An Application of AHP and G-TOPSIS for Prioritizing Capabilities and Related Practices for a Mature and Resilient Supply Chain During Disruption

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Abstract

Purpose: The purpose of this study is to identify and prioritize capabilities and practices to ensure a resilient supply chain during an unexpected disruption. In addition, this study ranks maturity factors that influence the main capabilities identified.

Design/methodology/approach: This paper is conducted in three stages. First, capabilities and practices are extracted through a literature review. Second, capabilities and practices are ranked using the Analytical Hierarchical Process (AHP) method. Third, a Grey Technique for Order Preference by Similarity to Ideal Solution (G-TOPSIS) method is used to rank maturity factors influencing capabilities.

Findings: The findings indicate that responsiveness, readiness, flexibility and adaptability are the most important capabilities for supply chain resilience. Also, commitment and communication are the highest maturity factors influencing resilience capabilities.

Research limitations/implications: The findings provide a hierarchical vision of capabilities and practices for industries to increase resilience. Limitations of the paper are related to capabilities, practices and number of experts consulted.

Practical implications: This paper highlights the importance of high maturity practices in resilience capability adoption. The findings of this study will encourage decisions-makers to increase maturity practices to build resilience against disruption.

Originality/value: The paper reveals that developing powerful capabilities, good practices and a high level of maturity improve supply chain resilience.

Keywords: Maturity, Resilience, Supply chain, Capabilities, Practices, AHP, G-TOPSIS.

1. Introduction

Supply chain complexity, uncertainty and external factors are responsible for risk and disturbance along global supply chains (S. Xu et al., 2020). As examples, earthquakes, tsunamis, man-made catastrophes and strikes are unexpected events that intensely affect supply chain linking and operations (Golan et al., 2020; Ivanov, 2020). Disruptions can lead to significant negative effects on business and industries. Hence, these disruptive events increase the priority to build more resilient supply chains (Essuman et al., 2020) and adopt digitalization (Zekhnini et al., 2021c).

In December 2019, coronavirus appeared in China. Very quickly, this virus spread throughout the whole world (M. Gupta et al., 2020). On 11 March 2020, the World Health Organization (WHO) declared SARS-CoV-2 as a pandemic (Guan et al., 2020). Due to the serious and negative impacts arising, decisions-makers were forced to rethink their supply chain models and strategies (Hobbs, 2020; Pujawan and Bah, 2022). In addition to unpredictable event specifications, pandemics have some specific characteristics. Firstly, the existence duration cannot be estimated and the development is unpredictable. Secondly, disturbance transmission in the supply chain and population occurs at the same time. Thirdly, there are disruptions in the purchasing, product request and logistics infrastructures. Fourthly, due to the contagious character, the virus disperses to many geographic regions (Ivanov, 2020).

An unpredictable event means increased attention to supply chain maturity and resilience. During this disturbance, lack of readiness, shortcomings in responsiveness and lower resilience are often observed (Remko, 2020). In addition, moving to supply 4.0 depends on a resilient supply chain (Zekhnini et al., 2021a). Thus, traditional strategies are no longer effective to face such situations. Organizations must improve their maturity and resilience through the development of suitable capabilities.

Much research on resilience capabilities has been carried out. Ekanayake et al. (2021) developed a framework of capabilities and actions to achieve supply chain resilience. Zavala-Alcívar et al. (2020) developed a conceptual framework to highlight the relationship between resilience and sustainability. Poberschnigg et al. (2020) studied the connection between resilience capabilities and cross functional integration. Zouari et al. (2021) investigated the relationship between supply chain resilience capabilities and digitalization. Yang et al. (2021) examined how risk management capabilities affect resilience in the post coronavirus environment. Han et al. (2020) developed a framework of metrics to measure supply chain resilience capability performance. A study conducted by Piprani et al. (2020) indicates that an integrated supply chain is the critical factor in resilience. In addition, the readiness phase is the most important resilience-building step. According to Das et al. (2021), government support is an important causal factor in helping supply chains during the Covid19 pandemic and cost optimization is the most important factor affecting the supply chain. Márcio Lopes Pimenta et al. (2022) propose the integration of multiple impacts and capabilities to overcome Covid19 disruptions. A review proposed by Ali et al. (2021) breaks down resilience reactive strategies into four quadrants based on time and cost. In the light of the above, we observe that during the last two years many efforts have been devoted to improving supply chain resilience. In this context, capabilities and practices are proposed to deal with disturbance. However, these capabilities and practices do not make the same contribution in resilience and supply chain maturity level. Moreover, organizations with higher levels of maturity are more resilient against disturbance (Frederico, 2021). Therefore, the following research questions arise:

RQ1: Which capabilities and practices should be developed to improve supply chain resilience during pandemic disruption?

RQ2: What are the high maturity practices that influence implementation of major resilience capabilities?

To answer these questions, we set out three aims for this paper. Firstly, we prioritize and classify supply chain capabilities contributing to resilience improvement. The classification objective is to provide a hierarchic vision for resilience capability adoption. Secondly, we prioritize practices associated to each capability. This sub-classification aims to identify the important and necessary practices to build resilience capability. Thirdly, we aim to identify which high maturity factors influence the adoption of major resilience capabilities.

The contributions of this paper give new perceptions concerning the impact of organization high maturity level in resilience improvement faced with unexpected events. In addition, the classification of resilience capabilities and associated practices is seen as a foundation to understand resilience building strategy.

The remainder of the paper is organized as follows. A literature review is conducted in section 2. The methodology is presented in section 3. Section 4 is devoted to results and discussion of these findings. Section 5 proposes practical and theoretical implications. Finally, section 6 concludes the paper.

2. Literature review

2.1 Supply chain maturity

The maturity concept originates from the quality management domain (de Almeida et al., 2020). Maturity refers to operating with documented, managed, measured, controlled and optimized processes. This concept shows the readiness of an organization to start a new project or develop a new business (Rudnicka, 2017). In order to measure supply chain maturity, several models are provided in existing literature (Balouei Jamkhaneh and Safaei

Ghadikolaei, 2022). Maturity level is a key element to the future performance of an organization. Maturity model describes the way in which a company operates, the potential to use experience and resources plus objectives to be reached in the future. The adopted model ensures continuous improvement of organizations by guiding the transition from undefined practices and processes to optimized processes (Tubis and Werbińska-Wojciechowska, 2021). High maturity organizations are recognized by several practices such as:

Quality and improvement culture: continuous improvement is seen as an enabler to higher levels of operational performance (Van Assen, 2021). To increase maturity level, continuous improvement activities should be implemented (Unzueta et al., 2020). Quality and continuous improvement are the building blocks of success (Akmal et al., 2021).

Skills and training: for high maturity levels, high skills are required (Omoraka, 2020). According to Wagire et al. (2021), skills and qualifications are considered to judge maturity levels. Employee training contributes to continuous improvement in organizations (Van Assen, 2021).

Measurement and audit: in high maturity levels, a measurement system is set, goals are clearly defined and process performance is expected. Thus, the global system is systematically managed with improvement vision (Wijbenga et al., 2021).

Customer focus: consumer satisfaction becomes the objective of each member of the organization. Therefore, the company collects customer feedback in order to improve managerial and operational practices (Wijbenga et al., 2021).

Commitment and communication: top management commitment and communication with workers or supply chain collaborators appear in high levels of a maturity model (Zanon et al., 2021). Top management commitment is reflected by encouraging training, developing projects, providing resources, setting and communicating strategies (Tanuwijaya et al., 2021).

A recent study conducted by Z. Xu et al. (2020) demonstrated Covid19 impacts on the global supply chain. Covid19 caused closure in almost all economic sectors. This unexpected event has deeply affected operations from raw materials to delivery. According to the same paper, improving resilience is the key factor to minimize vulnerability in the disturbance period. Craven et al. (2020) affirm that organizations have focused on customer satisfaction by anticipating needs and requirements, thereby navigating disruptions safely. Customer focus is seen as a priority in organizations with high maturity processes (Hackos, 2017).

2.2 Supply chain capabilities related to resilience

Resilience is defined as the organization's ability to persevere, adapt or change in times of disruption (Wieland and Durach, 2021), ensuring operational continuity (Kaviani et al., 2020). Supply chain resilience is the capacity to navigate unexpected events safely, return to the original state (Han et al., 2020) and adjust to uncertain future disturbance (Golan et al., 2020). Another definition of resilience is provided by Conz and Magnani (2020). As a dynamic attribute, resilience passes through three phases of time: proactive (t-1), adaptive or absorptive (t) and reactive (t+1). To improve resilience, the supply chain needs to adopt and develop capabilities (Han et al., 2020; Poberschnigg et al., 2020).

Capabilities play an important role in organizational success through increasing competitiveness (Sadeghian Esfahani et al., 2021). Supply chain capabilities are resistant to several supply chain vulnerabilities (Ekanayake et al., 2021; S. Gupta et al., 2020). Thus, supply chain capabilities contribute to operational and competitive performance (Rajaguru and Matanda, 2019). Supply chain capabilities facilitate a firm's activities by incorporating internal and external resources (Asamoah et al., 2021). In literature, there is a distinction between ordinary and dynamic capabilities. Ordinary or operational capabilities are defined as organizational competencies to produce and sell a product while dynamic capabilities enable change, innovation and improvement (Schriber and Löwstedt, 2020). Dynamic capabilities aim to reconstruct a firm's resources and operational routines in order to make effective improvement (Aslam et al., 2020; Cepeda and Vera, 2007). Dynamic capabilities are the capacity to sense opportunities and menaces, seize opportunities and sustain competitiveness (Bocken and Geradts, 2020).

Through a literature review, we identify the most relevant capabilities and practices related to supply chain resilience. Google Scholar, Scopus and Web of Science were interrogated to extract articles published since 2020 on resilience capabilities. To locate these articles, we used keywords: "capabilities AND resilience", "practices AND Resilience", "Supply chain resilience", Supply chain maturity AND resilience", "Maturity AND practices", "Resilience AND Covid19" and "Dynamic capabilities AND Resilience". From the collected articles, we only include articles that discuss capabilities and practices in disruptive times. The methods of identification and classification are made based on previous works (Ekanayake et al., 2021; Zouari et al., 2021). Table 1 summarizes resilience capabilities and practices.

Table 1. Capabilities and actions for resilient supply chains

Capabilities	Description	Practices	References

C1: Readiness	Ability to sense and anticipate menaces and threats and take actions.	Risk management Contingency planning Detect warning signals in advance Forecasting/predictive analysis Supervision of quality and defection Hybrid and concentered training Use tracking means	Han et al. (2020); Ekanayake et al. (2021); Geyi et al. (2020); Kaviani et al. (2020); Yang et al., (2021)
C2: Responsiveness	The ability of an organization to respond rapidly to an unpredicted event.	Quick response to customers' needs Quick response to competitors' strategies Effective response Developing a new product quickly	Asamoah et al. (2021); Geyi et al. (2020); Yang et al. (2021)
C3: Flexibility	Ability to change quickly.	People flexibility Multiple sources Supplier agreement flexibility Change distribution channels/ multimodal transportation Risk sharing Order fulfilment Vertical integration Production postponement	Asamoah et al., (2021); Benzidia and Makaoui, (2020); Daghar et al., (2021); Ekanayake et al., (2021); Geyi et al., (2020); Jafari, (2022)
C4: Adaptability	Company ability to adjust behaviour, product etc. in order to respond to business environment changes.	Supply chain design modification Quick rerouting of needs Learning from experience Using parallel processes rather than series processes Lead time minimization Home delivery	Ekanayake et al. (2021); Yang et al. (2021); Zouari et al. (2021)
C5: Recovery	Company ability to go back from disruption to original position.	Effect mitigation Communications strategy Crisis governance	Ekanayake et al. (2021); Tagarev and Ratchev (2020); Zouari et al. (2021)
C6: Dispersion	Ability for decentralization of key resources, capacities and markets.	Dispersed decision making Dispersed capacity and assets Decentralization of key resources	Daghar et al. (2021); Ekanayake et al. (2021); Zouari et al. (2021)
C7: Collaborative	Increasing trust between partners could improve collaboration, risk hedging and produce innovation.	Cooperative planning and decision making Collaborative prediction Public–private collaboration Investment in supplier plant	Asamoah et al. (2021); Ekanayake et al. (2021); Geyi et al. (2020); Han et al. (2020); Wei et al. (2020)
C8: Financial strength	Ability to absorb cash fluctuations.	Insurance Financial reserves and funds Price margin Portfolio diversification	Ekanayake et al. (2021); Zouari et al. (2021)
C9: Visibility	Knowledge of the	Products, assets, people visibility	Han et al. (2020);

	status of current operating resources and the environment.	Strong IT system and information sharing	Ekanayake et al. (2021); Wei et al. (2020); Yang et al. (2021)
		Real time data	
		Business intelligence gathering	
		Knowledge acquisition and evaluation	
C10: Market position	Product place in the market.	Customer loyalty, communication and relationship.	Han et al. (2020); Ekanayake et al. (2021); Geyi et al. (2020); Zouari et al. (2021)
		Increase process quality	
		Quick delivery	
		Market equity of the company	
		Market participation	
C11: Security	Defense against virtual or real attack.	Cyber-security	Ekanayake et al. (2021); Panda and Bower (2020); Weil and Murugesan (2020); Zouari et al. (2021)
		Physical security	

3. Methodology

The purpose of this study is to, first, prioritize capabilities and related practices for a resilient supply chain. Second, identify high maturity factors influencing the adoption of these capabilities and practices. The methodology of this study is shown in figure 1. To achieve the main goal, this study is realized in three stages. Firstly, we conduct a literature review on the most relevant capabilities related to a resilient supply chain. Then, we explore different practices and actions related to each capability as shown in table 1. In the second stage, we send an online survey to seven industry experts to determine the importance of each capability based on their experiences related to the COVID19 event. Details about experts are presented in table 3. As a multi-level hierarchical structure, the AHP method is used to prioritize capabilities and practices. The AHP method is the most used multicriteria decision-making (MCDM) method in the world (Munier and Hontoria, 2021). This technique is chosen due to its capacity to solve complex problems by assigning weights to criteria and sub-criteria through clear hierarchical insights (Ikram et al., 2020). The weights of each capability and each practice is calculated and according, capabilities and practices are ranked. These are shown in table 4 and table 5. The consistency ratio < 0.1 proves the reliability of consistent comparisons. In the third stage, we use grey TOPSIS to rank high maturity factors influencing the development of resilience capabilities and practices. Applied in multiple fields, G-TOPSIS continues to receive increasing interest from researchers (Heidary Dahooie et al., 2021). Among other MCDMs, G-TOPSIS is characterized by clarity and intelligibility (Ikram et al., 2020). This technique performs alternative rankings including qualitative and quantitative standards (Irfan et al., 2022). AHP and G-TOPSIS are used in complementary fashion in previous works (Ikram et al., 2020; Irfan et al., 2022). In this study, we combine these two methods to identify key capabilities and practices for resilience and recognize best high maturity level practices influencing the capability adoption. Descriptions of the AHP method and grey TOPSIS processes are now given in more detail.

3.1 AHP method

The analytic hierarchy process (AHP) is a multicriteria decision-making approach based on a hierarchy structure (Russo and Camanho, 2015). It is used in different domains to prioritize and classify factors when different alternatives are possible (Vaidya and Kumar, 2006). As an example, AHP was used recently by Zekhnini et al. (2021b) to discuss risk management related to supply chain 4.0. This methodology uses a pairwise comparison of identified elements. A consistency test is conducted to verify the reliability of results (Saaty, 1990). Compared to other similar MCDM methods, the AHP method is characterized by suppleness and the ability to generate consistent outputs (Das et al., 2021). It consists of four mathematical steps (Saaty, 1990). A sample of calculation is given in Appendix A2.

Step 1: Development of the hierarchy through the identification of resilience capabilities and related practices.

Step 2: Establish pairwise comparison matrixes to compare the first capabilities. practices on a scale of 1 to 9 (Table 2). Then, for each capability, comparisons are made between practices.

Table 2. AHP scale (adapted from Saaty, (1990)).

Numerical value	Equivalence
1	Same importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values
1/3,1/5,1/7,1/9	Value for inverse comparison

Step 3: Global and local weights are calculated for capabilities and practices. The procedure consists of dividing each member of the matrix by the sum of every column and calculating the average of each row.

Step 4: Evaluating consistency.

The consistency index (CI) is given in equation (1)

$$\mathrm{CI} = \frac{\lambda \max - n}{n-1} \quad (1)$$

Where λmax designates the eigenvalue and n designates the number of criteria.

The consistency ratio (CR) is calculated as follows:

$$CR = \frac{CI}{RI} \quad (2)$$

Where RI is the random consistency index.

3.2 Grey TOPSIS

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) concept was introduced in 1981 by Huang and Yun (Ikram et al., 2020). Supplier selection, transportation channel and healthcare are examples of problems resolved by the TOPSIS method (Tiwari and Kumar, 2021). This method consists of ranking n alternative by m criteria. Positive and negative problem solutions are provided. Finding optimal solutions is based on the distance to positive and negative alternatives (Feng et al., 2019). G-TOPSIS method steps are as recommended by previous research (Nyaoga et al., 2016; Tabor, 2019) (see Appendix A1)

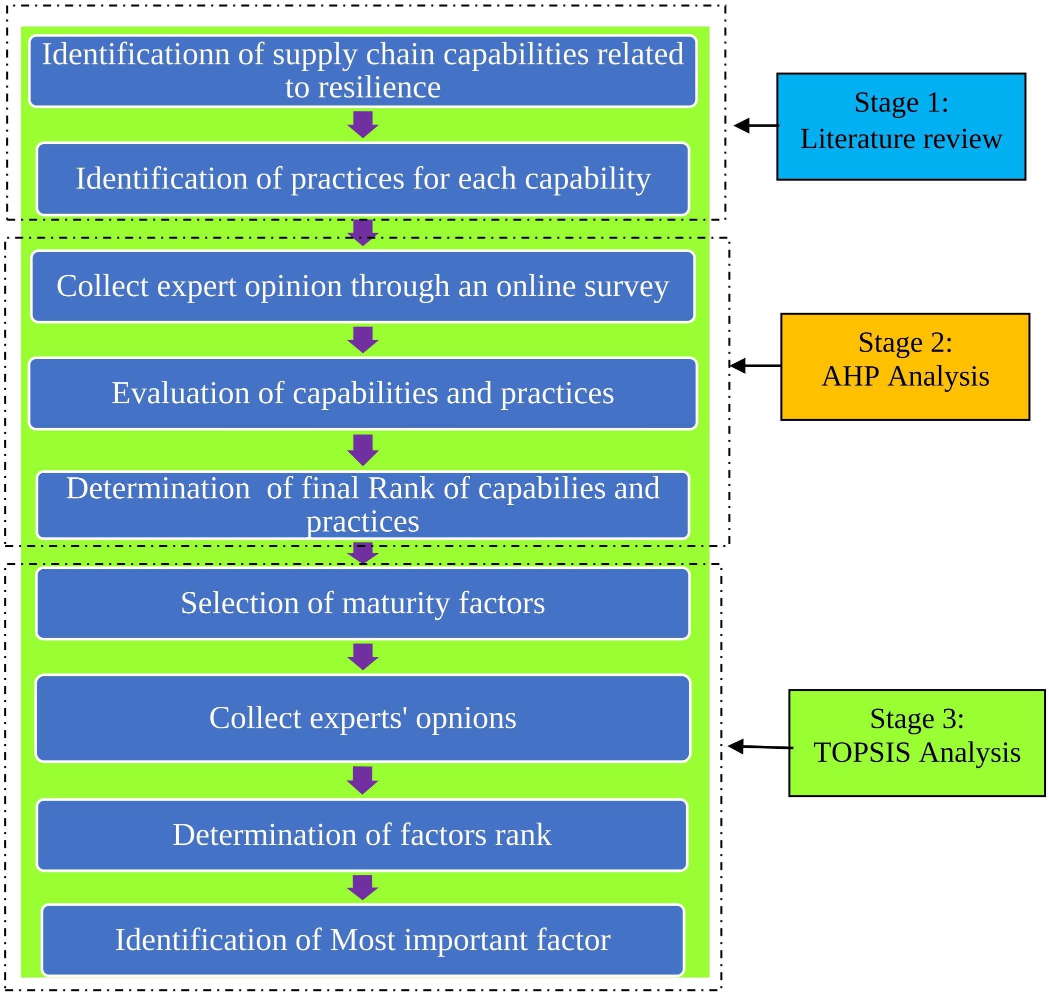

Figure 1: Research methodology

Table 3. Expert of decision panel

Expert	Position	Years of experience	Key responsibilities
Expert 1	Consultant	10	Study companies manufacturing problems and propose solutions.
Expert 2	Manager	5	Evaluate daily performance, deal with problems and train employees.
Expert 3	Project Manager	8	Manage an important production line.
Expert 4	Manager	15	Direct a medium business activity and ensure operation continuity.
Expert 5	Project Manager	12	Develop and implement continuous improvement practices
Expert 6	Engineer	10	Manage production, evaluate and improve current manufacturing practices.
Expert 7	Businessman	20	Identify business opportunities, deal with changes and manage relation with partners.

3. Results and discussion

This study aims to identify key capabilities, practices and high maturity factors to improve supply chain resilience. Findings are presented and discussed in two sub-sections. Capabilities and practices ranking are provided in the first sub-section. Then, G-TOPSIS results are presented in the second sub-section.

4.1 AHP Results

The process started with a pairwise comparison matrix to calculate the individual expert weight scores. This study used a multi-decision criteria method to prioritize capabilities and practices for a resilient supply chain. Based on the literature review, we considered eleven main supply chain capabilities, i.e. readiness, responsiveness, flexibility, adaptability, recovery, dispersion, collaborative, financial strength, visibility, market position and security. In the first stage of the AHP method, the eleven capability weights were obtained while in the second stage, we evaluated 50 practices. Capabilities and practices details are provided in table 1.

4.1.1 Capabilities ranking

Table 4 highlights the weight and ranking of resilience capabilities. Responsiveness occupies first place (15.9%), followed by readiness (14.6%) and flexibility (14.5%). Fourth place is adaptability (11.7%) followed by collaborative (9.1%), recovery (8.1%), and dispersion (7.8%). In the eighth ranking, we found financial strength (5.4%), followed by market position (4.8%), visibility (4.5%) and security (3.1%) respectively. Each of the detailed capability weights are shown in Figure 2.

Based on this study, it has been observed that responsiveness, readiness and flexibility are the main capabilities to improve resilience during unexpected events. These findings can be compared with other researchers (Chowdhury and Quaddus, 2016; Piprani et al., 2020). These scholars devote great importance to readiness, responsiveness and recovery. In our model, recovery is replaced by flexibility followed by adaptability. Several authors have proved the importance of flexibility in resilience (Carmichael, 2015; Chunsheng et al., 2019; Ishfaq, 2012). Findings can be explained by our research circumstances. As mentioned before, pandemic events are characterized by unknown duration and development. Hence, recovery cannot be the third capability aimed at ensuring supply chain survivability since propagation occurs several times. Flexibility and adaptability can adjust supply chain strategies and behaviors to meet unexpected changes in events. Recovery capability is placed after collaborative capability. The role of collaborative capability is strongly promoted in literature (de Almeida et al., 2021; O’Dwyer and Gilmore, 2018; Scholten and Schilder, 2015). Supply chain collaboration and information sharing have positive impacts on a firm’s results.(Haque and Islam, 2018; Mwesiumo et al., 2021). This capability is followed by dispersion. This ranking agrees with similar studies (Pettit et al., 2010). Collaboration and dispersion have the same frequency of appearance in a focus group as found by Pettit et al. (2010). Financial strength and market position are ranked in eighth and ninth places. As for visibility, the results were in contrast with many previous studies in literature (Pettit et al., 2013; Piprani et al., 2020; Zainal Abidin and Ingirige, 2018). Finally, security is considered the least important capability, having the least weight determined by the AHP method. Further, the 50 practices of the study were assessed through experts’ feedback using a pairwise comparison matrix.

Table 4. Capabilities Ranking

Capabilities	**Expert1**	**Expert2**	**Expert3**	**Expert4**	**Expert5**	**Expert6**	**Expert7**	**Weight**	**Rank**
Readiness	0,204728	0,113289	0,164794	0,078306	0,168569	0,146799	0,143390	0.145696	2
Responsive-ness	0,140251	0,197941	0,158945	0,156787	0,159772	0,149976	0,145302	0.158425	1
Flexibility	0,157487	0,146212	0,126420	0,130497	0,136442	0,146588	0,172332	0.145141	3
Adaptability	0,093015	0,159529	0,098128	0,134049	0,123356	0,101348	0,107017	0.116635	4
Recovery	0,075121	0,105555	0,057588	0,081815	0,089520	0,103709	0,059915	0.081889	6
Dispersion	0,076605	0,089990	0,099870	0,071123	0,079500	0,076564	0,048380	0.077433	7
Collaborative	0,064009	0,042063	0,117745	0,204442	0,050021	0,048364	0,115195	0.091691	5
Financial strength	0,061785	0,044299	0,069511	0,049048	0,049574	0,061943	0,047307	0.054781	8
Visibility	0,048366	0,040647	0,041944	0,022050	0,052346	0,032604	0,073850	0.044544	10
Market position	0,048185	0,047634	0,053985	0,057081	0,046978	0,049758	0,035720	0.048477	9
Security	0,030448	0,026739	0,030649	0,028798	0,028117	0,030608	0,041219	0.030940	11
CR	0,066278	0.090752	0.083038	0.085194	0.073995	0.092603	0.093597	0.033920	

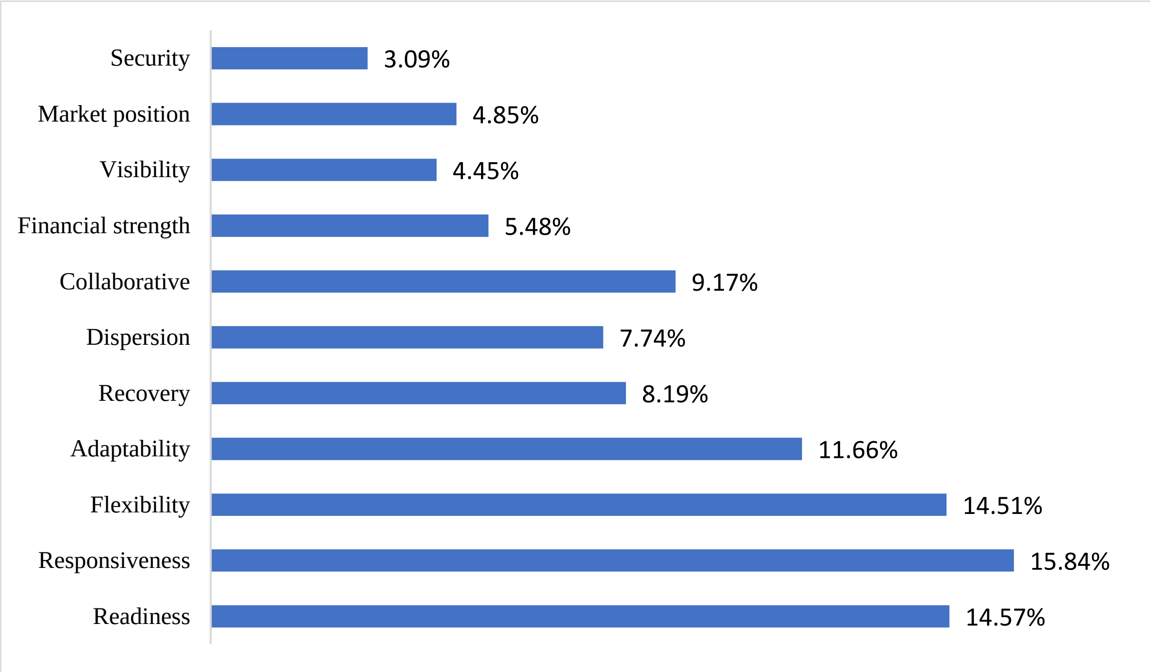

Figure 2. The ranking of main capabilities for supply chain resilience

4.1.2 Practices ranking

This section addresses the results of all practices shown in Table 5.

Readiness practices: The ranking of practices within the readiness capability is as follows: RD2 > RD1 > RD3 > RD4 > RD5 > RD6 > RD7. Contingency planning appeared the most important readiness resilience with a weight of 0.231369. Defined as a powerful resilience tool, contingency planning is a plan created before disturbance and applied during or after disruption (Pavlov et al., 2019). Each organization should have a plan B to manage unexpected events. In the same vein, it has been suggested by Black and Glaser-Segura (2020) that revised contingency plans are required to manage circumstances during a pandemic. The second highest weight within this category is risk management with a weight of 0.229501. These results agree with the findings of Piprani et al. (2020). The occurrence of Covid19 increases the interest to supply chain risk (Mwesiumo et al., 2021). Risk management is defined as the united effort of several entities of the supply chain to reduce disruption impacts (Fierro Hernandez and Haddud, 2018).To do so, sources of risks are analyzed and controlled (Khan et al., 2021). Tubis and Werbińska-Wojciechowska (2021) developed a risk management maturity model with five levels: ad hoc risk management, critical events in logistic system management, selective organizational risk management, cross-functional supply risk management and integrated supply risk management. This model is designed to measure the level of resilience. Detecting warning signals in advance is the third important practice with a weight of 0.187992. This practice indicates improving environmental sensing actions. Literature supports this argument; Sharma et al. (2020) indicate the importance of advanced technologies in detecting early warning signals. The fourth rank is forecasting/predictive analysis (0.147743) followed by supervision of quality and defection (0.085003), hybrid and concentered training (0.064024) then use tracking means (0.054368).

Responsiveness practices: Under the responsiveness capability, the ranking of practices is found to be: RS1 > RS3> RS2 > RS4. Quick response to customers' needs appears as the most important practice of responsiveness with a weight of 0.380741. The ranking of effective response also indicates its' importance with a weight of 0.303360. This result is in line with Chowdhury and Quaddus (2016). Third place is devoted to response to competitors' strategies with a weight of 0.220478. Finally, develop a new product has a weight of 0.095421. Quick response leads to agility and increased environmental competition. In addition, companies need to be vigilant to other companies' offers (Ali et al., 2017). In a pandemic environment, customers' needs and requirements change. Hence, organizations with quick and effective responses can maintain their market position.

Flexibility practices: From the results presented in figure 6, the ranking practices within flexibility are as follows: FL2 > FL3 > FL1 > FL8 > FL4 > FL7 > FL5 > FL6. Multiple sources is in first position with a weight of 0.236684, followed by supplier agreement flexibility (0.158123). These two practices are related to supplier sourcing. In literature, several authors endorse having many suppliers to ensure procurement continuity (Berger and Zeng, 2006; Handfield and Bechtel, 2002). Strategic sourcing affects positivity the global supply chain (Yildiz Çankaya, 2020). With a weight of 0.158062, people flexibility holds third place. Directors, managers and workers should be flexible enough to tackle many tasks by improving their skills. The fourth flexibility practice is production postponement with a weight of 0.142773. Postponement has a positive impact on logistic flexibility under uncertainty (Jafari, 2022). In a disturbance, postponement contributes to cost-effective and time-efficient contingency planning (Tang, 2006). Change distribution channels / multimodal transportation occupies fifth place with a weight of 0.111158. This position is explained by pandemic event characteristics. In other disturbances, defining multimodal transportation and multiple channel distribution are important practices (Tang, 2006). Literature supports the role of flexibility practices. Sharma et al. (2020) opined that traditional strict regulation of supply chains is deficient during crisis. These authors recommend opting for flexible operations in the whole organization. Shekarian and Mellat Parast (2021) also found that operational, manufacturing and sourcing flexibility are the most important factors to manage disturbance. The last three positions are devoted to vertical integration (0.066300), risk sharing (0.064361) and order fulfilment (0.062539).

Adaptability practices: The ranking in the category of adaptability practices is: AD1 > AD2 > AD6 > AD5 > AD3 > AD4. Supply chain design modification is ranked first with a weight of 0.296713. Supply chain design is considered a critical decision. The possibility to adjust supply chain configuration according to changes in circumstances is needed (Rajesh, 2017). In second position, with a weight of 0.224770, we rank quick rerouting of needs. Quick rerouting of needs allows a company to adjust requirements based on the situation. In disruption, requirement adaptability increases resilience and innovation. Home delivery is ranked third with a weight of 0.140691. According to Diebner et al. (2020), organizations that can innovate and migrate to home delivery during this pandemic are effectively handling the consequences of confinement. The next position is devoted to lead time minimization with a weight of 0.129563. Very popular in literature, lead time is a factor of competitive advantage (Tersine and Hummingbird, 1995). As making a quick response is an important practice in improving resilience, lead time should be reduced. The fifth and sixth places are learning from experience (0.118270) and using parallel processes rather than series processes (0.089993).

Recovery practices: Under the recovery capability, the ranking of practices is as follows: RC1 > RC2 > RC3. Effect mitigation is ranked first (0.476803), followed by communications strategy (0.299603) and finally crisis governance (0.223594). These results indicate that the most important practice of recovery capability is to minimize the negative impact of disruption. This finding is in line with results from other studies (Chowdhury and Quaddus, 2016; Pettit et al., 2010).

Collaborative practices: The ranking of practices within collaborative capability is CL1 > CL2 > CL4 > CL3. Cooperative planning and decision is ranked first with a weight of 0.412883, followed by collaborative prediction (0.295061). These practices help manufacturing companies to improve their performance, absorb new knowledge and select good partners (Singhry and Abd Rahman, 2019). These results were consistent with those obtained by Shekarian and Mellat Parast (2021). These authors stressed the importance of collaborative planning and forecasting to manage disruption. Invest in supplier plant

(0.165349) is ranked third. According to this study, public–private collaboration is the least important collaborative practice (0.126708). These results are in contrast with the study of Ali et al. (2017), indicating the benefits of collaboration between companies and government departments. Public agencies can be helpful in providing updates for companies; they can also provide financial and moral support during crisis.

Dispersion practices: In dispersion capability, the ranking of practices is: DS2 > DS1 > DS3. Dispersed capacity and assets are in first position (0.389810) followed by dispersed decision making (0.38959) and finally decentralization of key resources (0.220611). In literature, other researchers (Pettit et al., 2013; Zainal Abidin and Ingirige, 2018) consider resource dispersion as an important resilience capability factor.

Visibility practices: The ranking of practices within visibility capability is as follows: VS2 > VS3 > VS1 > VS5 > VS4. Piprani et al., (2020) indicate that visibility improves the fluidity of information flow along the supply chain. In a similar aspect, our findings ranked strong IT system and information sharing in first position (0.298764) followed by real-time data (0.278505). Information sharing among supply chain players enhance forecast accuracy (Siddiqui et al., 2022). Products, assets and people visibility is ranked third (0.216686) followed by knowledge acquisition and evaluation (0.117411); lowest ranking is business intelligence gathering (0.088634).

Financial strength practices: The ranking of these practices is: FS2 > FS1 > FS3 > FS4. Financial reserves and funds is ranked first (0.388385) followed by insurance (0.301541), price margin (0.178263) and portfolio diversification (0.131811). The results indicate that organizations must consolidate their financial situation. According to Pettit et al. (2010), companies with lower reserves and funds will be unable to navigate disruption safely. However, Zainal Abidin and Ingirige (2018) found that good financial strength on its' own is not sufficient to face the worst economic situations.

Market position practices: Under the market position capability, the ranking of practices is: MP1 > MP3 > MP2 > MP5 > MP4. Customer loyalty, communication and relationship is ranked first (0.334874) followed by quick delivery (0.217410). According to Pratama et al. (2021), Covid19 has changed customer behaviour towards products and markets. Lower prices are no longer a factor for customer loyalty. This fact aligns with the study of Gunawan et al. (2021). Price, quality of services and expectation response are the motivations for a customer to be loyal. Improving the quality of the supply chain process is ranked third

(0.187269) followed by market participation (0.167329) and finally, market equity of the company (0.093118).

Security practices: The ranking of these practices is SC1 > SC2. Cyber-security (0.539156) is in first position followed by physical security (0.460844). Pandey et al. (2020) identify three categories of cyber-attacks in the supply chain - supply risks, operational risks and demand risks. In the Covid 19 age, the lockdown has forced billions of people to work from home and change their social practices. During this pandemic, people have spent many hours online. In this situation, people are receiving, sending and dealing with confidential information related to work or personal issues. This opens up the possibility of increased cyber-attacks (Lallie et al., 2021). To prevent cyber-attacks and other cyber threats, companies need to improve their information security systems.

The overall ranking of resilience practices is as follows: RS1 > RS3 > RC1 > CL1 > RS2 > AD1 > FL2 > RD2 > RD1 > DS2 > DS1 > RD3 > CL2 > RD3 > AD2 > RC2 > FL3 > FL1 > RD4 > FL8 > RC3 > DS3 > SC1 > FS1 > AD6 > MP1 > FL4 > CL4 > RS4 > AD5 > VS2 > SC1 > AD3 > VS3 > CL3 > VS1 > MP3 > AD4 > FS3 > FL7 > FL5 > RD6 > FL6 > MP2 > MP5 > RD7 > VS5 > MP4 > VS4

For a resilient organization, the most important practice to develop is the quick response to customers' needs followed by making effective, appropriate responses; this results in an overall increase in supply chain responsiveness. Effect mitigation is the third most important practice with collaborative planning ranked fourth. These results indicate that while responding to customer changes, negative impacts of disruption must be controlled and minimized. Moreover, collaborative planning with other partners of supply chain allows identification of resources and capacities.

Table 5. Practices ranking

Capabilities	**Practices**	**Local Weight**	**Local Ranking**	**Global weight**	**Final ranking**
Readiness	RD1: Risk management	0.229501	2	3,34%	9
	RD2: Contingency planning	0.231369	1	3,37%	8
	RD3: Detect warning signals in advance	0.187992	3	2,74%	13
	RD4: Forecasting/predictive analysis	0.147743	4	2,15%	18
	RD5: Supervision of quality and defection	0.085003	5	1,24%	35
	RD6: Hybrid and concentered training	0.064024	6	0,93%	42
	RD7: Use tracking means	0.054368	7	0,79%	46
Responsiveness	RS1: Quick response to customers' needs	0.380741	1	6,03%	1

	RS2: Quick response to competitors' strategies	0.220478	3	3,49%	5
	RS3: Effective response	0.303360	2	4,81%	2
	RS4: Developing new product quickly	0.095421	4	1,51%	29
Flexibility	FL1: People flexibility	0.158062	3	2,29%	17
	FL2: Multiple source	0.236684	1	3,44%	7
	FL3: Supplier agreement flexibility	0.158123	2	2,30%	16
	FL4: Change distribution channels / multimodal transportation	0.111158	5	1,61%	27
	FL5: Risk sharing	0.064361	7	0,93%	40
	FL6: Order fulfilment	0.062539	8	0,91%	43
	FL7: Vertical integration	0.066300	6	0,96%	41
	FL8: Production postponement	0.142773	4	2,07%	20
Adaptability	AD1: Supply chain design modification	0.296713	1	3,46%	6
	AD2: Quick rerouting of needs	0.224770	2	2,62%	14
	AD3: Learning from experience	0.118270	5	1,38%	33
	AD4: Using parallel processes rather than of series processes	0.089993	6	1,05%	39
	AD5: Lead time minimization	0.129563	4	1,51%	30
	AD6: Home delivery	0.140691	3	1,64%	24
Recovery	RC1: Effect mitigation	0.476803	1	3,90%	3
	RC2: Communications strategy	0.299603	2	2,45%	15
	RC3: Crisis governance	0.223594	3	1,83%	21
Dispersion	DS1: Dispersed decision making	0.389579	2	3,02%	11
	DS2: Dispersed capacity and assets	0.389810	1	3,02%	10
	DS3: Decentralization of key resources	0.220611	3	1,71%	22
Collaborative	CL1: Cooperative planning and decision	0.412883	1	3,79%	4
	CL2: Collaborative prediction	0.295061	2	2,71%	12
	CL3: Public–private collaboration	0.126708	4	1,16%	36
	CL4: Invest in supplier plant	0.165349	3	1,52%	28
Financial strength	FS1: Insurance	0.301541	2	1,65%	25
	FS2: Financial reserves and funds	0.388385	1	2,13%	19
	FS3: Price margin	0.178263	3	0,98%	40
	FS4: Portfolio diversification	0.131811	4	0,72%	47
Visibility	VS1: Products, assets, people visibility	0.216686	3	1,06%	37
	VS2: Strong IT system & information sharing	0.298764	1	1,46%	31
	VS3: Real time data	0.278505	2	1,36%	34
	VS4: Business intelligence gathering	0.088634	5	0,43%	50
	VS5: Knowledge acquisition and evaluation	0.117411	4	0,57%	48
Market position	MP1: Customer loyalty, communication and relationship.	0.334874	1	1,62%	26
	MP2: Increase process quality	0.187269	3	0,91%	44
	MP3: Quick delivery	0.217410	2	1,05%	38
	MP4: Mark equity of the company	0.093118	5	0,45%	49

	MP5: Market part	0.167329	4	0,81%	45
Security	SC1: Cyber-security	0.539156	1	1,67%	23
	SC2: Physical security	0.460844	2	1,43%	32

4.2. G-TOPSIS results

We employed AHP to calculate the weights of capabilities and practices and set the rankings. In doing this, an important question arises; which high maturity organizational practices help in developing capabilities and practices of resilience? In this section, the ranking of five main maturity factors has been achieved by employing a grey TOPSIS approach. These factors are quality and improvement culture (Q&IC), skills and training (S&T), measurement (Me), customer focus (CF) and finally commitment and communication (C&C). Three experts have helped to make this analysis through an online interview. A researcher and two project managers from service and manufacturing companies. Through these experts' opinions, we established grey evaluation matrices by linguistic variable. The linguistic variables rating matrix was configured after comparing the high maturity factors and the four most important resilience capabilities - responsiveness, readiness, flexibility and adaptability. Table 6 presents the results.

Based on the values obtained from the closeness coefficient, the ranking of the maturity factors is drawn up as follows: C&C > S&T > CF > Q&IC > Me.

The findings of the grey TOPSIS method in Table 6 reveal that commitment and communication are the most important maturity factors to implement capabilities for resilience with a value of 0.662. Skills and training factor is ranked second (0.618) followed by customer focus (0.573). Quality and improvement culture is ranked fourth (0.366). The least influencing factor is measurement, with a weight of 0.344. These results indicate that the more mature an organization is, the more resilience capabilities and practices can be implemented. For a high maturity organization, top management and workers' commitment is a key to develop and improve resilience capabilities and practices. This view is also supported by Mandal (2021). Skills, training and empowerment increase workers' awareness and innovation. In a similar vein, Keirs et al. (2022) defended the importance of skills and competence to improve resilience during pandemic events. High maturity processes increase customer focus. This factor facilitates the development of some capabilities, such as quick and effective response to customers' needs, flexibility to fulfil demand and adaptability with environment change.

Table 6. Final ranking of maturity factors based on G-TOPSIS

Code	Maturity factors	Distance from positive ideal solution	Distance from negative ideal solution	Closeness coefficient	Rank
Q&IC	Quality and improvement culture	0,916	0,528	0,366	4
S&T	Skills and training	0,551	0,892	0,618	2
Me	Measurement	0,947	0,496	0,344	5
CF	Customer focus	0,616	0,828	0,573	3
C&C	Commitment and Communication	0,488	0,955	0,662	1

4.3. Sensitivity analysis

In this sub-section, we conducted a sensitivity analysis (SA) to verify the robustness of the results and the stability of the rankings (Ikram et al., 2020). SA helps to check the variation in the current criteria weights that leads to ranking position change (Kumar et al., 2020). Six tests are performed by changing capability weights to test the validity of the ranking. We accomplished this SA by making arbitrary changes to the weights in test 1 and test 2. In test 3 we allocated the same weight to each criterion. We assigned percentages (60%, 40%), (70%, 30%) and (80%, 20%) to test 4, test 5 and test 6 respectively. Table 7 presents the ranking associated to each test. For graphical presentation, the reader is referred to figure 3. Based on the results, it can be seen that C&C keeps its position in top ranking. The observed variation concerns CF and S&T. Q&IC and Me change positions in one test. These findings reveal that communication and commitment are the most important maturity factors to improve supply chain resilience. Additionally, customer focus as well as skills and training both contribute in devolving resilience capabilities.

Table 7. Maturity factors ranking for the testing weights

	Original	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Q&IC	4	4	4	5	4	4	4
S&T	2	3	3	3	2	2	2
Me	5	5	5	4	5	5	5
CF	3	2	2	2	3	3	3
C&C	1	1	1	1		1	1

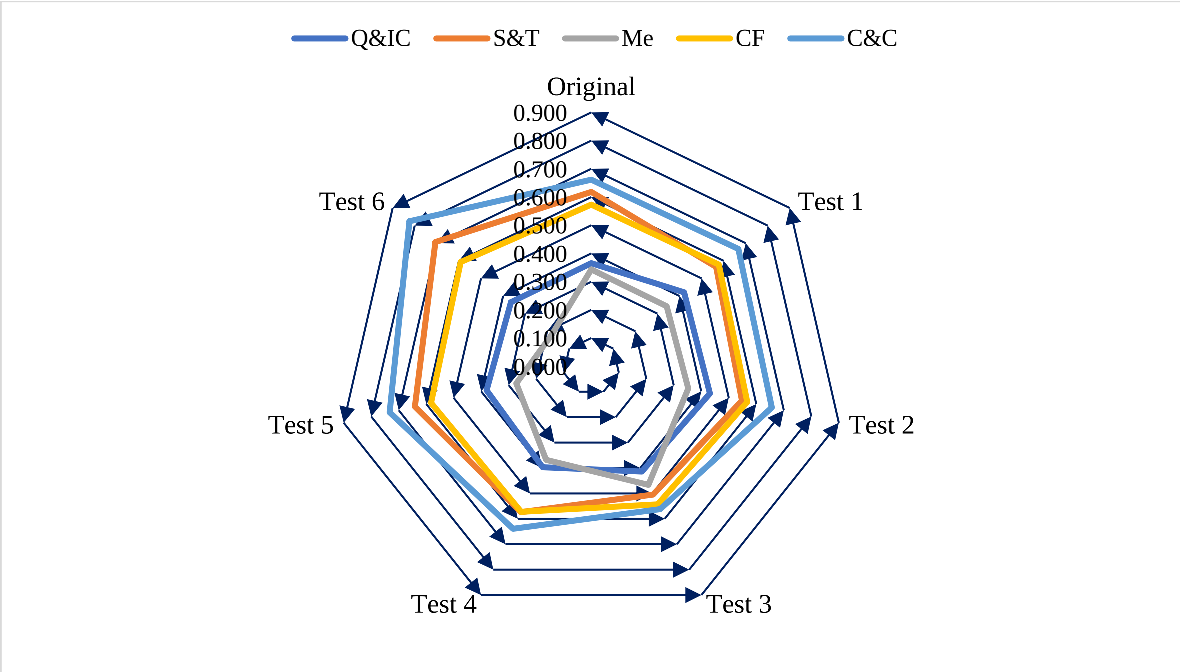

Figure 3 Representation of sensitive analysis results

5. Theoretical and practical implications

The findings are of direct practical relevance. Critical capabilities, practices and high maturity influencing factors for resilience are identified. Managers should be aware that improving global supply chain resilience is not only based on developing the capabilities and practices mentioned before. High maturity practices influence the adoption and the efficiency of these capabilities. Hence, a high level of maturity is a prerequisite to managing disruptive events. For instance, improving communication and commitment could lead to a clear vision of the current situation by every member of the company and unify efforts to attain objectives. Additionally, with a high maturity level, employees are in continuous training to develop their skills. In this case, it would be easier for managers to reassign and reorganize operations according to new circumstances caused by disruption. A quick response to eventual changes is ensured because everyone is focused on customer satisfaction. Therefore, organizations should focus on improving their maturity levels through defining, documenting, controlling and optimizing their processes. The degree of maturity could be considered as a key factor to adopting supply chain resilience capabilities. To build a resilient supply chain, decision-makers cannot focus on different capabilities at the same time. For this reason, this study provides a rank of the most important capabilities and associated practices to be developed.

Managers can identify which capability to adopt first and which are the practices needed to build this capability. As an example, to improve readiness to address future unpredictable events, managers should draw up contingency planning. This tool can reduce the confusion in a time of disruption since it provides another plan to handle new circumstances. Moreover, decisions-makers should develop techniques to manage potential risk and detect the early warning signals.

As for theoretical implications, this study methodology is based on a combination of two MCDM methods - AHP and TOPSIS. In doing this, the study contributes in advancing researches in hybrid MCDM. Thus, researchers can be motivated to integrate other methods to resolve more complex decision-making problems. Additionally, this study gathers and prioritizes relevant capabilities and practices distributed in many papers. These findings offer to future researchers a hierarchic vision of resilience capabilities. Hence, academics can use these results to orientate their research to significant and main capabilities. This study indicates that commitment, communication, skills and training are the most significant maturity factors influencing resilience improvement. Researchers can focus their works on these factors to build new knowledge of the relationship between resilience and supply chain maturity.

6. Conclusion

This paper provides a classification of relevant capabilities and related practices contributing in resilience improvement. Additionally, the influence of supply maturity level in the development of these capabilities is analyzed. The findings of this study contribute to knowledge in the field of supply chain management. This study proposes a hierarchical vision of capabilities and related practices to navigate unpredictable events safely.

Based on the results, it can be concluded that responsiveness, readiness, flexibility and adaptability are the most important capabilities to develop. To increase their resilience, organizations should respond quickly and effectively to customers' changing needs. In addition, companies should increase readiness through contingency planning, risk management and sensing early warning signals. To ensure flexibility, firms have to adopt multiple sourcing, acquire flexible supplier agreements, increase human capital flexibility and operate with production postponement. Since pandemic events have a long-term duration, organizations should develop adaptability by adjusting networks, requirements and distribution based on the fluctuating situation. This paper has shown that high supply chain maturity factors influence resilience capabilities. The most important factors for implementing these capabilities are commitment, communication, skills and training.

This study has some limitations. Capabilities and practices are collected from current literature. Improvement can be made by adding other inputs through industrial interviews. Another limitation is the number of experts and the subjectivity of answers. Researchers can organize meetings for a significant number of experts where discussions can be conducted. This study only analyses capabilities and practices. In future, researchers can add more hierarchical levels to introduce practical actions and build a map to achieve a high level of resilience. In this study, we provide a ranking of five high maturity factors influencing capability resilience. For future works, we propose to use other techniques such as ISM and DEMATEL to highlight the interaction between resilience and high maturity practices. Other studies can explore digital tools that could be used to further examine resilience and maturity.

Appendix A1: G-TOPSIS steps

Step 1: Assess preference by using the linguistic variable. The correspondent grey numbers values of verbal variable are: Highly unfavorable [0.0, 0,2], Unfavorable [0.2,0,4], favorable [0.4,0.6], fairly favorable [0.6, 0.8] and highly favorable [0.8,1.0].

$$\otimes w_r = \frac{1}{b}[\otimes w_r^1 + \cdots \otimes w_r^b] \quad \text{where } w_r^b = [\underline{w}_r^b, \overline{w}_r^b] \qquad (3)$$

Step 2: Check the status of each alternative in each criterion.

$$\otimes G_{lr} = \frac{1}{b}[\otimes G_{lr}^1 + \cdots \otimes G_{lr}^b] \qquad (4)$$

Where $\otimes G_{lr}^b, (l = 1,2,\ldots,m), (r = 1,2,\ldots,n)$ is the evaluation of the criterion r by the bth expert. The presentation is given by: $\otimes G_{lr}^b = [\underline{G}_{lr}^b, \overline{G}_{lr}^b]$.

Step 3: Implement the grey decision matrix.

$$D = \begin{bmatrix} \otimes G_{11} & \cdots & \otimes G_{1n} \\ \vdots & \ddots & \vdots \\ \otimes G_{m1} & \cdots & \otimes G_{mn} \end{bmatrix} \qquad (5)$$

Step 4: Normalize the grey decision matrix.

$$D^* = \begin{bmatrix} \otimes G_{11}* & \cdots & \otimes G_{1n}* \\ \vdots & \ddots & \vdots \\ \otimes G_{m1}* & \cdots & \otimes G_{mn}* \end{bmatrix} \qquad (6)$$

$$\text{Where } \otimes G_{lr}^{*} = [\frac{\underline{G}_{lr}}{G_r^{max}}, \frac{\overline{G}_{lr}}{G_r^{max}}] \text{ and } G_r^{max} = \max_{1 \le l \le m} \{\overline{G}_{lr}\}$$

Step 5: Formulate the weighted normalized grey decision matrix.

$$D_w^* = \begin{bmatrix} \otimes V_{11} & \cdots & \otimes V_{1n} \\ \vdots & \ddots & \vdots \\ \otimes V_{m1} & \cdots & \otimes V_{mn} \end{bmatrix} \text{Where } \otimes V_{lr} = \otimes G_{lr}^{*} \times \otimes w_r \quad (7)$$

Step 6: identify the pattern in line $A^{\max}$ and the anti-pattern $A^{\min}$ as follow:

$$A^{\max} = \{\otimes V_1^{\max}, \otimes V_2^{\max}, \ldots, \otimes V_n^{\max}\} \quad (8)$$

Where $A^{\max} = \{[\max_{1 \le l \le m} \underline{V}_{l1}, \max_{1 \le l \le m} \overline{V}_{l1}], [\max_{1 \le l \le m} \underline{V}_{l2}, \max_{1 \le l \le m} \overline{V}_{l2}], \ldots, [\max_{1 \le l \le m} \underline{V}_{ln}, \max_{1 \le l \le m} \overline{V}_{ln}]\}$

$$A^{\min} = \{\otimes V_1^{\min}, \otimes V_2^{\min}, \ldots, \otimes V_n^{\min}\} \quad (9)$$

Where $A^{\min} = \{[\min_{1 \le l \le m} \underline{V}_{l1}, \min_{1 \le l \le m} \overline{V}_{l1}], [\min_{1 \le l \le m} \underline{V}_{l2}, \min_{1 \le l \le m} \overline{V}_{l2}], \ldots, [\min_{1 \le l \le m} \underline{V}_{ln}, \min_{1 \le l \le m} \overline{V}_{ln}]\}$

Step 7: Calculate the value of distance to the positive and negative solution:

$$d_l^{+} = \sum_{r=1}^{n} d(V_{lr}, V_r^{max}) \text{ and } d_l^{-} = \sum_{r=1}^{n} d(V_{lr}, V_l^{min}) \quad (10)$$

$$\text{Where } d\,(V_A, V_B) = \sqrt{1/2\,[(\underline{V}_A - \underline{V}_B)^2 + (\overline{V}_A - \overline{V}_B)^2]}$$

Step 8: Calculate the coefficient of closeness between alternatives.

$$CC_l = \frac{d_l^{+}}{d_l^{+} + d_l^{-}}, \; l = 12,3, \ldots, \mathrm{m} \quad (11)$$

Step 9: Rank the alternatives according to the coefficient of closeness.

Appendix A2: AHP sample calculation for expert 1.

Table A1 shows the assessment of capabilities using a scale from 1 to 9.

Table A1. Pair-wise comparison matrix

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**
C1	1	2	2	2	3	4	4	3	3	4	5
C2	1/2	1	1	2	3	3	3	2	3	2	3
C3	1/2	1	1	2	3	3	2	3	5	3	5
C4	1/2	1/2	1/2	1	2	1	2	2	2	3	2

C5	1/3	1/3	1/3	1/2	1	1	2	2	2	3	2
C6	1/4	1/3	1/3	1	1	1	3	1	2	2	3
C7	1/4	1/3	1/2	1/2	1/2	1/3	1	2	2	3	2
C8	1/3	1/2	1/3	1/2	1/2	1	1/2	1	2	3	2
C9	1/3	1/3	1/5	1/2	1/2	1/2	1/2	1/2	1	3	2
C10	1/4	1/2	1/3	1/3	1/3	1/2	1/3	1/3	1/3	1	6
C11	1/5	1/3	1/5	1/2	1/2	1/3	1/2	1/2	1/2	1/6	1
Sum	**4,45**	**7,17**	**6,73**	**10,83**	**15,33**	**15,67**	**18,83**	**17,33**	**22,83**	**27,17**	**33,00**

The normalized pairwise comparison matrix (Table A2) is formulated through dividing each row by the sum of the column. The weight is calculated using the average of all elements in the row.

Table A2. Normalized pairwise comparison matrix

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**Weight**
C1	**0,224719**	**0,279070**	**0,297030**	**0,184615**	**0,195652**	**0,255319**	**0,212389**	**0,173077**	**0,131387**	**0,147239**	**0,151515**	**0,204728**
C2	**0,112360**	**0,139535**	**0,148515**	**0,184615**	**0,195652**	**0,191489**	**0,159292**	**0,115385**	**0,131387**	**0,073620**	**0,090909**	**0,140251**
C3	**0,112360**	**0,139535**	**0,148515**	**0,184615**	**0,195652**	**0,191489**	**0,106195**	**0,173077**	**0,218978**	**0,110429**	**0,151515**	**0,157487**
C4	**0,112360**	**0,069767**	**0,074257**	**0,092308**	**0,130435**	**0,063830**	**0,106195**	**0,115385**	**0,087591**	**0,110429**	**0,060606**	**0,093015**
C5	**0,074906**	**0,046512**	**0,049505**	**0,046154**	**0,065217**	**0,063830**	**0,106195**	**0,115385**	**0,087591**	**0,110429**	**0,060606**	**0,075121**
C6	**0,056180**	**0,046512**	**0,049505**	**0,092308**	**0,065217**	**0,063830**	**0,159292**	**0,057692**	**0,087591**	**0,073620**	**0,090909**	**0,076605**
C7	**0,056180**	**0,046512**	**0,074257**	**0,046154**	**0,032609**	**0,021277**	**0,053097**	**0,115385**	**0,087591**	**0,110429**	**0,060606**	**0,064009**
C8	**0,074906**	**0,069767**	**0,049505**	**0,046154**	**0,032609**	**0,063830**	**0,026549**	**0,057692**	**0,087591**	**0,110429**	**0,060606**	**0,061785**
C9	**0,074906**	**0,046512**	**0,029703**	**0,046154**	**0,032609**	**0,031915**	**0,026549**	**0,028846**	**0,043796**	**0,110429**	**0,060606**	**0,048366**
C10	**0,056180**	**0,069767**	**0,049505**	**0,030769**	**0,021739**	**0,031915**	**0,017699**	**0,019231**	**0,014599**	**0,036810**	**0,181818**	**0,048185**
C11	**0,044944**	**0,046512**	**0,029703**	**0,046154**	**0,032609**	**0,021277**	**0,026549**	**0,028846**	**0,021898**	**0,006135**	**0,030303**	**0,030448**

To calculate the consistency ratio, we first calculate the weighted sum value through dividing the weight of criteria by the elements of the matrix in table A1 and calculating the sum of each row. Then λ_{max} is obtained by the average of the third column of table A3. CI and CR are calculated using the formulas (1) and (2) respectively.

Table A3. Consistency ratio

	Weighted Sum value	$\frac{\text{Weighted Sum value}}{\text{Weight}}$
C1	2,449485	11,964554
C2	1,689718	12,047832
C3	1,893307	12,021962[2]
C4	1,124865	12,093398
C5	0,919492	12,240164
C6	0,933426	12,184911
C7	0,776040	12,123963
C8	0,747508	12,098474
C9	0,585574	12,107178
C10	0,557077	11,561283
C11	0,354355	11,638033
λ_{max}		12,007432
CI		0,10074319
CR		0,06627842

The same process is followed to calculate weight of criteria for each expert. The average is taking for the final weight. In the sub-level of the hierarchy, the same steps are followed to identify the local and the global weight of each practice.

Appendix A3: G-TOPSIS sample calculation.

The implementation of G-TOPSIS is presented in the following:

Table A4 shows the correspondent grey numbers for expert's assessment.

Table A4. Grey assessment for the three experts.

Expert 1				
	Responsiveness	Readiness	Flexibility	Adaptability
Q & IC	[0.2, 0.4]	[0.4, 0.6]	[0.4, 0.6]	[0.4, 0.6]
S&T	[0.6, 0.8]	[0.4, 0.6]	[0.6, 0.8]	[0.2, 0.4]
Me	[0.2, 0.4]	[0.0, 0.2]	[0.2, 0.4]	[0.4, 0.6]
CF	[0.6, 0.8]	[0.4, 0.6]	[0.4, 0.6]	[0.4, 0.6]
C&C	[0.8, 1.0]	[0.6, 0.8]	[0.8, 1.0]	[0.8, 1.0]

Expert 2				
	Responsiveness	**Readiness**	**Flexibility**	**Adaptability**
Q & IC	**[0.4, 0.6]**	**[0.4, 0.6]**	**[0.4, 0.6]**	**[0.2, 0.4]**
S&T	**[0.8, 1.0]**	**[0.6, 0.8]**	**[0.4, 0.6]**	**[0.6, 0.8]**
Me	**[0.0, 0.2]**	**[0.2, 0.4]**	**[0.2, 0.4]**	**[0.0, 0.2]**
CF	**[0.4, 0.6]**	**[0.4, 0.6]**	**[0.4, 0.6]**	**[0.2, 0.4]**
C&C	**[0.6, 0.8]**	**[0.8, 1.0]**	**[0.8, 1.0]**	**[0.6, 0.8]**
Expert 3				
	Responsiveness	**Readiness**	**Flexibility**	**Adaptability**
Q & IC	**[0.2, 0.4]**	**[0.4, 0.6]**	**[0.4, 0.6]**	**[0.2, 0.4]**
S&T	**[0.8, 1.0]**	**[0.6, 0.8]**	**[0.4, 0.6]**	**[0.8, 1.0]**
Me	**[0.2, 0.4]**	**[0.2, 0.4]**	**[0.2, 0.4]**	**[0.2, 0.4]**
CF	**[0.8, 1.0]**	**[0.4, 0.6]**	**[0.4, 0.6]**	**[0.2, 0.4]**
C&C	**[0.8, 1.0]**	**[0.8, 1.0]**	**[0.8, 1.0]**	**[0.6, 0.8]**

Using formulas (4), (5) and (6), we build the normalized grey matrix as shown is Table A5.

Table A5. Normalized grey assessment

	Responsiveness	**Readiness**	**Flexibility**	**Adaptability**
Q & IC	**[0.267,0.467]**	**[0.400,0.600]**	**[0.400,0.600]**	**[0.267,0.467]**
S&T	**[0.733,0.933]**	**[0.533,0.733]**	**[0.467,0.667]**	**[0.733,0.933]**
Me	**[0.133,0.333]**	**[0.133,0.333]**	**[0.200,0.400]**	**[0.200,0.400]**
CF	**[0.600,0.800]**	**[0.400,0.600]**	**[0.400,0.600]**	**[0.267,0.467]**
C&C	**[0.733,0.933]**	**[0.733,0.933]**	**[0.800,1.000]**	**[0.667,0.867]**

The weighted normalized grey matrix is presented in Table A6 using formula (7). This matrix is used to calculate the pattern A^{max} and anti-pattern A^{min} using formulas (8) and (9) respectively.

Table A6. Weighted normalized grey matrix

	Responsiveness	**Readiness**	**Flexibility**	**Adaptability**
Q & IC	**[0.210,0.467]**	**[0.286,0.386]**	**[0.300,0.133]**	**[0.200,0.200]**

S&T	**[0.576,0.933]**	**[0.381,0.471]**	**[0.257,0.120]**	**[0.073,0.100]**
Me	**[0.105,0.333]**	**[0.095,0.214]**	**[0.600,0.200]**	**[0.267,0.233]**
CF	**[0.471,0.800]**	**[0.286,0.386]**	**[0.300,0.133]**	**[0.200,0.200]**
C&C	**[0.576,0.933]**	**[0.524,0.600]**	**[0.150,0.080]**	**[0.080,0.108]**
A^{max}	**[0.576, 0.933]**	**[0.524,0.600]**	**[0.600,0.200]**	**[0.267,0.233]**
A^{min}	**[0.105, 0.333]**	**[0.095,0.214]**	**[0.150,0.080]**	**[0.073,0.100]**

.

Then, the distance between negative and positive solution is calculated using formula (10) and presented in table A7. Based on these distances we calculated Coefficient of closeness using the formula (11). Results are presented in table 5.

Table A7. Distances of alternative from A^{max} and A^{min}.

d^+	**Responsiveness**	**Readiness**	**Flexibility**	**Adaptability**
Q & IC	**0,41966**	**0,22650**	**0,21731**	**0,05270**
S&T	**0,00000**	**0,13590**	**0,24895**	**0,16642**
Me	**0,53956**	**0,40771**	**0,00000**	**0,00000**
CF	**0,11990**	**0,22650**	**0,21731**	**0,05270**
C&C	**0,00000**	**0,00000**	**0,32932**	**0,15911**
d^-	**Responsiveness**	**Readiness**	**Flexibility**	**Adaptability**
Q & IC	**0,11990**	**0,18120**	**0,11257**	**0,11445**
S&T	**0,53956**	**0,27180**	**0,08087**	**0,00000**
Me	**0,00000**	**0,00000**	**0,32932**	**0,16642**
CF	**0,41966**	**0,18120**	**0,11257**	**0,11445**
C&C	**0,53956**	**0,40771**	**0,00000**	**0,00749**

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