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REVIEW ARTICLE

APPLICATION OF LATENT CLASS ANALYSIS TOWARD SUPPLY CHAIN RESILIENCE OF SELECTED MANUFACTURING COMPANIES IN REGION 4A, PHILIPPINES

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ABSTRACT

Supply chain disruptions cause cascading negative impacts, extending beyond immediate effects to destabilize entire networks and result in significant financial losses. Despite growing research on supply chain resilience (SCR), a classification system to differentiate firms' resilience levels remains underdeveloped, particularly within the Philippine manufacturing sector. This research examines the idea of supply chain resilience by empirically identifying specific capabilities that contribute to it. Specifically, this study proposes a model of Supply Chain Resilience stages. Supply Chain Resilience is the system's ability to maintain its original capabilities in the face of disruptions. To test the correlation between respondent demographic profiles and levels of supply chain resilience, a survey of 10 Region 4A manufacturing firms was conducted. The study utilized Pearson correlation analysis, which revealed a significant positive correlation. The study proposed that the firms can be categorized into three categories, based on the level of supply chain resilience capabilities of the firms. These categories are basic, cautious, and progressive. Based on the findings, transitioning from cautious to progressive category is less difficult compared to advancing from basic to cautious category. Management within the Philippine manufacturing sector may use the proposed framework in evaluating their current supply chain resilience category. Firms may also use the framework as a guide in implementing significant process and procedural adjustments to improve their supply chain resilience.

KEYWORDS

Supply Chain Resilience, Capabilities Assessment, Manufacturing Categories, Firm Classification

1. INTRODUCTION

Supply chains are vulnerable to disruptions that can have a significant impact (Ahmad and AlBazi, 2023). At the most severe, these perturbations in any phase – raw materials, transportation, production- can cause a domino effect that induces instability in the whole network, and result in significant financial loss (Li and Zobel 2020; Donadoni 2019).

Supply Chain Resilience (SCR) is defined as the firm's capability to bear, respond, and recover from disruptions, as described by (Kaviani et al., 2020). For business continuity and competitiveness in high-risk sectors such as the manufacturing industry, where required levels of SCR are predetermined, ensuring SCR quality is feasible. In the turbulent world environment in which business now operates, a strong supply chain is not just a logistical backbone. It is increasingly becoming recognized as a strategic lifebelt for any manufacturing business.

Although numerous studies investigated enablers and barriers of resilience and the relationship between them and performance, there is no standardized framework for the evaluation of resilience-maturity levels among manufacturing sectors (Karmaker and Ahmed, 2020; Pettit et al., 2019; Junaid et al., 2019). So is the same in the Philippine context. While the manufacturing industry has made significant contributions to the economy, no common framework has been established to categorize SC resilience categories yet. As testified the industry sector contributed 19% to the country's gross domestic product in 2022 and is expected to have an annual growth rate of 6% from 2023 to 2024 (Canto et al., 2024). This gap is further addressed by examining differences in resilience practice adoption across manufacturers in this study. The study suggests a framework for categorizing manufacturing companies in Region IV-A, Philippines, according to their supply chain resilience capabilities.

The research is based on the Resilience Framework which describes resilience as a balance between strengths and weaknesses by (Peţt et al., 2013). A balanced approach is essential, as excessive capabilities can diminish profits, whereas excessive vulnerabilities increase risk exposure for firms. This study concentrates on the "capabilities" dimension of resilience, acknowledging its significance in mitigating a firm's vulnerability to excessive risk. Additionally, Latent Class Analysis (LCA) and Welch ANOVA were utilized to delineate distinct stages of resilience.

Since SCR is closely tied to a company's ability to keep running during disruptions, the findings of this study provide a useful perspective on business continuity for the Philippine manufacturing sector. The proposed classification model provides actionable insights for Philippine manufacturing firms to strengthen continuity and risk management. The proposed model would also serve as a practical tool for guiding Philippine manufacturing firms toward greater resilience and sustained competitiveness in an increasingly volatile global environment.

2. LITERATURE REVIEW

Supply chain resilience, in accordance with refers to a firm's capability of adjusting to and repairing disruptions, while ensuring consistent service and performing operations efficiently (Smith, 2024). This analysis supply chain resilience is an essential capability for dealing with the intricacies and uncertainties of contemporary supply chains, especially in the current environment with increasing customer expectations, broadening portfolios, and the requirement to maintain continuity of supply (Jafarnejad et al., 2019). With a varied and dynamic global scenario, organizations can drive their success by adapting to the principles of supply chain resilience (Mishra et al., 2024). As a study evidence that effective supply chain resilience leads to firm performance (Wong et al., 2020). Moreover, resilience theory highlights the capacity of systems to change and to return from setbacks. In the Philippine context, this calls for adaptive measures to reduce the impact of natural disasters on businesses, such as the development of strong risk management plans, alternate supplier sourcing strategies, and investments in resilient infrastructure.

Developing supply chain resilience requires the development of particular capabilities. Some of the main strategies to become resilient are to diversify the supply base, use strategic inventory management, and use an agile process (Smith, 2024). However, the study of reveals a fragmented literature, with several inconsistent terminologies used to describe these elements (Castillo, 2022). Common terms include capabilities indicators, elements, antecedents, competencies, strategies, and enablers (Al Naimi et al., 2021; Donadoni et al., 2018; Kochan and Nowicki, 2018; Pettit et al., 2010; Singh et al., 2019; Ali et al., 2017; Sabahi and Parast, 2020; Wieland et al., 2013; Tukamuhabwa et al., 2015). This study adopts the term "capabilities," aligning with supply chain resilience model (Pettit et al., 2013).

Existing research has defined and validated these capabilities, which are crucial for anticipating and overcoming disruptions (Pettit et al., 2010). According to the literature, resilient supply chains incorporate capabilities such as flexibility collaboration, visibility, agility, robustness, market position, ambidexterity, and security (Tukamuhabwa et al., 2015; Voss and Williams, 2013; Pettit, Fiksel, and Croxton, 2010; Piprani et al., 2020a; Scholten and Schilder, 2015; Pettit et al., 2010; Ali et al., 2017; Hohenstein et al., 2015; Saenz et al., 2015; Wieland, 2013; Fiksel, 2015; Pettit et al., 2010; Aslam et al., 2020). As attested by the study, these capability factors are essential for ensuring sustainable supply chain performance of (Gani et al., 2022).

Developing these capabilities requires large investments of time, people, and money. It is of prime importance to concentrate on the development of capabilities that provide maximum resilience. As emphasize, reaching an appropriate balance of resilience is critical to avoid loss and risk exposure (Pettit et al., 2019). This balanced approach ensures that capabilities are neither over-invested nor insufficient to effectively absorb and adapt to unforeseen circumstances.

These capabilities can be classified into three: proactive, concurrent, and reactive (Hollnagel, 2017). Although being proactive is important for organizations in terms of anticipating future threats and preparing for them effectively, firms also need to have the capability of responding to new threats and crises (Cedergren and Hassel, 2024; Singh, Soni, and Badhotiya, 2019). Concurrent strategies, as introduced are the development of competencies that enable the activation of reactive mechanisms, though allowing one to adapt and react to unplanned occurrences (Wu and co-workers, 2012). On the other hand, reactive strategies, as identified focus on building stronger supply chain components in order to quickly react to and recover from disruptions by (Bui et al., 2020). Although less commonly covered in the literature, concurrent strategies are also distinct from reactive strategies (Ali et al., 2017).

Proactive strategies are conducted pre-disruption (readiness), and concurrent and reactive tactics are executed during and post-disruptions, respectively. This analysis suggest that SCR phases emerge from developing a two-phase model of SCR (during and post-disruption) toward a three-phase model (pre-, during-, and post-disruption) (Ali et al., 2017). The earlier emphasis was on response and recovery (Datta et al., 2007). However, subsequent research emphasized the significance of the pre-disruption preparation phase (Ponomarov et al., 2012). More recent studies have also incorporated "growth" alongside recovery in the post-disruption phase (Day, 2014; Hohenstein et al., 2015; Johnson et al., 2013).

The concept of a supply chain resilience maturity classification model builds upon existing supply chain maturity models. These models propose that companies evolve through various maturity levels, with higher levels typically linked to better performance. For example, Lockamy and five-level process management model shifts its focus from internal to external factors as firms mature McCormack's, 2004). Lahti, developed a process-based four-stage model that focuses on collaboration and integration, and introduced a five-level model of S(CM)2 and provided detailed recommendations for improvement (Shamsuzzoha, and Helo, 2009; Reyes and Giachetti, 2010). This current study builds on the existing knowledge of supply chain management models to develop a focused model designed with the aim of improving resilience.

3. Methods

A survey instrument based on the Supply Chain Resilience Assessment Model (SCRAM) 2.0 was used as the data collection tool for this study. The SCRAM 2.0 device was selected because of its systematic approach and potential to become a standard tool in the industry (Sangwan and Choudhary, 2018; Pettit et al., 2013). The survey specifically centred on sixteen SCR capabilities drawn from the literature including sourcing flexibility, order fulfilment flexibility, capacity flexibility, efficiency flexibility, visibility, adaptability, anticipation, recovery, dispersion, collaboration, organisation, market position, security, financial strength, manufacturing flexibility, and product stewardship (Pettit et al., 2013; Tobin et al., 2014). The respondents rated their firm on each capability using a five-point Likert scale (1= Strongly Disagree to 5= Strongly Agree).

The data were obtained from 50 research participants representing 10 manufacturing firms in Region IV-A, Philippines, which were identified through the national stock exchange website. Response rate: The initial list of contacts included 481 professionals; 266 agreed to participate, and 50 completed the questionnaire (62.4% response rate). Online and in-person surveys, and clarifications to participants' responses, were used to gather data. Five-day reminders were sent to preserve response rates. The sample represented a wide range of manufacturing sub-sectors, including food and personal care products, pharma and textiles, among others (Kushwah and Kumar, 2017). To mitigate possible common method bias, Harman's one-factor test was performed (Agarwal and Narayana, 2020; Agyabeng-Mensah et al., 2020). Non-response bias was reduced by the anonymity, the response period that lasted several days, and a follow-up that was sent out regularly, as well as the use of a survey that was optimized for the small screen of a smartphone and the inclusion of an independent samples t-test comparing early and late respondents (Belhadi et al., 2021).

Statistical analyses were conducted with SPSS version 26 and JAMOVI. The reliability of the SCR abilities was confirmed using EFA with maximum likelihood and varimax rotation, using Cronbach's alpha for reliability assessment and KMO and Bartlett's for factor analysis suitability (Al-Hakimi et al., 2020; Al Naimi et al., 2020; Paulraj et al., 2012). The classification method, latent class analysis (LCA), was used to categorize companies according to their SCR capability adoption degree. The optimal number of clusters was defined by AIC and BIC comparisons among models with a range from 2 to 5 clusters. Cluster means were compared by Welch ANOVA corrected for unequal variances (Field, 2013; Shingala and Rajyaguru, 2015). These clusters were then labelled and interpreted to form a taxonomy of SC Resilience maturity stages.

4. Data Analysis

Table 1: Respondents' Demographic Profile

Respondents	Frequency	Percentage
Managerial Experience		
Below three years	6	12.0%
Between 3 & 5 years	11	22.0%
Between 6 & 10 years	19	38.0%
Between 11 & 15 years	8	16.0%
Above 15 years	6	12.0%
Designations		
Officer/Executive	8	16.0%
Assistant Manager	9	18.0%
Manager	23	46.0%
Team Lead/Deputy Manager	5	10.0%
Unit Head	3	6.0%
General Manager/Director	2	4.0%
Functional Role		
Planning/Scheduling	11	22.0%
Purchasing	11	22.0%
Logistics	7	14.0%
Marketing/Sales	7	14.0%
Production	6	12.0%
Engineering	2	4.0%

Table 1 (cont) : Respondents' Demographic Profile		
Other	2	4.0%
Quality Control	1	2.0%
Research and Development	1	2.0%
Finance/Accounting	1	2.0%

The demographic profile of the 50 respondents is categorized into three dimensions: managerial experience, designations, and functional roles.

In terms of managerial experience, respondents exhibited varying levels of experience. The largest group (38.0%) had between 6 and 10 years of experience. This was followed by 22.0% with 3 to 5 years of experience, 16.0% with 11 to 15 years, and 12.0% each for those with below three years or above 15 years of experience.

In terms of designation, a majority of the respondents (46.0%) were managers. Assistant managers accounted for 18.0%, while 16.0% were officers or executives. Smaller proportions included team leads or deputy managers (10.0%), unit heads (6.0%), and general managers or directors (4.0%).

For functional roles, the respondents represented a wide array of functional roles. The largest proportions were in planning/scheduling and purchasing, each accounting for 22.0%. Logistics and marketing/sales followed at 14.0% each, while production made up 12.0%. Engineering, quality control, and other roles each represented 4.0%, and research and development and finance/accounting accounted for 2.0% each.

Table 2: The relationship between the respondents' demographic profile and supply chain resilience

	N	Spearman's rho	p-value	Decision
Demographic Profile & Supply Chain Resilience	50	0.734	0.035	Reject H_0

Table 2 presents the results of the Pearson product-moment correlation coefficient analysis, which examines the relationship between respondents' demographic profiles and supply chain resilience. The correlation coefficient (r = 0.734) signifies a strong positive linear relationship, indicating that variations in demographic characteristics are associated with changes in supply chain resilience. The p-value of 0.035, being below the significance threshold of 0.05, demonstrates statistical significance. Consequently, the null hypothesis, suggesting no significant relationship between the variables, is rejected.

These results are consistent with previous studies that highlight the role of human capital and demographic variables in the relationship to organizational resilience. The researchers emphasized the importance of capabilities and vulnerabilities in promoting supply chain resilience For instance, (Tukamuhabwa et al., 2015). Furthermore, an analysis highlighted that individual- and organization-based factors lead to dynamic capabilities that help firms to respond and recover from disruptions (Yu et al., 2019).

The significant positive relationship found in this study also underscores the importance of human capital in building supply chain resilience. As noted in the analysis, the qualities of education, experience, and training serve as drivers of decision-making and adaptability in uncertain circumstances (Kumar and Anbanandam, 2020). This view is also consistent with the dynamic capability view (DCV), which treats resilience as a dynamic capability that allows organizations to effectively maneuver through and adjust amid disruptions. In practical terms, this could mean that organizations need to develop sector-targeted interventions for resilience building. These strategies may involve specialized forms of workforce development, diversity and inclusion programs, and leadership development—all of which are critical components of strong, flexible supply chains.

This significant positive relationship between demographic factors and supply chain resilience reported in this article complements the general literature on resilience. The integration of human capital into resilience plans will enable organizations to respond effectively to any disruptions.

Prior to this, maximum likelihood-followed by a varimax-rotation EFA was applied to check how the survey items loaded on the capabilities that were found (Vanpoucke et al., 2009). Only factors that an item loaded > 0.5 were retained for further analysis. Scale reliability was checked by computing the Cronbach alpha coefficient (Al-Hakimi et al., 2020; Al Naimi et al., 2020, 2020). Moreover, KMO and Bartlett¡¦s test of sphericity were examined to confirm the appropriateness of conducting factor analysis (Paulraj et al., 2012).

Latent class analysis (LCA) was performed using JAMOVI software to group similar firms based on their adoption of capabilities. Latent class analysis LCA is a statistical modeling technique that aims to identify classes (unobserved categories) in a data set of responses to categorical items. This approach is more accurate than hierarchical clustering based on statistical tests of significance and adjustment to find out the appropriate number of clusters, which can reduce personal bias. To determine the optimal number of clusters, an iterative approach was used, increasing the number of latent classes and evaluating the model fit based on statistical criteria, parsimony, and interpretability. No standardization was required for our data, so it remained unchanged during the clustering process.

SPSS version 26 was used for data analysis. In addition, the researcher used Welch ANOVA to compare differences across the resulting clusters, as it is robust to the homogeneity of variances. The post hoc Games-Howell test was also used to further compare the groups as it is insensitive to variance and sample size (Field 2013; Shingala and Rajyaguru, 2015).

4.1 Exploratory Factor Analysis

This section discusses the findings of the Exploratory Factor Analysis (EFA) that was performed to investigate the dimensions of SC Resilience capabilities. The accompanying annexure provides details on descriptive statistics and factor analysis. The Cronbach's alpha values ranged from 0.79 to 0.92, indicating satisfactory internal consistency. The KMO value of 0.924 suggested the presence of underlying factors, and Bartlett's Test of Sphericity confirmed the suitability of factor analysis for our data with a probability level less than 0.05.

Through EFA using maximum likelihood and varimax rotation, nine distinct capability factors were extracted from the dataset, demonstrating strong convergent validity. These factors included manufacturing flexibility, visibility, recovery, collaboration, organization, market position, security, and product stewardship. Items with loadings below 0.5 or cross-loadings were removed to ensure reliable and valid results.

Due to the limited sample size of 50 and the large number of items, data validation and analysis faced certain challenges. encountered a similar issue when working with a detailed supply chain resilience questionnaire (Zouari et al., 2021). They addressed this limitation by omitting certain variables during the analysis stage.

4.2 Cluster Analysis

To identify the optimal number of distinct classes, the researcher evaluated global goodness-of-fit indices, specifically the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), across four models comprising two to five clusters. The model demonstrating the lowest values on these indices is deemed most suitable.

Table 3: Goodness of fit index

Number of Clusters	Goodness of Fit Index	
	AIC	BIC
2	23453	24721
3	21998	23902
4	22309	24849
5	21829	25004

As shown in Table 3, the BIC reached its minimum in the three-latent class model, whereas the AIC was lowest for both the three- and five-class models, with only a negligible difference between them. Notably, the five-class model displayed less clearly defined patterns, which reduced the interpretability of the results. Consequently, the three-latent class model was selected, as it provides an optimal balance between model simplicity and accuracy.

Firms were grouped into three clusters based on the nine capability factors, as shown in Table 4. The three-cluster solution revealed distinct patterns among the groups with reasonable group sizes. The largest cluster comprised 63.3% of the sample, while the smallest was approximately 10%. Based on the nine SC Resilience capabilities, mean scores for each cluster were found to be 2.45, 3.47, and 4.08.

Table 4: Cluster Analysis

		Basic	Cautious	Progressive
		Cluster 1 N=5 (10%)	**Cluster 2** N=14 (28%)	**Cluster 3** N=31(62%)
Low SC Resilience Level →High SC Resilience Level				
Flexibility in Manufacturing	Cluster Mean	2.35	3.12	3.39
	SD	0.68	0.52	0.67
Capacity	Cluster Mean	2.34	3.41	3.83
	SD	0.81	0.66	0.70
Visibility	Cluster Mean	2.18	3.81	4.35
	SD	0.73	0.50	0.50
Recovery	Cluster Mean	2.43	3.46	4.20
	SD	0.81	0.52	0.42
Collaboration	Cluster Mean	2.44	3.59	4.13
	SD	0.93	0.48	0.51
Organization	Cluster Mean	2.37	3.53	4.21
	SD	0.80	0.45	0.56
Market Position	Cluster Mean	2.63	3.92	4.36
	SD	0.85	0.44	0.55
Security	Cluster Mean	2.68	3.19	4.08
	SD	1.01	0.47	0.54
Product Stewardship	Cluster Mean	2.62	3.24	4.20
	SD	0.92	0.55	0.44
Mean Cluster Score		**2.45**	**3.47**	**4.08**

Cluster 1 represents the least resilient firms, accounting for 10% of the sample. Within this group, security was the most emphasized strategy, with an average score of 2.68, while visibility ranked lowest at 2.18. Firms in this cluster showed consistent levels of manufacturing flexibility, indicated by the lowest standard deviation of 0.68, but exhibited the greatest variation in security, with a standard deviation of 1.01.

Cluster 2, the second largest group comprising 28% of the sample, demonstrated strong capabilities in market position and visibility, with mean scores of 3.92 and 3.81, respectively. Manufacturing flexibility scored the lowest in this cluster, averaging 3.12. This group also displayed relatively small variations across all capability factors, with standard deviations ranging between 0.44 and 0.66, suggesting more uniformity among firms.

The largest and most resilient group is Cluster 3, consisting of 31 firms (62% of the sample). Visibility and market position were the highest-rated capabilities, with mean scores of 4.35 and 4.36, respectively. Manufacturing flexibility again had the lowest mean at 3.39. The standard deviations within this cluster ranged from 0.42 to 0.70, indicating moderate consistency across the measured capabilities.

Table 5: Percentage of increase in mean scores across all clusters

Dimension	**Cluster-1 to Cluster-2**	**Cluster-2 to Cluster-3**
Flexibility in Manufacturing	32.63%	8.76%
Capacity	45.41%	12.58%
Visibility	74.74%	14.20%
Recovery	42.15%	21.37%
Collaboration	47.14%	15.11%
Organization	48.84%	19.30%
Market Position	48.85%	11.26%
Security	19.42%	27.81%
Product Stewardship	23.76%	29.53%
Mean % Rise	**42.55%**	**17.56%**

Cluster analysis also revealed that the percentage increase in mean scores from Cluster 1 to Cluster 2 was much higher than that in subsequent clusters. As demonstrated in Table 5, the capability factor of visibility showed the most significant change, followed by market position and organization.

Table 6: Test of Significance of the results of clusters on nine SC Resilience strategy factors

Dimensions	F Statistic	df1	df2	Sig.
Flexibility in Manufacturing Capacity	20.287	2	47.473	.000
Visibility	31.786	2	45.596	.000
Recovery	89.666	2	43.610	.000
Collaboration	76.802	2	41.303	.000
Organization	46.694	2	42.805	.000
Market Position	70.062	2	44.690	.000
Security	45.177	2	44.317	.000
Product Stewardship	69.700	2	43.188	.000

Welch ANOVA was applied to verify significant differences among the mean scores across the clusters. This test is robust regardless of the homogeneity of variances, and its results are presented in Table 6. The p-value of 0.000 indicates that the mean of at least one cluster for the nine SC Resilience capabilities is significantly different from the remaining clusters.

Table 7: Sectoral Distribution with each cluster

Sectors	**Cluster 1**	**Cluster 2**	**Cluster 3**
Food & Personal Care Products	16.12%	24.15%	59.69%
Pharmaceutical	6.90%	19.69%	73.41%
Textile	4.17%	37.50%	58.33%
Other industries	20.05%	21.85%	57.10%
Automobile	6.56%	33.16%	60.23%
Electronics	8.75%	20.00%	71.25%
Oil & Gas	13.50%	12.50%	75.00%

Table 7 (cont): Sectoral Distribution with each cluster			
Chemical	0.00%	45.55 %	54.45%
Paper & Board	0.00%	20.00%	80.00%
Cement	0.00%	0.00%	100.00%

The study also provided insights into the sectoral performance in terms of resilience. Table 7 reveals that pharmaceutical firms demonstrated the highest resilience, with 73.41% falling into the progressive cluster, followed by 19.69% in the cautious cluster and a small percentage (6.90%) in the basic cluster. In the food and personal care products category, 59.69% of companies were classified as progressive, followed by 24.15% and 16.12% in the preceding clusters. For textile companies, 58.33% were categorized as progressive, while 37.50% were in cluster 2, and a small percentage (4.17%) were in the least performing group. These findings indicate that the distribution of companies within each sector across the clusters is distinctive.

This study develops a taxonomy of supply chain (SC) resilience based on manufacturing firms' adoption of resilience practices, shown in Figure 1. Cluster analysis identified three distinct SC resilience levels, confirming the research question. Findings indicate that moving from Cluster 1 to Cluster 2 is more difficult than advancing to higher stages. This research fills a gap by defining three SC resilience maturity stages, offering a useful framework for understanding progression. The model's stage labels and descriptions help firms assess their position and guide improvement efforts.

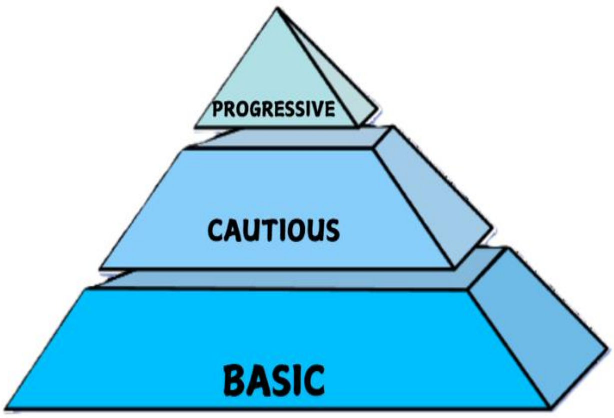

Figure 1: Supply Chain Resilience Capabilities Cluster Model

To interpret the clusters, each was assigned a label that accurately reflects its characteristics. The analysis indicates that the clusters are not linearly arranged but rather represent an evolutionary process that requires the most effort from firms in the initial stages, when resilience concepts may be unfamiliar. Supply chain risk awareness emerges as a critical resilience strategy (Ur Rehman and Ali, 2021). Therefore, firms in the first cluster should prioritize increasing their awareness of potential disruptions.

The three clusters can be identified as three stages of resilience, aligning with the concept of stages in supply chain management maturity models (Batista et al. 2019; De Oliveira, Ladeira, and McCormack 2011; Frederico et al., 2019). These clusters/stages are labeled as "basic," "cautious," and "progressive," forming SC Resilience Stages" The rationale behind each cluster/stage's name and its characteristics based on empirical findings is discussed herein:

The "basic" cluster exhibits minimal or no adoption of SC Resilience practices. Firms at this level may not recognize the importance of resilience for achieving key business objectives. These firms often have limited resources, allocating funds primarily to operational requirements. While this group outperforms in security, indicating an awareness of security programs and platforms, they may neglect other critical areas, such as visibility. Visibility, encompassing information systems for equipment, inventory, and personnel status, is often lacking in this cluster. This can lead to information gaps between the firm and its suppliers, potentially resulting in the bullwhip effect. Additionally, firms in this cluster generally perform similarly in manufacturing flexibility, with low mean scores, suggesting limited adaptability to disruptions.

The second cluster, labeled "cautious," includes firms that are aware of resilience and are gradually implementing practices. Although these practices are noticeable, they may not be regularly updated. Visibility and market position are commonly adopted capabilities in this cluster, indicating a focus on operational and strategic techniques. The relatively small variations in mean scores across all factors suggest a higher level of SC Resilience alignment in this cluster, with firms emphasizing all strategies equally. However, similar to the "basic" cluster, this group lags in manufacturing flexibility, which remains a concern during disruptions.

In the "progressive" cluster, firms have matured their practices and procedures to build resilience. Sufficient resources are allocated to ensure backup systems and prevent disruptions. Market presence and visibility are still the most accepted capabilities at this point. At this stage, market presence and visibility are, by and large, the most acceptable competencies. S&OP (sales and operations planning), CMI (co-managed inventory), and CPFR (collaborative planning, forecasting, and replenishment) are practiced. Interestingly, manufacturing flexibility is still the weakest in building resilience, even though the cluster's average level of resilience has improved overall.

While manufacturing flexibility is typically important for supply chain resilience, its low relevance scores among all three resilience clusters indicate that enterprises have limited abilities to respond to perturbations, including demand fluctuation or machine breakdown, which cause tardiness of activities and obstruct market steering (Karmaker and Ahmed, 2020; Kumar and Anbanandam, 2019). This limitation could be due to a myopic cost-reduction focus or unknown long-term benefits of SC resilience. On the other hand, the market position always had the highest effect estimate corresponding with results, less adept firms may focus on it for short-term attestations, whereas more adapted firms use it to attain strategic acceleration in recovery from supply chain disruptions (Pettit et al., 2013).

Clusters 1 and 2 are not significantly different, and this means that a certain security behavior has become standard industry culture, even for companies in the basic stage. For companies to advance to a higher stage, they should implement further capabilities that augment resilience. The three clusters show that manufacturing firms are performing their operations at different levels of SC Resilience. The move from one stage to another will be subject to special measures, and attaining higher levels of SC Resilience is an emergent process involving the constant discovery of potential disruption and cooperation to fill in SC Resilience gaps.

The findings of this paper also align with the dynamic capability view (DCV). As firms progress from Cluster 1 to Cluster 2, they exhibit significant improvements in capabilities such as visibility, collaboration, organization, and market position. This suggests that firms are developing adaptive competencies, aligning with DCV's emphasis on sensing and seizing opportunities by managing existing assets and adjusting operations to meet unforeseen circumstances. The substantial improvement in the visibility capability indicates that companies are not only enhancing their tracking of supply chain operations but also fostering information sharing. This resonates with dynamic capabilities, as knowledge sharing can catalyze improved visibility.

In the transition from Cluster 2 to Cluster 3, firms demonstrate significant improvements in recovery, product stewardship, and security, indicating a shift towards a higher level of dynamic capability orchestration. These firms prioritize innovation and change initiatives. The focus on product stewardship and security reflects a more forward-looking approach, dynamically protecting products, processes, and relationships within the supply chain network. Additionally, the strengthened recovery capability demonstrates firms' capacity to learn from disruptions, adapt strategies, and enhance overall resilience.

5. Conclusion

The findings of this research offer critical insights for managers. Firms classified as basic must implement significant process and procedural adjustments to advance. A primary challenge for these businesses lies in cultivating a mindset that recognizes the importance of establishing SC Resilience. As highlighted and, SC Resilience positively impacts firm performance and, ultimately, financial performance by (Liu et al., 2018; Polyviou et al., 2019).

This research employed hierarchical clustering analysis using Ward's method to identify underlying patterns of SC Resilience among manufacturing industries. Based on nine SC Resilience capabilities, firms were categorized into three homogeneous clusters representing increasing resilience levels. The results revealed that firms require the most effort to transition from the primitive to the precautionary cluster. This research filled a gap in the literature by presenting the "SC Resilience Stages" through an empirical taxonomy, contributing to a shared understanding of SC Resilience stages.

Recommendation

Therefore, firms should analyze their specific vulnerabilities and adopt and upgrade resilience-enhancing capabilities. The cluster analysis findings provide a valuable model, the "three clusters of SC Resilience Stages," for managers to assess their firms' current stage of SC Resilience and develop improvement agendas for progressing to higher stages.

A significant number of firms were found to be inflexible in their manufacturing processes, posing a substantial threat to customer satisfaction and the overall supply chain. Businesses should prioritize adopting manufacturing flexibility practices to enhance their resilience. This may involve machine reconfiguration or upgrades, personnel training, and policy adjustments. For example, firms operating in a make-to-order environment can achieve production flexibility by implementing a flexible manufacturing system, enabling easier adaptation to variations in type and quantity.

From a managerial perspective, it provided a comprehensive assessment of firms' current SC Resilience levels, aiding in the identification of capabilities requiring special attention. Managers can benchmark their firms' resilience levels against the findings of this study.

While this study focused on the manufacturing industry, the results may apply to a broader population of manufacturing firms due to the diverse range of sub-sectors represented by the surveyed companies. However, the cross-sectional survey design without qualitative exploration techniques limited the depth of explanation and description for each cluster. Additionally, the majority of responses represented single companies, which may be considered a limitation of this study.

Future research could explore the relationship between clusters/stages and firm performance, helping managers determine whether a higher SC Resilience stage guarantees superior firm performance. Other areas of focus include classifying resilience elements, capabilities, and vulnerabilities under more prominent factors such as operational, tactical, and strategic, to enhance the comprehensiveness of the three Ps model. Longitudinal studies are also necessary to understand the long-term value of specific resilience strategies for firms.

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