has hit all dimensions of the SC such as logistics, sales, and people in addition to the topic considered in this work (i.e., supply). The proposed methodology could be tailored to accommodate elements, criteria, and enablers of these dimensions towards a comprehensive resilient SC. Although this methodology was applied in the food sector, it would be worthy to explore its applicability on another affected sector such as pharmaceutical manufacturers towards better generalizations of the proposed recommendations. Also, it could be applied on different food types that may require more processing at the middle of the SC.

Finally, the growing implementation of the triple bottom line of sustainability into SC management practices highlights another avenue for potential future research. An investigation and analysis on how those two concepts are linked and correlated in the existence of the COVID-19 pandemic or similar disruptions is certainly needed. For instance, did suppliers try to fulfil urgent demands but lacked the ability to address social and environmental aspects? The possibility of presenting their enablers into a unified theoretical framework could be used as a guide to improve the sustainable and resilient competitiveness of SCs during and after experiencing such a disruption.

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