Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/EU08.20250356
Published: July 2, 2025

Multi-effects Strategic Decisions in the Context of Supply Chain Resilience for the Maritime Port System

Fabricio Moreno-Baca
Facultad de Industrial y Logística, Universidad Popular Autónoma del Estado de Puebla (UPAEP), México
Center Leo Apostel, Vrije Universiteit Brussel (VUB), Belgium
Universidad Internacional de La Rioja, España
fabricio.moreno@upaep.edu.mx

Patricia Cano-Olivos, Diana Sánchez-Partida, José-Luis Martínez-Flores
Facultad de Industrial y Logística, Universidad Popular Autónoma del Estado de Puebla (UPAEP), México
patricia.cano@upaep.mx, diana.sanchez@upaep.mx, joseluis.martinez01@upaep.mx

Tomas Veloz
Center Leo Apostel, Vrije Universiteit Brussel (VUB), Belgium
Departamento de Matemáticas, Universidad Tecnológica Metropolitana, Santiago 833038, Chile
UM6P - IAS - Institute for Advanced Studies, 43150, Ben Guerir, Morocco
tomas.veloz@vub.be

Abstract

In an increasingly volatile world, strategic decision-making has become a key discipline in ensuring resilience in supply chains. However, there must be a critical gap in the quantitative application of strategies for Resilience, limiting their effectiveness in actual contexts of uncertainty. This study responds to this need by developing an innovative combination of methodologies and models designed to strengthen resilience in high-demand environments. Integrating classic strategies from military philosophy (Sun Tzu, Musashi) to modern management approaches (Emergency Leadership, Disruptive Innovation, Blue Oceans), we have created nine strategic representations that redefine resilient cooperativity based on system dynamic equations and Nowak´s rules, in addition with an optimization resilience model inspired on the Ramsey-Cass-Koopmans economic framework. These findings offer practical and transformative new tools to turn strategy into an essential pillar of resilience in supply chains, establishing a clear path towards operational sustainability in the face of global challenges.

Keywords
Strategic Decisions, Maritime Supply Chain Resilience, Game Theory, Nowak's Rules, Ramsey-Cass-Koopmans.

1. Introduction
Add Strategic decisions are vital for any operational field because, in this highly complex and competitive world, it is no longer enough to optimize scarce resources but also to know how to implement improvements through strategic decisions to be able to foresee factors that are not totally under control in supply chains (SC). That is why supply chains must have agile and robust strategic mechanisms to achieve resilience between their different links, as resilience is one of the most essential conditions to ensure operational and economic stability within a supply chain (Chen et al. 2019). The use of strategic approaches from authors such as Sun Tzu and Musashi is based on their timeless and

interdisciplinary values. Although initially developed in military contexts, these strategies encompass universal principles related to adaptation, anticipation, asymmetric advantage, and conflict management—all of which are crucial for building resilience in supply chains facing disruption. Recent studies have begun to explore this analogy, emphasizing that modern supply chain management benefits from interpreting strategy beyond conventional frameworks (Foo, 2010).

A resilient supply chain (Figure 1) has the operational capacity to prepare, respond to, and recover from a disruption to recover its normal operational state or even better than the initial one (Huang et al., 2021). That is why resilience control is essential in any supply chain, mainly when turbulent and exogenous changes exist in different forms. However, Qazi et al. (2015) mention that risk strategies have not been fully explored within Supply Chain Risk Management. There is also a research gap in the control of such strategies to achieve a resilient effect on supply chains (Tukamuhabwa et al. 2017) as well as on the impact of the risk of such resilient strategies within the plans of companies (Prataviera et al., 2022).

Resilience in supply chains (SCR) is only partially a study of a 100% operational and logistical nature, as it might be perceived. As Ekanayake et al. (2021) mention, advanced supply chain strategies based on Resilience are widely adopted today in the competitive economy, allowing for proven and successful management in the face of unpredictable disruptions. For all of the above, the design and control of resilient strategies is the lowest common denominator in operational, logistical, and economic factors within supply chains, and therefore, not taking a holistic strategic approach in implementing actions for Resilience in supply chains would be a notable mistake since the total logistical and operational analysis is only part of the gears that make up the phenomenon of supply chain resilience.

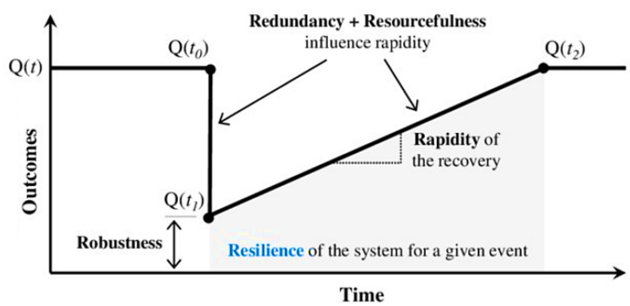


Figure 1. Resilience of a system. Adapted from Maslak et al. (2017)

1.1 Objectives

Therefore, the present research analyzes the different phenomena that circumscribe the Resilience of Supply Chains in order to design and control logistics strategies, as well as operational, logistical, and economic tactics, specifically in Maritime Port Supply Chains (case of Mexico, period 2000 – 2022), using methodological models proposed with a mixed multi-effects approach previously developed and proposed by Moreno et al. (2024). The contribution of this research (Figure 2), which expands on the current theory and methodology of supply chain resilience, is based on its methodological application of the typology of strategies and tactics of supply chain resilience under a dynamic simulation approach and taking into account four structural effects in the context of SCR (synchronization, spillover, bullwhip, ripple, and economic effects). This contribution is based on the typology of strategy from renowned authors in the military field (such as Sun Tzu, Musashi) to the management level (such as Wheatley, Christensen, Chan & Mauborgne).

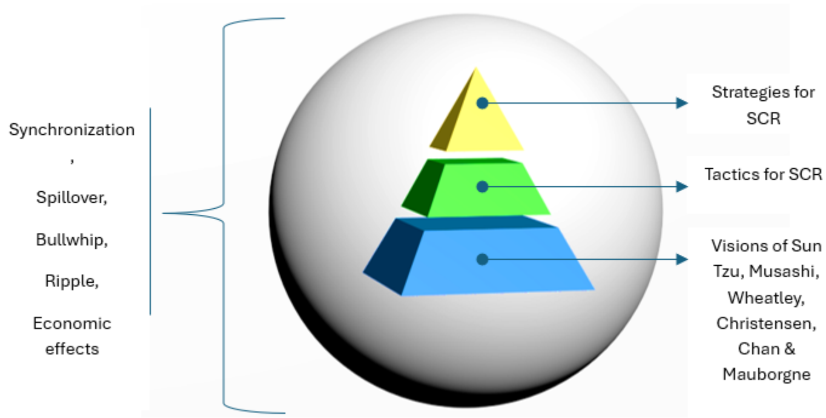


Figure 2. Research contribution

As can be seen, there is a considerable research gap on resilience strategies for supply chains, taking into account their simultaneous representativeness and the effects of synchronization, spillover, bullwhip, ripple, and economics, grounded in specific strategies and tactics since most research is limited to providing generalizations of strategies taking into account only some aspect of the nature of supply chains. This research expands the current theory and methodology of the field of supply chain resilience through the application of the field of study of the strategy, analyzing the phenomena that circumscribe resilience under a simultaneous approach.

2. Literature Review

For this research, 69 articles published on the Web of Science were reviewed, related to keywords such as Supply Chain, Resilience, and Strategy. These studies were selected during the period 2015 – 2023 and analyzed based on both their methodological approach and the type of resilient phenomenon that they address in the supply chain, which resulted in the following results: methodological approach: 34.7% were research with quantitative research approaches, and the rest with a qualitative approach; 1.4% related to Synchronization effect strategies or the Spillover effect; 2.8 % were research articles related to bullwhip or ripple effect strategies; 33.3% were research articles related to economic cost strategies; 75.3 % were research articles related to internal operational strategies; 30.4%, related to qualitative or subjective strategies; 4.34%, related to strategies based on complex networks; 40.57%, related to strategies exclusively designed for the Manufacturing sector, and only 2.8% related to strategies designed for the maritime port sector. As can be seen, there is a notable research gap in the study of supply chain resilience in the field of strategy through quantitative methodology, taking into account the multi-effects that circumscribe supply chain resilience. Of all the research previously analyzed, the most relevant and related to our object of study are described below:

Qualitative methodology

As is well known, Qualitative Methodology is understood to be the type of techniques that collect research information through interviews, surveys, or group dynamics of experts, among others. Within this classification, we can find the one made by Jamali et al. (2023) where they analyze the resilience of energy supply chains, detecting key determinants such as performance, storage, dependence, distance, recovery, and government incentive; Yaroson et al. (2023) analyze pharmaceutical supply chains by detecting proactive and reactive resilience strategies, based on product design, dissatisfaction, and uncertainty; in the manufacturing supply chain sector, there is abundant research on the subject, detecting strategies such as resilience and performance relationship at three levels of disruption such as Supply, Infrastructure, and Catasproicity (Hamidu et al., 2023); insertion of technological innovation (Hamidu et al., 2023b); improvement of intellectual capital at the human, social, and organizational levels (Yu et al., 2023); analysis of performance in relation to the resulting complexity of networks (Hamidu et al., 2023c); strengthening the influence of digital technologies (Ning et al., 2023); insertion of digital supply chains in conjunction with industry 4.0 technologies (Joshi & Sharma, 2022); Cross-functional coordination, information exchange, openness to technological innovation (Yu et al., 2022); implementation of Anticipation, Response, Recovery, Resilience (Badhotiva et al., 2022); knowledge management (Inrfan et al., 2022); Postponement, Relationship with Suppliers, Uncertainty (Hakimi et al., 2022); interrelation of improvement of resilience indicators with respect to domino effect factors (Hsu et al., 2022); Analysis of Reciprocity in Preparedness, Response, Recovery (Yang et al., 2022); promotion of innovation and entrepreneurship

(Hakimi et al., 2021); improvement in the analysis of capabilities such as Agility, Capability, Visibility, Connection, Product Development, Information Transfer (Hsu et al., 2021); attention in Supply, Production, and Delivery (Um & Han, 2020); promotion in Lean and Agile strategies, based on market orientation and quality (Ahmed & Rashidi, 2020; Huma & Siddiqui, 2018); strengthening of financial performance, resilient capacity, disruptive orientation, supply dynamism (Yu et al., 2019); boosting innovation and risk capabilities (Kwak et al., 2018); analysis of the frontier of operations and trajectory (Cheng & Lu, 2017); implementation of external, integration and flexibility capabilities (Berusset & Teller, 2017). In the agricultural supply chain sector, it is possible to mention the insertion resilience strategies of the implementation of the Internet of Things (Yadav et al., 2023), as well as capacity factors such as international collaboration, compensation, capacity, brand, and loyalty (Zhao et al., 2022); within the food and food supply chain sector, there are strategies based on Procurement, Production, and Distribution (Prataviera et al., 2022), as well as on the promotion of intellectual capital in Human, Relational and Structural approaches (Murabil et al., 2021). Misbauddin et al. (2023) present resilience strategies based on feasibility, integration, and risk control in floral supply chains. In supply chains in the technology sector, Wang & Pan (2022) establish resilience strategies based on the application of artificial intelligence. Kahn et al. (2022) provide strategies based on 3A's (agility, adaptability, and alignment) in textile supply chains. In construction supply chains, Ekanayake et al. (2022) present strategies based on four capabilities (procurement, flexibility, dispersion, and capacity) on five types of vulnerabilities (economic, procedures, production, organization, and technology). In automotive supply chains, Agarwal et al. (2021) point out strategies based on the interaction of enablers and resilient dimensions. For various types of supply chains (health, retail, beverages, among others) resilience strategies are: social, environmental, and economic sustainability (Zhu & Wu, 2022); strengthening, empowerment and innovation (Ozdemir et al., 2022); entropy, co-creation, openness to innovation, and network governance (Durmaz et al., 2021); disaggregation of macro-environmental aspects ranging from Political, Economic, socio-cultural, environmental and investment (Appia et al., 2021); circular economy approach and implementation (Mohammed et al., 2021); boost in performance, relationship with suppliers, risk, supply stability, and technology (Ajalli et al., 2021); insertion of agility, collaboration, and integration (Naimi et al., 2020); implementation of advantages of Big Data Analytics (Singh & Singh, 2019); advantages of external capabilities, integration and flexibility (Berusset & Teller, 2017); implementation of particular and specific resilience enablers (Jain et al., 2017); implementation of types of supply under high and low-risk modalities (Namdar et al., 2017). Finally, research on resilience strategies for supply chains in the maritime port sector is proposed by Shi et al. (2022) in which they propose strategies based on prices, integration, and competition; Loh & Thai (2015) propose four perspectives such as financial, customer service, processes, and learning.

Quantitative Methodology:
As is well known, quantitative methodology is understood as a set of research techniques based on mathematical or statistical models that collect information or study some phenomenon. For this type of methodology, they are more proliferating in the manufacturing supply chain sector: Surday & Rau (2023) propose strategies based on multi-region suppliers, as well as multisourcing, reserve inventory, and alternative shipping strategies; Oi et al. (2022) use response prediction, adaptability, and recovery as resilience strategies; Hsu et al. (2022) insert strategies based on the application and use of Big Data Analytics; Paul et al. (2022) implement optimization strategies based on Supply, Demand, and Risk Capacity; Ivanov (2021) proposes strategies based on the extreme points of the disruptive event; Rajesh (2020) inserts the Theory of Grey and Networks for certain types of risks; Tan et al. (2019) develop short- and long-term strategies through various types of redundancy (standard, structural, capacity, and backup); Chowdhury and Quaddus (2015) apply multi-objective optimization through a risk portfolio.

Chang & Jiang (2023) propose spatial factors in risk prevention, prediction, transformation, learning, recovery, and digestion for grain sector supply chains. Fu et al. (2023) apply strategies based on the plan, do, check, and act cycle for supply chains in the electronics sector. Liang et al. (2022) provide strategies based on the spread of risk for automotive supply chains. For supply chains in the steel sector, Nikian et al. (2022) apply a multi-objective sustainability programming approach based on economic, social, and environmental aspects. Luo and Zhu (2020) apply a multi-objective optimization analysis based on management, sourcing, inventory, and risk for aviation supply chains. Andres and Marcucci (2020) apply strategies based on collaboration perspectives for supply chains in the textile sector. For supply chains in the food sector, Gruzauskas et al. (2019) propose strategies based on the influence of information transmission in the supply chain. For the rest of the types of supply chains, as well as theoretical research, the proposals for resilience strategies are based on the application of Blockchain technology (Lohmer et al. , 2020; Shi et al. , 2023); insertion of horizontal competition (Massari & Giannoccaro, 2021); strategies based on the present value of the loss (Behzadi et al., 2020); indicators based on additional inventory, dual sourcing, and agility (Chen et al., 2020); strategies based on the nature of density and critical nodes of the network (Mikhail et al., 2019); strategies based entirely on inventory management (Jabilles et al., 2018); strategies based on capacity adjustments, information control, emergency, and incentives (Geng & Xiao, 2017); sourcing strategies based on production capacity, product quality, and cost of production (Wang et al., 2016); strategies based on the microscopic behavior of agents participating in the chain as well as macroscopic ones of the chain (Geng et al., 2014).

As can be seen, there is a considerable research gap on resilience strategies for supply chains, taking into account their simultaneous representativeness and the effects of synchronization, spillover, bullwhip, ripple, and economics, grounded in specific strategies and tactics since most research is limited to providing generalizations of strategies taking into account only some aspect of the nature of supply chains (Table 1). This research expands the current theory and methodology of the field of supply chain resilience through the application of the field of study of the strategy, analyzing the phenomena that circumscribe resilience under a simultaneous approach.

Table 1. Quantitative Literature Review Summary, CS Resilience

Author	year	Synchronization	Spillover	BE / RE	Economic Costs	Operational Factors	Qualitative Factors	Networks
Lohmer et al.; Shi et al.	2020; 2023			✓		✓		
Chang & Jiang	2023		✓		✓	✓	✓	
Fu et al.	2023					✓	✓	
Surdayi & Rau	2023					✓		
Qi et al.	2022					✓		
Hsu et al.	2022					✓		
Paul et al.	2022				✓	✓		
Liang et al.	2022					✓		✓
Nikian et al.	2022				✓	✓		
Ivanov	2021			✓		✓		
Massari & Giannoccaro	2021					✓		
Behzadi et al.	2020				✓			
Chen et al.	2020					✓		
Luo & Zhu	2020					✓		
Kazemian et al.	2020					✓	✓	
Andres & Marcucci	2020						✓	
Rajesh	2020					✓		✓
Tan et al.	2019				✓	✓		
Mikhail et al.	2019						✓	
Gruzauskas et al.	2019					✓		
Jabilles et al.	2018					✓		
Geng & Xiao	2017	✓				✓		
Wang et al.	2016					✓		
Chowdhury & Quaddus	2015					✓		
Geng et al.	2014					✓		✓

* BE= Bullwhip effect; RE= Ripple effect

3. Methods

The methodological strategy of this research is to represent, evaluate, and optimize the most relevant topology of strategies in the RCS for synchronization, spillover, bullwhip effect, and domino effect scenarios that arise within supply chains, using the proposed model of Moreno et al. (2024). The phases of the proposed methodology are described below:

1ra. Phase: Representation of strategies in the dynamic plane

In the first phase, the objective is to quantitatively represent the behavior of classical strategies based on their dynamic behavior of supply chain resilience through a stochastic algorithm that represents each strategy. To this end, some of the representative strategies of the most prominent strategic planning authors for this research (Sun Tzu, Musashi, Wheatley, Christensen, Chan & Maugborne) were selected. In order to define the behavior of each of the above strategies within the context of supply chain resilience in the port system, the following stochastic simulation algorithm is designed whose pseudocode is (Algorithm 1, see Annex 1). The selection of distribution types in the simulation model was based on the nature of the underlying data. A normal distribution was applied to variables that follow a historical average pattern with random deviations, such as cargo tonnage and port capacity. Uniform distributions were applied to variables lacking reliable historical data or discernible central tendencies, assuming equal likelihood across a plausible range, such as inflation rates or random distances between nodes. These choices were validated through exploratory data analysis and justified by precedent in maritime logistics simulations (Ivanov, 2021). While the resilience factor (FR) is expressed in the model as a linear decay during a disruption window, this simplification was adopted for computational tractability and interpretability. However, we acknowledge that real supply chain behavior may exhibit non-linear responses. To account for this, future iterations of the model can incorporate piecewise or sigmoid decay functions that allow for inflection points and asymmetric recovery curves. We calibrated the simulation model using real data from Mexican seaports collected between 2008 and 2023, adjusting key parameters to match how ports actually responded to past disruptions. To test how reliable the results were, we also ran a sensitivity analysis on critical factors like how long the disruptions lasted, how much cargo volume fluctuated, and how inflation changed over time. Even when we varied these inputs within a realistic range, the model's results stayed consistent, showing strong robustness. Python software was used to design, develop, and apply the above algorithm using stochastic simulation, descriptive statistics, numerical calculations (Numpy library), and complex network analysis (Network library). The proposed topology for the set of strategies, based on the descriptive characteristics of the strategies, is proposed and described below:

a) *Sun Tzu´s strategies*:

"*Defeating without war*": The strategy developed by Sun Tzu is the victory through military strategy and guile, rather than fighting through resource-draining battles to attain an immediate goal. Sun Tzu says military genius is in defeating the enemy on the battlefield and defeating the enemy without fighting unnecessary battles. This strategy focuses on weakening the opponent through intelligence, disinformation, and exploiting their weaknesses to achieve victory more efficiently and with less sacrifice and use of resources. Instead of openly confronting, the aim is to influence circumstances to favor this strategy (Cleary, 2012). To represent this strategy within algorithm 1, the following design is proposed [3]:

$$EST1_{(T)} = Supply_{(I,T)}(1+Z) * I(grade_i > Ugrade)$$
$$I = \begin{cases} 1 \Rightarrow true \\ 0 \Rightarrow false \end{cases} \quad [3]$$

where $EST1_{(T)}$ is the previous Sun Tzu strategy applied throughout the simulation period; $Supply_{(i,t)}$ is the port's customer portfolio (i) already established and based on its cabotage and locality, represented in tons; Z represents the percentage of deliberate increase in the port's customer base by the leading port of the entire supply chain; $grade_i$ is the level of arc connection that a said node has to be increased by Z, with respect to the rest of the nodes; $Ugrade$ is the desired percentage to be considered as viable an increase in Z on that node based on the average degrees of all nodes. Note that with this tactic, the increase in resilience in the supply chain is "won without a fight" by forcing the node's connection advantage to saturate its limit and thus initiate the "Knock-on" effect, i.e., an increase in the operation of a ship in one terminal will decrease its operation in the other. Thus, they take advantage of the capacity of these disadvantaged ports and consequently increase their resilience (Jiang, 2016).

"*Know yourself and know your enemy*": Sun Tzu highlights that success hinges on a clear understanding of the strengths and weaknesses of the strategist and the enemy. This process requires a balance between accurately assessing resources, capacity, and incentive to create an information-based choice and plan particular strategies. Sun Tzu's wisdom highlights that ignorance of self or the enemy can result in costly and avoidable defeats (Cleary, 2012). For this strategy, the following tactic is proposed [4]:

$$EST2_{(T)} = Cp_{(i,t)}(1+Z) * I(EB_i > UEB)$$
$$I = \begin{cases} 1 \Rightarrow true \\ 0 \Rightarrow false \end{cases} \quad [4]$$

where $Cp_{(i,t)}$ represents port capacity i full-service vessel, Z represents the percentage of deliberate increase in the capacity of that port by the leading port of the entire supply chain, EB_n Excess Vessels of a Node, y UEB is the desired percentage to be considered an increase in Z in that node based on the average of the excess vessels of all nodes. With this tactic, Sun Tzu's second strategy is applied, thus managing to "understand" the nodes that require direct support in infrastructure investment to serve the ships they receive and prevent them from continuing to seek to be unloaded in other ports.

"*Attacking the enemy's strategy*" means to destabilize and stave off the adversary's plan to execute their intentions. He emphasizes the critical need to "be inside the enemy's head" or to dominate over their mind and predict their actions. This strategy is about taking action when the adversary moves to impede their intention and identifying the adversary's intentions and undermining it before the adversary's intentions are fully developed. Attacking the enemy's strategy incorporates the pillars of intelligence, deception, and flexibility, which centers on undermining the enemy's basal plan and obtaining a significant tactical advantage (Cleary 2012). For attacking the enemy's strategy, the following tactic will be displayed below [5]:

$$EST3_{(T)} = Cp_{(t)}(1+Z) * I(Vts_{(i,T)} < UVts) \qquad I = \begin{cases} 1 \Rightarrow true \\ 0 \Rightarrow false \end{cases} \qquad [5]$$

where $Vts_{(i,T)}$ represents sales for all nodes in the simulation period; $UVts$ is the desired percentage to be considered an increase in Z on that node based on the sales of all nodes. Note that with this tactic, it is possible to "anticipate" the degree of disruption that the supply chain will face, but this time the capacity of the port of the entire maritime system will be increased, which represents a significant economic investment and diverse resources.

b) Musashi Strategies:

"*With one movement, you can win two times*": Musashi emphasizes using measure, efficiency and multiple purposes in all actions. To commit to win two times with a single movement means not only to win the present encounter, but to create a more advantageous scenario for future encounters as well. This commitment reflects Musashi's tactical genius (the application of the art of war) and strategic thinking (the intellectual transparency in the art of war) (De Angelis, 2022). In order to fulfill this commitment; the following tactics will be proposed [6]:

$$EM1_{(i,T)} = ([Cp_{(i,T)}, Demand_{(i,T)}](1+Z)) * I(Vts_{(i,T)} < UVts_{(i,T)}) \qquad I = \begin{cases} 1 \Rightarrow true \\ 0 \Rightarrow false \end{cases} \qquad [6]$$

with this tactic in [6], it is possible to reduce the level of non-synchronization between the nodes (concerning their port capacity, tonnage, and sales) by detecting those nodes that are below the average threshold of these variables and thus receiving support in these areas from the supply chain itself or the federal government. This tactic, as can be seen, is the most costly in terms of investment and infrastructure since such support is provided in each unit of time in which the previous inequality is fulfilled.

"*Don't get hit, don't get cut*": Musashi advocates avoiding enemy attacks rather than simply resisting them. This tactic emphasizes mobility, anticipation, and stealth, with the goal of not getting hit not just physically, but to disrupt the opponent's ability to attack before they even completed their action. The philosophy is to remain unscathed and then be able to retaliate (De Angelis, 2022). The following tactic is proposed for this tactic [7]:

$$EM2_{(I,T)} = \sigma_{Ds_{(I,T)}} \leq U\sigma_{Ds} \qquad [7]$$

where Cu is random unit costs of production per ton of cargo, carried out by the links in the supply chain. With this tactic, it should be noted that the standard deviation between distances of each node is less than a previously established threshold, thus focusing on the "mobility" referred to in this strategy, also predisposing to the proliferation of clusters within the supply chain.

"*Adapt to circumstances*": presents the need for flexibility and the ability to adjust to changing conditions in combat. Musashi emphasizes adaptability in tactics, and notes that circumstances, especially in conflict, can quickly shift. The adapt position includes altering focus and tactics, so that the warrior can processes varying problems (De Angelis, 2022). For this strategy, the following tactic is proposed [8]:

$$EM3_{(i,t)} = (Cu_{(i,t)}(1-Z)) * I(Vts_{(i,t-1)} < UVts) \qquad I = \begin{cases} 1 \Rightarrow true \\ 0 \Rightarrow false \end{cases} \qquad [8]$$

with this tactic, it should be noted that "adaptation" to adversity is applied based on the behavior of sales of the economically weakened ports, according to each unit of time, having the flexibility to be able to compete on prices and costs in order to be able to compete in this regard, based on a previously established threshold.

c) *Wheatley's strategy*:

"*Emergency Leadership*": Wheatley encourages moving from the authorizing model to a more collaborative model of leadership in uncertain situations. The purpose of this model is to promote effective communication, connections, and a fast mobilizing of resources. Wheatley further explains that leaders must be nurtured to be resilient and adapt to the inevitable uncertainties of emergencies (Wheatley, 1999). The following strategy is suggested for this method [9]:

$$EW_{(i,j,T)} = \forall i,j \in Nodes \cup (Ds_{(i,j)} = \kappa) \quad [9]$$

where κ is a constant. It should be noted that this tactic makes the distances between nodes (ports) equidistant, either geographically or by contributing to this through the necessary infrastructure of multimodal transport between them, achieving effective "connection" and mobilization between these nodes at all times. Of course, this represents an expensive tactic for its implementation if one does not previously have a moderate multimodal infrastructure.

d) Christenses Strategy:

"Disruptive Innovation Theory": centers on the idea that, unlike incremental innovations, disruptive innovations are the events that radically disrupt industries and markets. Christensen suggests that leading companies often do not realize the potential threat presented by disruptive innovations because they evolve from lower cost, with targets focused on the marginalized segments of an existing industry (Christensen, 1997). The following tactic is suggested for this strategy [10];

$$ECh_{(i,T)} = [\, Demand_{i,t}(1+Z), Cu_{i,t}(1-Z) \,] * I(Vts_{i,T} < UVts) \quad [10]$$

$$I = \begin{cases} 1 \Rightarrow true \\ 0 \Rightarrow false \end{cases}$$

it should be noted that in this tactic, innovative "disruption" (which can be either the direct application of Artificial Intelligence, or application measures for environmental sustainability related to maritime port operations, and so forth) translate in the short term into a percentage of sales as well as cost reduction, applying this tactic only in those nodes that are below a previously established sales threshold.

e) Kim & Mauborgne's strategy:

“Blue Ocean Strategy": Chan Kim and Renée Mauborgne advocate the creation of new uncontested markets, in contrast to competition in existing markets, called "Red Oceans". The goal is to tap into untapped markets, innovation, and differentiation, encouraging companies to identify and fill untapped market niches where competition is minimal or nonexistent. The objective of this method is to avoid overcrowding and narrow margins of direct competition, and instigate disruptive change and distinctive offerings for customers (Kim & Mauborgne, 2005). In attempting to execute this strategy, this follow tactic is proposed [11]:

$$ECh_{(i,T)} = [\, Demand_{(i,t)}(1+Z), Inf_{(i,t)}(1-Z)] * I(CO_{(i,T)} < UCO) \quad [11]$$

$$I = \begin{cases} 1 \Rightarrow true \\ 0 \Rightarrow false \end{cases}$$

where $CO_{(i,T)}$ is the opportunity cost of a node, and this is less than a previously established threshold. Note that this tactic can reduce the stochastic level of demand, costs, production, and inflation, characteristics where "competition is minimal or non-existent”.

2nd phase: Determination of spillover payment matrix & direct effects

As mentioned above, the objective of this research is to determine the strategic nature of CSR in the case study as an activity resulting from cooperation between links in the supply chain, and this is achieved over time thanks to the greater desire for cooperation between links than those links that do not wish to cooperate to achieve such an objective. Therefore, two types of links are proposed: those who are more willing to implement supply chain agreements in order to achieve CSR and those who, despite being part of the supply chain itself, do not cooperate because they prefer to put their individual interests before those of the supply chain itself. Therefore, once it has been determined which type of strategy obtains the most economic benefit in the Supply Chain (Phase 1) with the data collected from the supply chain itself, we now proceed to analyze the spatial behavior to analyze the spillover effect as well as the direct effect of the said supply chain in order to be able to make an in-depth analysis, in addition to the fact that it has been verified that if the spillover effect is not analyzed, the spatial part of a phenomenon would be analyzed incompletely. Moreover, in order to model interactivity of resilience collaboration between local ports and international ports, this research represents the rules of cooperating evolution (Nowak, 2006). The rules are represented in Table 2.

Table 2. Payment Matrix of Nowak Cooperation Mechanisms. Source: (Nowak, 2006).

		Payoff matrix C	Payoff matrix D	Type of cooperation ESS	Type of cooperation RD	Type of cooperation AD
Kin Selection	C	$(b-c)(1+r)$	$br-c$	$\frac{b}{c}>\frac{1}{r}$	$\frac{b}{c}>\frac{1}{r}$	$\frac{b}{c}>\frac{1}{r}$
	D	$b-rc$	0			
Direct Reciprocity	C	$(b-c)/(1-w)$	$-c$	$\frac{b}{c}>\frac{1}{w}$	$\frac{b}{c}>\frac{2-w}{w}$	$\frac{b}{c}>\frac{3-2w}{w}$
	D	b	0			
Indirect Reciprocity	C	$b-c$	$-c(1-q)$	$\frac{b}{c}>\frac{1}{q}$	$\frac{b}{c}>\frac{2-q}{q}$	$\frac{b}{c}>\frac{3-2q}{q}$
	D	$b(1-q)$	0			
Network Reciprocity	C	$b-c$	$H-c$	$\frac{b}{c}>k$	$\frac{b}{c}>k$	$\frac{b}{c}>k$
	D	$b-H$	0			
Group Selection	C	$(b-c)(m+n)$	$(b-c)m-cn$	$\frac{b}{c}>1+\frac{n}{m}$	$\frac{b}{c}>1+\frac{n}{m}$	$\frac{b}{c}>1+\frac{n}{m}$
	D	bn	0			

According to Nowak (2006), in Table 2 the nomenclature used is as follows: "C" y "D" represent two types of players, cooperating and uncooperating respectively; *c* is the cost paid by a cooperator; *b* is the benefit received for third parties derived from the payment of c; *r* is the parenting coefficient which must exceed the cost-benefit ratio to generate cooperativity; *w* is the probability of reciprocity which must exceed the cost-benefit ratio to generate cooperativity; *q* is the probability of the reputation of cooperativity which must exceed the cost-benefit ratio to generate said cooperativity; k is the average number of neighbors per individual; *H* is the simplified expression of [(b − c)k − 2c]/[(k + 1)(k − 2)] (Novak, 2006); *m* is the number of groups formed; *n* is the maximum group size. Nowak presents the matrices in such a way that the cooperation between these players is optimized and achieved through 5 types of forms of cooperation, each with three types of strategies to achieve them. The five types of forms of cooperation are kinship selection (cooperativity is possible thanks to a kinship link between players), direct reciprocity (cooperation based on the repetition of the type of action between players), indirect reciprocity (cooperation based on the reputation of the participants' request for help), reciprocity of networks (cooperation based on group relationships of grouping in the form of networks), group selection (cooperation based on the design of well-defined groups). There are three types of cooperation: evolutionary stable strategy (ESS), which means that such a strategy is robustly cooperative if the cooperatives can withstand an invasion of the non-cooperative population; dominant risk (DR), which means that there is a high-risk aversion to be or not to be cooperative on the part of the players; advantageous (AD) which means an overwhelming superiority of the cooperative population over the non-cooperative population. The equations used by Nowak are based entirely on his proposal (Nowak, 2006). Additionally, in order to determine the nature of cooperativity for resilience between the different links of the supply chain under study, the equation [12] proposed by Moreno et al. (2025) is applied in order to obtain the spillover effect and the direct effects, which will serve to represent both the cost (c) and the benefit (b) respectively, indicated by Nowak:

$$\Gamma = K^{\alpha_1} L^{\alpha_2} Q^{\alpha_3} F^{\alpha_4} Z^{\alpha_5} e^{\lambda} \qquad [12]$$

where Γ is the tonnage handled by seaport (between exports and imports), K es el stock de capital portuario, L is a maritime port workforce, Q is the level of intensity of seaports (measured in empty containers), F is the average inflation level of the regions where seaports are located, Z represent the global exogenous phenomena of a disruptive nature that affect the maritime port sector, and e^{λ} is the exponential of the technological factor. The spillover effect as well as its direct effects are obtained using the Spatially Lagged X's Model technique, General Nesting Spatial Model, and Spatial Durbin Error Model. To recap: In Phase 1, it is possible to represent the most appropriate strategy for the logistical-economic benefit of the prevailing reality of the supply chain under study. Subsequently, in Phase 2, it is possible to determine, using payment matrices for subsequent analysis of Game Theory, the spatial nature of the type of cooperation that exists between the different links that comprise the supply chain under study. These two phases, 1 and 2, help us infer the logistical-economic-spatial strategies they currently use in the study supply chain. Now, once the prevailing strategic-spatial reality of the study supply chain has been captured, we will proceed to detect the best strategy in this regard through the optimization tool, which is detailed below.

3rd. phase : Budgetary constraints of the links for the SCR.

The integration of Nowak's cooperation model with the Ramsey-Cass-Koopmans intertemporal framework responds to the need for modeling dynamic cooperation among actors subject to budgetary constraints. Although these models originate from different disciplines, their combination enables the representation of both strategic interaction (as proposed by Nowak) and dynamic optimization of aggregate logistical benefits (via Ramsey-Cass-Koopmans). While this approach is uncommon in port logistics literature, it offers a holistic modeling framework suited for highly complex and uncertain environments (Gourinchas, 2014; Nowak, 2006).

Once the behaviors of the different study strategies applied in the supply chain have been obtained, as well as the payment matrices of Nowak's rules, we proceed to define the budgetary constraints of such strategies as well as their optimization, based on the logic of the Ramsey-Cass-Koopmans model (Gourinchas, 2014) but making certain modifications proposed for the present research, which are presented below: for this third phase, equation for resilience proposed by Moreno et al. (2025) is taken where the behavior of the growth of the RCS is described as a function of five logistic effects (synchronization, spillover, bullwhip, ripple, and economic effects), but representing it as R as a function of the rest of the logistic effects to obtain the magnitudes of each phenomenon concerning the growth of the RCS. To do this, we start from the time horizon in which the phenomenon of resilience occurs [13]:

$$\int_0^T f(RC)dt \qquad [13]$$

where T_r is the maximum time limit where the RCS ends; f, represents a function of economic utility that all the links of the SC seek during the Resilience period individually (per node), the same function that is sought to be maximized and that at the same time is composed of R that interacts with consumption (C) of the node. Continuing with [3], we proceed to specify and break down, the same function that must be represented by a nodal economic utility, and that is proportional to the population of nodes of said network in order to represent the entire supply chain in question, therefore we obtain [14]:

$$\int_0^T u(R_t C_t) N_t dt \qquad [14]$$

where u represents the nodal economic utility function that depends on the vector of variables that represent CSR (R_t), and N_t represents the total number of nodes in a given period of time that make up the supply chain. Subsequently, in order to give more weight to the consumption of RCS in the present than in the future (since this is generally the approach that is more in line with reality in supply chains), a discount rate is added to this phenomenon [15]:

$$\int_0^T e^{-\rho t} u(R_t C_t) N_t dt \qquad [15]$$

where ρ represents such discount rate ($\rho > 0$), in which the higher the value ρ indicates that a given node in CS is more interested in generating and consuming more of the benefit of SCR in the present than in the future (or at the end of it); e is the exponential. In [5], ρ it plays a fundamental role as it is the element that connects both Phase 1 and Phase 2 with Phase 3, and ρ also represents, as a discount rate, the level of cooperativity needed in the system to achieve maximum resilience, and therefore this Phase 3 will tell us which strategy of the set described in Phase 1 is the most appropriate for the supply chain under study. To simplify the proposed model, we make the growth of nodes (links) in the study supply chain not constant, but grows at an exponential rate [16]:

$$\frac{\dot{N}_t}{Nt} = n \qquad [16]$$

Subsequently, in order to insert the behavior of resilience generation and consumption performance in a stable way over the time of the existence of the disruptive event, i.e., that not all the benefits derived from the resilience of the CS are consumed at a single point in the time of the disruption, the utility function is made to be concave in nature [17]:

$$u(R_t) = \frac{R_t {C_t}^{1-\theta} - 1}{1-\theta} \qquad [17]$$

where θ It is a parameter that helps that when it has a value equal to 1, the maximum concavity is obtained, and when it is equal to zero, the function becomes linear. θ will help us to ensure that consumption has a stable and proportionate behavior over time. Therefore, the utility function of the RCS that the nodes of the network have to maximize, would be substituting [16] and [18] obtaining [18]:

$$\int_0^t e^{-(\rho-n)t} \frac{R_t {C_t}^{1-\theta} - 1}{1-\theta} dt \qquad [18]$$

where $\rho > n$

However, it is necessary to remember that, in any scenario of business units, such as the links of the SC, there are limitations in both operational, financial and economic resources. To represent the above context, income is taken from the links (Y_t), echelons´assets (B_t), Rate of Return on echelons´assets (i_t), C_t represent the purchases made by the links for their production cycles, (M_t) are the taxes levied by the government system, (F_t) it is regional inflation where the echelons meet. Therefore, the dynamics of the behavior of the values of the assets of the SC during Resilience is represented as follows [19]:

$$\dot{B}_t = Y_t + i_t B_t - R_t C_t - M_t - F_t - nB_t \qquad [19]$$

Finally, [9] represents the budgetary constraint over time of the resilience period, to which the links of the SC are subject. Therefore, we finally have the structure of the optimization model with respect to the utility they generate [Figure 3].

$$max \int_0^t e^{-(\rho-n)t} \frac{R_t {C_t}^{1-\theta} - 1}{1-\theta} dt$$

Subject to restrictions:

$$\rho > n$$
$$\theta \neq 0$$
$$\frac{dB}{dt} = Y_t + i_t B_t - R_t C_t - M_t - F_t - nB_t$$
$$\frac{dR}{dt} = f(, D, \Gamma, \varphi, \Lambda_t, \Phi_t, R)$$
$$W, D, \Gamma, \varphi, \Lambda_t, \Phi_t \neq 0$$

where W is Bullwhip effect; D is Ripple effect; Φ is Synchronization effect; Λ is the spillover effect; φ is the Preventive work rate; Γ is the Tonnage Movement; R is the Resilience index.

Figure 3. Optimization model for the present research

For this optimization analysis, the "trust-constr" optimization algorithm is applied to find the optimal values of the variables that maximize the target function subject to the given constraints. The 'trust-constr' method implements the Trusted Region algorithm for constrained optimization. This method uses the derivative (gradient) information and Hessian matrix of the target function and constraints to iterate in a trusted region around the current solution. This allows one to handle optimization issues with nonlinear constraints efficiently. The Trust-Constr algorithm was selected due to its suitability for large-scale nonlinear constrained optimization problems. It combines features of trust-region strategies with interior-point methods, which makes it particularly effective for models involving nonlinear objectives and complex constraint sets, as is the case in port resilience planning. Among tested methods in preliminary experiments (e.g., COBYLA, SLSQP, and Powell), Trust-Constr provided the most stable convergence and computational efficiency when handling both economic utility maximization and inequality constraints.

The constraints built into the optimization model were designed to reflect the real-world limits faced by maritime ports—like budget caps, equipment wear and tear, inflation-adjusted revenues, and the need for ongoing investments at each port. We took into account ripple effects, bullwhip behavior, and coordination issues, but kept them within practical limits to reflect how logistics systems operate in the real world. These constraints were shaped by actual financial and operational records, helping ensure the model stays realistic and aligned with the infrastructure and policy conditions ports truly face.

To assess how well the proposed resilience model performs, we compared its results with widely accepted benchmarks from existing research—such as how quickly operations recover after a disruption, how flexibly cargo flows respond, and how efficiently the port continues to function. These indicators showed that the model responds much like real supply chains do during disruptions. By testing it across various scenarios, we ensured its results are both consistent and reliable. To ensure the optimization results were reliable, we conducted a sensitivity analysis on key factors, including the discount rate, cargo volumes, and changes in inflation. This helped us see how much the outcomes would shift under different conditions and confirm the model's stability. Confidence intervals (95%) were computed for the resilience index using bootstrapping across 1,000 simulations. The optimization remained stable within these bounds, indicating that the proposed model is resilient to moderate parameter uncertainty.

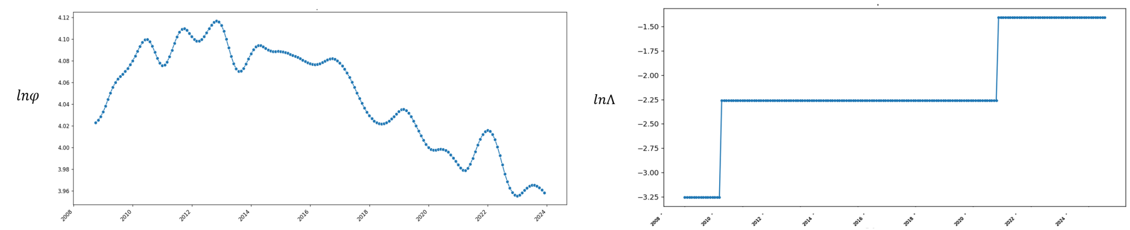
4. Data Collection

Add The dataset used for this research was built from multiple official sources, including the Mexican Secretariat of Communications and Transportation (SCT), the General Coordination of Ports and Merchant Marine (CGPMM), the National Port Statistics System (SIAP), and Customs Records published by the Mexican Tax Administration Service (SAT). These sources provided yearly and quarterly indicators on cargo throughput, port infrastructure, vessel arrivals, container movements, labor force, and macroeconomic variables, including inflation and investment. All time-series data were standardized using z-score normalization to ensure consistency across scales. Inflation adjustments were applied to monetary variables using official CPI indices. Outliers were removed based on interquartile range thresholds, and missing values were interpolated using cubic spline methods. These preprocessing steps were implemented in Python using the Pandas and SciPy libraries.

5. Results and Discussion

For this section, the results will be analyzed in the following sections: Descriptive analysis, which will allow us to visualize the behavior of the time series of each of the study variables; Analysis of strategic algorithms, which will allow us to make a comparison of the results obtained from each of the nine strategies concerning the study variables; Game Theory Analysis, which will allow us to analyze the current behavior of cooperativity that exists between the nodes during the period of study of resilience; and finally the Optimization Analysis.

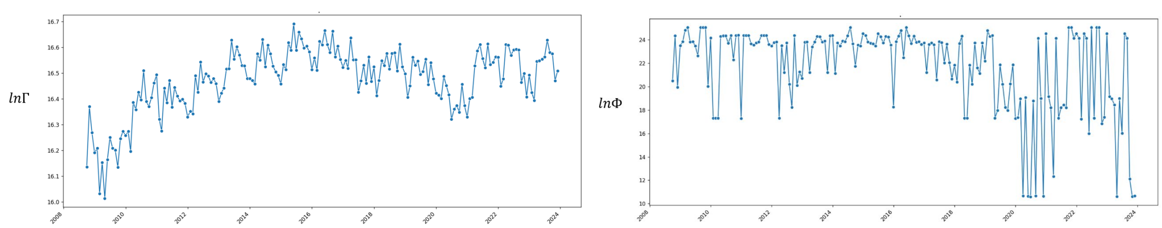
In a descriptive way, the behavior of the variables R, W, D, Γ, φ, Λ, Φ, corresponding to Figure [3]. In Figure 4a, we can see the rate of preventive work in Mexico, which has been declining since mid-2013. This represents an area of opportunity in the prevention systems of the maritime port supply chain in Mexico, and it also represents the need to encourage reinforcement mechanisms in this regard.



a) b)

Figure 4. Variable φ (Preventive work rate) and Variable Λ (Spillover effect)

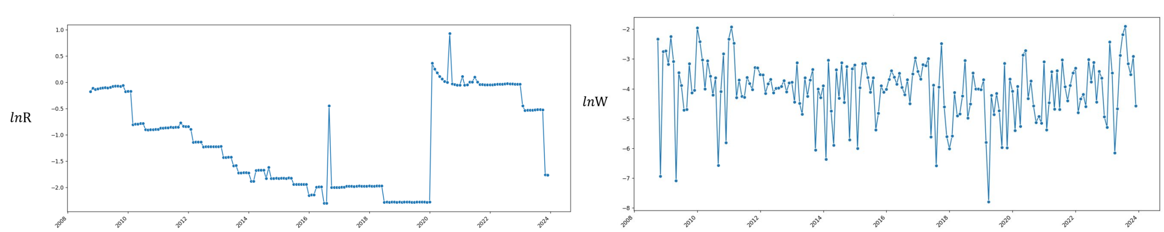
On the other hand, in Figure 4b, we can see the behavior of the spillover effect variable (average of the variables of this effect). We see that it has had an improving behavior at a general level since its negative nature has been reduced, inferring that at the regional level, the port areas have applied policies and strategies to take advantage of the location as a competitive advantage in port operations. However, there is still a considerable area of opportunity for improvement in this regard. In Figure 5a, we can see how the movement of average tonnage in ports (tons received between imports and exports) grew from 2008 to mid-2016. From this year onwards, it began to show moderate stability, except at the beginning of the COVID-19 pandemic. It is interesting to see how Mexico was one of the few countries in the world that more than recovered its port rhythm in a short time.



a) b)

Figure 5. Variable Γ (Tonnage Movement) and Variable Φ (Synchronization Effect)

In Figure 5b, we can see the behavior of the results obtained from the synchronization effect by applying the model proposed by Moreno et al. (2024). This phenomenon worsens during almost the entire second disruption (2020-2023), thus representing port non-coordination and operational gaps between the Mexican ports. This also means that the effects of this pandemic are still present in the maritime port supply chain. Figure 6a shows the behavior of the resilience index proposed by Moreno et al. (2024) in Mexican seaports for 2008-2023. It is observed that, in general, it took Mexican ports approximately eight years to recover the initial state they had before receiving the first disruption (2008-2009) and then again begin to recover what was lost due to the pandemic. However, unlike the first disruption, this pandemic has made the level of recovery more significant and sustained.



a) b)

Figure 6. Variable R (Resilience) and Variable W (Bullwhip effect)

Figure 6b shows the behavior of the bullwhip effect. Periods are observed where there were significant bullwhip effects on the supply side, but there are also several minor and quantity bullwhip effects on the demand side. Figure 7a shows the domino effect. Because the values represented are logarithmic, it is observed that there were predominantly positive risks and less than 1, which infers that the level of disruptive impact on the supply chain is unstable when a disruption occurs.

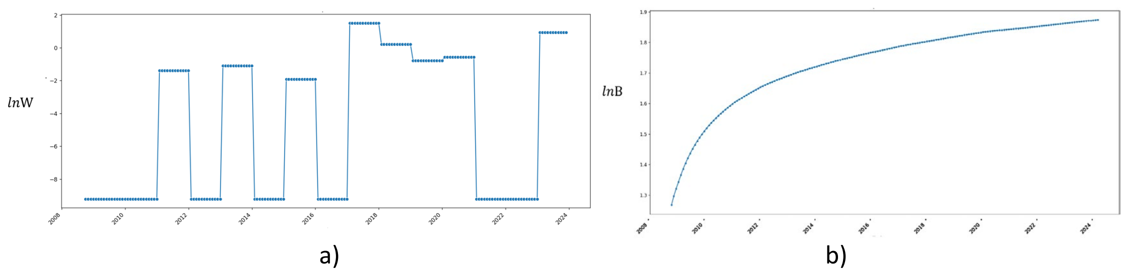


Figure 7. Variable D (Ripple effect) and Variable B (Maritime port capital)

Moreover, in Figure 7b, the behavior of the port maritime capital of the different Mexican ports is observed. Note that this capital behaves as a stock of capital over time.

Strategic algorithm analysis
After applying the previous nine strategies using algorithm 1, the matrix resulting from the ranking of the values for each strategy for the variables of Sales, Production, Opportunity Costs, and Resilience is shown in Table 3:

Table 3. Representation of proposed strategies

Strategy	Sales	Production	Opportunity Cost	Resilience	Total
(a)	8	6	2	2	18
(b)	6	5	8	7	26
(c)	5	4	5	9	23
(d)	9	8	9	1	27
(e)	2	2	7	5	16
(f)	1	1	1	4	7
(g)	4	3	6	3	16
(h)	3	9	3	8	23
(i)	7	7	4	6	24

Ranking Strategy	Total
(d)	27
(b)	26
(i)	24
(c)	23
(h)	23
(a)	18
(e)	16
(g)	16
(f)	7

a) "Defeating without war"
b) "Know yourself and know your enemy"
c) "Attacking the enemy's strategy"
d) "With one movement, you can win two times"
e) “Don't get hit, don't get cut"
f) "Adapt to circumstances"
g) "Emergency Leadership"
h) "Disruptive Innovation Theory"
i) “Blue Ocean Strategy"

Notes: The value used for Z was 30%.

Note that in Table 4, it was given a weight (1 for the last position, 9 for the highest position), thus obtaining from each strategy its sum at the end, thus leaving the final ranking as follows:
At the global level, evaluating all the variables (Sales, Production, Opportunity Cost, Resilience) it is observed that the most appropriate strategy for the studio supply chain is Musachi's "Win twice with a single move" strategy, followed by Sun Tzu's "Understanding oneself and one's enemy", and then Kim and Mauborgne's "Blue Ocean".At the individual level, specifically for the Resilience variable, it is observed that the most appropriate strategy is "Attacking the enemy's strategy" by Sun Tzu, followed by "Understanding oneself and the enemy" by the same author, and later by "Blue Ocean" by Kim & Mauborgne.

The model was empirically validated using historical data from Mexican seaports between 2008 and 2023. Input variables, including port capital stock, workforce, inflation, and cargo movement, were obtained from national maritime databases and statistical sources. These datasets enabled the calibration of simulation parameters and provided a reliable basis for comparing observed disruptions (e.g., the 2008 crisis and the COVID-19 pandemic) against model predictions. The results obtained are perfectly congruent with reality: Musachi's strategy (Win twice with a single move) is related to relying on predominantly using the reduction of non-synchronization of the links in the supply chain, which makes it the most appropriate strategy not only during the disruption but throughout the study period. On the other hand, Sun Tzu's strategy (Attack the enemy's strategy), his tactic designed in equation [5], is based on the expansion of the seaport's capacity whenever it does not reach the established average threshold and thus reduces its opportunity cost, thus minimizing the Knock-on effect. Therefore, in addition to being the most expensive strategy in infrastructure, it is observed that it is the most effective for Resilience. However, it is necessary to point out that this strategy represents an ideal scenario but is predominantly infrequent in its development. It is also interesting that the strategy that most integrate the aspects of sales, production, opportunity costs, and Resilience itself is the Blue Oceans strategy. On the other hand, the results of spillover, as well as the direct effects, were as follows (Tables 4 and 5):

Table 4. Spillover generated by study sub-period

		K	*L*	*F*	*Q*	*Z*
South Central Pacific	2008-20019	---	-1.000107***	---	---	---
	2010-2019	1.50581***	0.75065**	-1.56613***	-0.184419**	---
	2020-2023	---	-0.59141***	-0.14017**	-0.08265**	6.5301***
North Pacific-California	2008-20019	-0.11876*	0.99521**	---	---	---
	2010-2019	0.26723**	---	---	---	---
	2020-2023	---	---	---	---	0.74143**
Gulf-Caribbean	2008-20019	---	---	---	---	---
	2010-2019	0.08329*	0.68271***	---	---	---
	2020-2023	-0.39135***	---	---	---	---

Note: ***:P < 0.01; **:P < 0.5; *P < 0.1

Table 5. Direct effects generated by study sub-period

		K	*L*	*F*	*Q*	*Z*
South Central Pacific	2008-20019	---	---	7.7961*	---	---
	2010-2019	-1.29131***	---	3.2362***	0.13863**	---
	2020-2023	---	1.9069***	0.45195**	0.2665***	-6.5196***
North Pacific-California	2008-20019	0.27200***	---	-5.64104***	---	-0.20324***
	2010-2019	-0.86430***	-1.2204*	---	0.17678**	---
	2020-2023	---	---	---	---	---
Gulf-Caribbean	2008-20019	---	0.9021*	-6.6694*	---	0.1732*
	2010-2019	---	-1.0081***	2.57649***	-0.04125***	---
	2020-2023	0.64222***	-0.39115***	---	0.099546***	---

Note: ***:P < 0.01; **:P < 0.5; *P < 0.1

These results corroborate those proposed by Moreno et al. (2025). Table 5 shows that the Central-South Pacific region is the port region with the most positive spillover in general, thus representing a benefit of externalities for the foreign regions that interact with these Mexican ports; in this regard, it is followed by the North Pacific-California region and later the Gulf-Caribbean region. As for the direct effects (Table 6), it represents the externalities that only benefit internally the ports that confirm that port region, observing that the North-South Pacific region is also the region with the highest direct effects; in this regard, it is followed by the Gulf-Caribbean region and later the North Pacific-California region, the latter two regions presenting predominantly negative spillover. These values obtained and represented in tables 5 and 6, represent the weights of economic advantages of each type of strategy that, in combination with the game theory payment matrices based on Nowak's strategies, will help us to understand the final nature of these strategies to strengthen the resilience of the supply chain under study.

Game Theory Analysis

Applying Table 2 to determine the nature of cooperativity that arises between the nodes of the supply chain during the study period (before and during the resilience of the supply chain), the results for each variable of the model representing the tonnage movement of seaports were the following payment matrices in game theory (Tables 6 and 7). It can be seen in the results of Table 7 that the Inflation factor, specifically in its Direct Reciprocity strategy, is evolutionarily stable (high value in its Nash Equilibrium), preferred by those who avoid risk and, at the same time, offers substantial advantages in terms of results or rewards. This type of strategy could become the dominant norm in the game, as it is difficult to displace due to its evolutionary stability, low-risk aversion, and superior returns. The above infers that for resilience to evolve sustainably in Mexican port supply chains in the face of the effect of inflation, it is more beneficial that there is a "parenticity" factor among its links since inflation represents a cost for neighboring countries (negative spillover) since this phenomenon occurred during the stable period, This made Mexican products expensive for this sector, thus reducing exports, but on the other hand, it represented an internal advantage (resulting positive direct effects), indicating that this appreciation of the Mexican peso generated internal benefits in Mexican ports since it increased their purchasing power and also decreased their import costs. As the Kinship Selection strategy is more advantageous in this scenario, it also means that this favorable scenario would represent the possibility of strengthening commercial relations between links that have some degree of parentage or also being able to make long-term plans taking advantage of this line of kinship. Family SMEs would benefit significantly in this scenario. It should also be noted that for this period of stability (2010-2019) for the rest of the variables, there is no predisposition to cooperativity between links to strengthen resilience in the supply chain. On the other hand, for the disruptive period 2020-2023, it is observed that for variable "L" (maritime personnel and labor) as well as variables "F" (inflation) and "Q" (intensity of use of the supply chain) the ideal strategy as a common denominator continues to be that of Direct Reciprocity Selection (due to the high value in its Nash Equilibrium). It is also observed in the results of the previous tables, 7 and 8, that the only variable in which there is no interest in cooperating for its resilience in the supply chain is that of port maritime capital (K) in any of the subperiods of study. This also means that it is necessary to improve and create new mechanisms for investment in maritime port infrastructure, not only through federal or private investment, since this also confirms the need for more investment in this area. Finally, we can see in the results obtained from tables 7 and 8 that the characteristic of collaboration between nodes arises in ≈ 30% and ≈ 80% of the study variables, respectively. Therefore, these percentages will represent the level of collaboration that can be counted on to achieve logistics resilience in the supply chain in each study period (stable period and disruption period).

Table 6. Stable Period 2010-2019

			C	D	ESS	RD	AD
K	Kin selection	C	-0.14964	0.259508	---	---	---
		D	-0.40915	0			
	Direct reciprocity	C	-0.19952	0.618777	---	---	---
		D	-0.71854	0			
	Indirect reciprocity	C	-0.09976	0.309388	---	---	---
		D	-0.35927	0			
	Network reciprocity	C	-0.09976	0.619088	---	---	---
		D	-0.71885	0			
	Group selection	C	-1.89544	9.601147	---	---	---
		D	-11.4966	0			
			C	D			
L	Kin selection	C	-0.39757	0.10637	---	---	---
		D	-0.50394	0			
	Direct reciprocity	C	-0.53009	0.477787	---	---	---
		D	-0.74283	0			
	Indirect reciprocity	C	-0.26505	0.238893	---	---	---
		D	-0.37142	0			
	Network reciprocity	C	-0.26505	0.460671	---	---	---
		D	-0.72572	0			
	Group selection	C	-5.03589	6.849447	---	---	---
		D	-11.8853	0			
F	Kin selection	C	2.12328	0.446738	✓	✓	✓
		D	1.676542	0			
	Direct reciprocity	C	2.83104	-0.52204	✓	✓	---
		D	1.937563	0			
	Indirect reciprocity	C	1.41552	-0.26102	✓	✓	---
		D	0.968782	0			
	Network reciprocity	C	1.41552	-0.39941	---	---	---
		D	1.814931	0			
	Group selection	C	26.89488	-4.10613	---	---	---
		D	31.00101	0			
Q	Kin selection	C	0.044871	-0.01578	---	---	---
		D	0.06065	0			
	Direct reciprocity	C	0.059827	-0.06147	---	---	---
		D	0.091387	0			
	Indirect reciprocity	C	0.029914	-0.03074	---	---	---
		D	0.045693	0			
	Network reciprocity	C	0.029914	-0.05966	---	---	---
		D	0.089571	0			
	Group selection	C	0.56836	-0.89383	---	---	---
		D	1.462187	0			

* Note: results with r, w, q = 0.5; n=16, m=3. The values of the weights are the averages of the spillover effect in all regions.
* Note: Green = Pure Nash Equilibria

Table 7. Disruptive period 2020-2023

			C	D	ESS	RD	AD
K	Kin selection	C	0.125435	-0.02341	---	---	---
		D	0.148848	0			
	Direct reciprocity	C	0.167247	-0.13045	---	---	---
		D	0.214073	0			
	Indirect reciprocity	C	0.083623	-0.06523	---	---	---
		D	0.107037	0			
	Network reciprocity	C	0.083623	-0.12474	---	---	---
		D	0.208361	0			
	Group selection	C	1.588843	-1.83633	---	---	---
		D	3.425173	0			

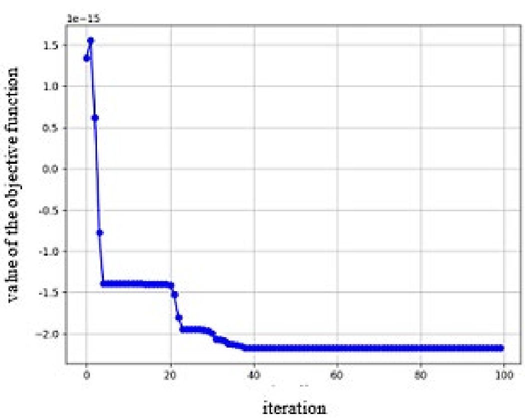
Table 7
Continued)

L	Kin selection	C	0.46217	0.055488	✓	✓	✓
		D	0.406682	0			
	Direct reciprocity	C	0.616227	-0.19714	✓	---	---
		D	0.50525	0			
	Indirect reciprocity	C	0.308113	-0.09857	✓	---	---
		D	0.252625	0			
	Network reciprocity	C	0.308113	-0.17173	---	---	---
		D	0.479842	0			
	Group selection	C	5.854153	-2.22985	---	---	---
		D	8.084	0			
F	Kin selection	C	0.15589	0.028602	✓	✓	✓
		D	0.127288	0			
	Direct reciprocity	C	0.207853	-0.04672	✓	✓	---
		D	0.15065	0			
	Indirect reciprocity	C	0.103927	-0.02336	✓	✓	---
		D	0.075325	0			
	Network reciprocity	C	0.103927	-0.03785	---	---	---
		D	0.141776	0			
	Group selection	C	1.974607	-0.43579	---	---	---
		D	2.4104	0			
Q	Kin selection	C	0.141698	0.033458	✓	✓	✓
		D	0.10824	0			
	Direct reciprocity	C	0.188931	-0.02755	✓	✓	✓
		D	0.122015	0			
	Indirect reciprocity	C	0.094465	-0.01378	✓	✓	✓
		D	0.061008	0			
	Network reciprocity	C	0.094465	-0.01925	---	---	---
		D	0.113719	0			
	Group selection	C	1.794841	-0.1574	---	---	---
		D	1.952245	0			
Z	Kin selection	C	0.375965	1.337243	---	---	---
		D	-0.96128	0			
	Direct reciprocity	C	0.501287	2.423843	---	---	---
		D	-2.1732	0			
	Indirect reciprocity	C	0.250643	1.211922	---	---	---
		D	-1.0866	0			
	Network reciprocity	C	0.250643	2.48427	---	---	---
		D	-2.23363	0			
	Group selection	C	4.762223	39.53342	---	---	---
		D	-34.7712	0			

*Note: results with r, w, q = 0.5; n=16, m=3. The values of the weights are the averages of the spillover effect in all regions.
* Note: Green = Pure Nash Equilibria

Optimization Analysis

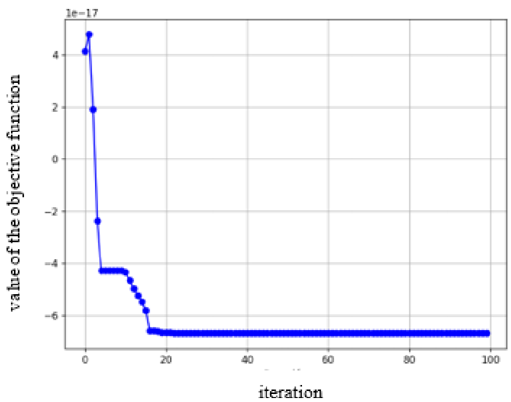
Applying the "Trust-Constr" algorithm to optimize the model proposed in Table 4, obtaining the results shown below: for the period of stability (2010-2019), an acceptable convergence was obtained for this algorithm (Figure 8 and Figure 9) by applying the Python software (PyCharm 2022.3.2), obtaining the optimization results shown in Table 10.



Variable, function	Optimal value
R	0.753985
C	1.50353
$\frac{dB}{dt}$	-2.89467
$\frac{dR}{dt}$	-0.00010873
Function Objective	2.172596 e-15

Figure 8. Convergence of the objective function, period 2010-2019

For this period, a depreciation rate was used (ρ) of 0.30 (approximate value obtained in the results of Figure 8), in order to indicate that in this stability there is a greater tendency to think about future consumption than in the present due to the same prevailing stability. We can see that the profit generated in this model is greater than that of the disruptive period (compare Figure 9), which is congruent. It should also be noted that the Consumption, Resilience and the speed of port-maritime capital are very similar, this is due to the fact that during the disruption a depreciation rate was applied (ρ) de 0.8 (approximate value obtained in the results of table 7) in order to represent the need for high consumption of the benefits of resilience due to the prevailing need for pandemic disruption. This also means that the links need to maintain the same commercial and operational rhythm they had before the disruption, sacrificing their future savings.



Variable, function	Optimal value
R	0.753969
C	1.50357
$\frac{dB}{dt}$	-2.89471
$\frac{dR}{dt}$	-0.004937
Function Objective	6.6933595 e-17

Figure 9. Convergence of the objective function, period 2020-2023

For both optimization periods, a population growth rate was used (n) of 1.5 %, and a concavity parameter (θ) of 0.1, thus, the latter indicates that agents are less likely to change their present consumption in response to changes in future consumption. He designated this concavity value (0.1) due to the results obtained in Table 4, since the first strategies that turned out to have a higher percentage of participation in the ranking obtained predominantly high values of sales and, therefore, of consumption.

An interesting result is that, in both scenarios, Figures 9 and 10, the value of the objective function of the representative agent is close to zero, indicating that the economic agent has reached a stationary equilibrium in which the discounted intertemporal utility is relatively low but not negative. This could mean that although the agent is not maximizing its utility optimally, it has achieved a stable equilibrium in which present and future consumption are sufficiently balanced.

What the optimization of both periods tells us is that the strategies of cooperation between links for resilience in the supply chain must meet the following characteristics to achieve sustainable resilience with the lowest possible cost of resources:

Focus on reducing the asynchronous effect of Mexican maritime-port chains ("Win twice with a single move" strategy) at all times as the main resilient objective.

Take advantage of the time of appreciation of the Mexican peso to strengthen the SMEs that are part of the maritime port supply chain. Invest enormously in port-maritime emergency infrastructure in the face of disruptive events because although there are dominant strategies to proliferate resilience in the face of a lack of it, the benefits would multiply. Given the income, purchases, taxes, inflation, and port capital of the supply chain under study, it is possible to maintain the same levels of consumption and resilience, having as the central control variable the speed of resilience achieved by applying each of the previous paragraphs.

6. Conclusion

Even though the model uses continuous-time equations behind the scenes, it was designed to reflect how different events currently play out during real disruptions. We adjusted the inputs—like when the disruption happens, how severe it is, and where it hits—to see how the system would react. By looking at each case on its own, we were able to better capture how resilience really works in different, real-life situations.

The results of the performance evaluation of each of the nine strategies proposed (by Sun Tzu, Musashi, Wheatley, Christensen, Chan & Maugborne) and shown in Table 4, indicate that the most efficient strategy is Musachi's "Win twice with a single move", obtaining the maximum total weight in their respective variables, followed by "Understanding Yourself and the Enemy" by Sun Tzu and later "Blue Ocean" by Chan & Maugborne). The result of Musachi's strategy for its first positioning is that it reduces the existing asynchrony throughout the supply chain; however, to be able to carry out the above requires enormous and considerable investment and infrastructure, both economic and human, which can, at some point be challenging to carry out. The second resulting strategy, Sun Tzu's, is similar to Musachi's previous one, only with the difference that its support in resources for those nodes that need such support is discriminatory and that in some complex economic contexts, it may also be challenging to apply, but to a lesser degree compared to Musachi's previous strategy. However, Chan & Maugborne's strategy (Blue Ocean) is more balanced and measured, as it is both efficient in that it does not require enormous resources to sustain resilience and practical in that it allows resilience itself to be robust in the study period. Therefore, these three previous strategies are the most recommended to promote efficient and effective resilience in the supply chain.

Mexico was selected as a case study due to its strategic geographic location, the diversity of its port regions (Pacific, Gulf, and Caribbean), and the availability of reliable longitudinal data. While the findings are tailored to the Mexican context, the methodology itself is generalizable. Similar resilience modeling can be replicated in other countries by calibrating the model with local parameters, as the core structure allows for adaptation to different port systems and disruption profiles.

Compared to traditional models in classical game theory, which often rely on rigid assumptions and static interactions, our approach introduces more realistic cooperation dynamics by considering how trust and reputation evolve between ports. Unlike robust optimization models—which are mainly designed to reduce risks in worst-case scenarios—this approach focuses on making the most of potential gains when ports choose to work together. By combining cooperation and strategic planning, it offers a more realistic and flexible way to deal with the complexity and interdependence that define port logistics today. Future studies could directly compare the performance of this model with that of more conventional ones to better understand its practical advantages.

The recommendations derived from the spillover analysis (Table 5) are as follows:
About Capital (K): In the South-Central Pacific (SCP), its infrastructure is predominantly designed to operate in stable periods (coefficient of 1.50581***), neutrally influencing foreign ports during disruptive periods. To correct this area of opportunity, it is necessary to continue expanding dock capacity and introducing state-of-the-art technology.

About the staff (L): Maritime personnel still have an area of opportunity to correct in terms of preparation for disruptive events since a coefficient of 0.75065** was obtained during stable periods and -1.00*** and -0.591*** during disruptive periods, representing a negative influence for foreign ports and customers during disruptions.

On Inflation (F): Mexico has been characterized by high import behavior in its trade balance, which is why a stable inflation that occurred in the stable period negatively influences foreigners. However, this inflation increased at the beginning of the COVID-19 pandemic, diminishing this negative influence. The phenomenon of inflation must be accompanied by incentive mechanisms for product substitution in order to reduce this negative influence abroad. It is worth mentioning that this influence on this variable only occurs in the Central-South Pacific region, being neutral in the rest of the regions, mainly due to the volume that this region handles in tonnage with the outside.

On supply chain intensity (Q): This variable only impacted the PCS region (-0.1844* and -0.0826**, stable and disruptive periods, respectively). This means that it is imperative to apply mechanisms to reduce empty TEUs in that region since it is affecting the port efficiency of foreign ports and, with it, the customer portfolio of Mexican ports.

On disruptive events per se (Z) : it is detected that the COVID-19 pandemic represented a positive and beneficial effect for foreign ports on the part of Mexico (6.5301*** for the PCS region; 0.7414** for the PNC region) since this is proven in the high levels of exports made during that period and therefore reducing the gap towards the recovery point that the resilience of such a supply chain has.

The recommendations derived from the analysis of the direct effects (Table 6) are as follows:
On maritime capital (K): A contrasting figure can be observed since, in the PCS and PNC regions, the influence between ports is negative (during the stable period). This means that the ports that make up each region have internal

adversities that minimize the performance of their maritime capital, such as poor internal communication and bottlenecks in maritime cabotage, among others. This represents a notable area of improvement for these port regions. However, the Gulf-Caribbean Region (RGC), specifically during the COVID-19 pandemic, was the only region with efficient internal performance of its port-maritime infrastructure. The recommendation is to apply and analyze the good practices of this region in the rest of the port-maritime regions.

On maritime personnel (L): Conflicts and internal factors predominantly affect the performance of the PCN and PCG port areas. However, maritime personnel in the PCS region have optimal internal synchrony, specifically during the disruption of the pandemic (1.9069***); however, this is only in terms of domestic activities or maritime cabotage, which contrasts with its performance with respect to activities related to the foreign sector.

On inflation (F): Undoubtedly, the stability of inflation has benefitted seaports internally since most of the coefficients in Table 6 are positive. This is because internal price controls benefit internal transactions between the links in the supply chain.

On supply chain intensity (Q): the accumulation of empty TEUs represents an operating benefit for most periods in seaports. This is because the accumulation of such units facilitates the instant transaction and termination of contracts and discharges between internal activities. However, in the end, the above also represents a disadvantage when it comes to providing an optimal service for the foreign sector.

On disruption (Z): Although the pandemic's disruptive event represented a business opportunity in some ports, as discussed in the spillover effect section, it is observed that the disruptive event has a predominantly negative internal behavior due to adversities that are not reflected in the commercialization with the foreign sector.

Regarding the results of the type of Cooperativity (Tables 6 and 7):
About the stable period (2010-2019)): Table 6 shows that the only strategies where Nash Equilibrium Points are observed are concerning the inflation variable (F), specifically for the kinship section (SP), direct reciprocity (REDI), and indirect reciprocity (RI), with the highest stability of this equilibrium being the REDI type, in addition to the fact that the latter has a level of long-term stability cooperativity (SSE) as well as dominant in the face of the risk (RD). This means that for the maritime port supply chain under study, stable inflation is a solid and stable option that offers resistance to invasion by other strategies and a preference for less risky outcomes. However, the SP option is even more advantageous for the port supply chain (despite not having the highest Nash equilibrium value), as the SP option is of the ESS, RD, and AD type, which means that it has features that make it especially beneficial in terms of maximizing profits or in-game outcomes. This could imply that, besides being stable and secure, the strategy offers competitive advantages compared to other available strategies. Therefore, it is observed that for stable non-disruptive periods, the level of cooperativity between links that prevails is of the REDI and SP type, the latter being the one that finds the most benefit to the links because they apply intensely close relationships and ties, including family, to be able to influence the transactions of each of them efficiently. If stability and security are priorities, the strategy with a high Nash equilibrium may be the best option (REDI strategy). However, if profit maximization and competitive advantage are valued, the SP strategy may be preferable.

About the stable period (2019-2023): In this disruptive period, there are several Nash equilibria (see Table 7). It is observed that for scenarios where stability and security are a priority (which is essential during a disruption), the most appropriate strategies are those of the RD type; therefore, it is observed that the variable L is suitable for the SP strategy; for both F and Q variables, the SP, REDI, RI strategies are adopted. Concerning L, it is observed that during this disruptive period, close and family ties between maritime personnel play an essential role in their performance towards foreign and domestic ports. Building and maintaining strong and lasting relationships is valued in a relationship-based culture, both inside and outside the system. This can manifest in prioritizing open and transparent communication, resolving conflicts through dialogue and negotiation, and emphasizing teamwork and collaboration. Trust and mutual loyalty are critical components in this type of culture, as they allow system members to trust that others will fulfill their responsibilities and work together to achieve common goals. However, the disadvantages in this scenario are that in these seaports, there needs to be more objectivity, risks of exclusion, resistance to change, fragility in the face of personal conflicts, and difficulty in maintaining performance standards. In the same way as above, it behaves strongly for the variable F. On the other hand, the REDI strategy has a high Nash equilibrium, making it the most stable and secure strategy during that period for the Q variable. This means that if one seaport cooperates with another and receives a benefit in return, it will likely be willing to cooperate again in the future with that same port. This is because cooperation is expected to be reciprocal and a continuous exchange of benefits.

About the results of the optimization analysis, it can be seen that the levels of consumption and maritime assets can be maintained predominantly over time, even in disruptive periods, simply by increasing the speed of resilience in the supply chain. This also proves that synchronization is the most significant among the different predominant effects (spillover, bullwhip, ripple, economics) and, in this way, optimizes resources to a single objective instead of attacking all the previous effects. To increase the synchronization effect, there are minimal activities to be implemented in a system such as those mentioned below:

Better communication and visibility: Effective and transparent communication channels between all actors in the supply chain are essential to achieve synchronization. Information systems and communication technologies that share real-time information on demand, inventory, and lead times can help anticipate and respond quickly to changes in customer needs.

Collaborative planning: Foster collaboration between different supply chain partners in planning and decision-making. This can improve synchronization. This requires sharing information and knowledge and collaborating on production, inventory, and delivery planning.

Shorter delivery time: Minimizing lead times throughout the supply chain can improve synchronization. This can be achieved, for example, by optimizing transport routes, using warehouses close to points of consumption, and implementing fast delivery systems such as just-in-time.

Flexibility and agility: Building a supply chain Being flexible and agile helps to adapt quickly to changes in demand or disruptions. This can include quickly changing production, reallocating resources, and adjusting inventory levels. Create the right incentives: Incentives to foster collaboration and achieve supply chain goals can encourage different actors to work in sync. These may include financial incentives, recognition of outstanding performance, or profit-sharing from synchronization. Interestingly, the predominant, stable, and most efficient solution to increasing resilience in the study supply chain is to increase synchronization between nodes. Unlike other strategies, this strategy does not require expensive infrastructure since it predominantly relies on skills that emanate from maritime human capital.

This research provides several contributions to the field of supply chain resilience, which are listed below:

a) A new methodology in Game Theory is offered which can characterize nine management strategies expressed through a set of differential equations to promote sustainability and enhance scalable resilience in the supply chain.

b) A new methodology is provided based on the contributions of Nowak (2006) and through the insertion of the phenomenon of spillover and direct effects to represent the most appropriate lines of game theory for cooperativity between the supply chain nodes in favor of their resilience.

c) A new model based on the Ramsey-Cass-Koopmans utility is provided to measure the utility generated during the supply chain's resilience and obtain its variables optimization by applying the Trust-Constr algorithm.

The future lines of research proposed by this research are representations of the restriction of the customers of each link in the supply chain for the proposed optimization model. Another future line is the Analysis of Nash equilibria, Stackelberg equilibria, mixed strategy equilibria, and Pareto Optimal equilibria of the proposed payoff matrices.

References

Ahmed, W. and Rashdi, M. Understanding the influence of lean and agile strategies on creating firms' supply chain risk management capabilities. Competitiveness Review: An International Business Journal. Emerald Publishing Limited 1059.-5422. 2020.

Ajali, M., Al, M., Borade, D., Saleh, M. The mediating role of innovation between entrepreneurial orientation and supply chain resilience. Asia-Pacific Journal of Business Administration. Emerald Publishing Limited 1757.-4323., 2021. DOI: 10.1108./APJBA-10-2020.-0376

Andres, B. and Marcucci, G. A. Strategies Alignment Approach to Manage Disruptive Events in Collaborative Networks. Sustainability 2020, 12, 2641, DOI: 10.3390./su1207.2641, 2020.

Appiah, M., Sedehag, D. and Akolaa, R. The implications of macroenvironmental forces and SMEs investment behaviour in the energy sector: the role of supply chain resilience. Heliyon 7 (2021.) e0842.6, 2021.

Badhottya, G., Soni, G., Jain, V., Joshi, R. and Mittal, S. Assessing supply chain resilience to the outbreak of COVID-19 in Indian manufacturing firms. Operations Management Research (2022.) 15:1161.–1180., 2021. DOI: 10.1007./s1206.3-021-0023.6-6

Behzadi, G., O.´Sullivan, M. and Olsen, T. On metrics for supply chain resilience. European Journal of Operational Research 287 (2020.) 145–158, 2020.

Brusset, X. and Teller, C.h. Supply chain capabilities, risks and resilience. International Journal of Production Economics 184 (2017.) 59–68, 2017.

Chang, J. and Jiang, H. Spatio-Temporal Differentiations and Influence, F.actors in China's Grain Supply Chain Resilience. Sustainability, 15, 8074. DOI: 10.3390./su1510.8074, 2023.

Chen, J., Zhang, W., Wan, Z., Li, S., Huang, T., Fei and Y. Oil spills from global tankers: Status review and future governance. Journal of Cleaner Production, 2019.

Chen, L., Dui, H. and Zhang, C.h. A. resilience measure for supply chain systems considering the interruption with the cyber-physical systems. Reliability Engineering and System, S.afety 199 (2020.) 1068.69, 2020.

Chowdhury, M. and Quaddus, M. A. multiple objective optimizacion base QFD approach for efficient resilient strategies to mitigate supply chain vulnerabilities: The case of garment industry of Bangladesh.Omega. http://dx.DOI: 10.1016./j.omega.2015.05.016, 2015.

Christensen and C. M. The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail. Harvard Business Review Press, 1997.

Cleary and Thomas. El Arte de la Guerra. Shambala Pubications, Inc.ISBN 978-6118.0-022-7, 2012.

De Angelis and D. El libro de los 5 anillos. Miyamoto Musashi. ISBN 9791.2213.6333.3, 2022.

Dong-Wook Kwak, Young-Joon Seo, Robert Mason, "Investigating the relationship between supply chain innovation, risk management capabilities and competitive advantage in global supply chains", International Journal of Operations & Production Management and Vol. 38 Issue: 1, pp.2-21, DOI: 10.1108./IJOPM-06-2015.-0390, 2018.

Durmaz, A., Demir, H. and Sezen, B. The role of negative entropy within supply chain sustainability. Sustainable Production and Consumption 28 (2021.) 218–230, 2021.

Ekanayake and E. M. A. C., Shen, G., Kumaraswamy, M., Owusu, E. K., & Xue, J. Capabilities to withstand vulnerabilities and boost resilience in industrialized construction supply chains: a Hong Kong study. Engineering, construction and architectural management, 29(10), 3809.-3829. is available at 10.1108./ECAM-05-2021.-0399, 2022.

Eula Margareth and Y. Jabilles, Justin Marie, T. Cuizon, Precious Marie, A. Tapales, Renelyn, L. Urbano, Lanndon, A. Ocampo & Dennis Anthony, A. Kilongkilong. Simulating the impact of inventory on supply chain resilience with an algorithmic process based on the supplyside dynamic inoperability input–output model, International Journal of Management Science and Engineering, M.anagement, DOI: 10.1080./1750.9653.2018.1555.693, 2019.

Foo and C. T. Exploring thinking from antiquity in managing logistics, supply and resources: Chinese Sun Tzu, Indian Kautilya and supply chain management. International Journal of Indian Culture and Business, M.anagement, 3(2), 121–137. 10.1504./IJICBM.2010.0307.50, 2010.

Fu, W., Jing, S., Liu, Q. and Zhang, H. Resilient Supply Chain Framework for Semiconductor Distribution and an Empirical Study of Demand Risk Inference. Sustainability, 15, 7382. DOI: 10.3390./su1509.7382, 2023.

Geng, L., Xiao, R. and Xu, X. Research on MAS-Based Supply Chain Resilience and Its, S.elf-Organized Criticality. Hindawi Publishing Corporation Discrete Dynamics in Nature and Society, V.olume 2014, Article ID 6213.41, 14 pages http://dx.DOI: 10.1155./2014./6213.41, 2014.

Gourinchas and P. O.Notes for Econ202A: The Ramsey-Cass-Koopmans Model. Fall 2014. UC Berkeley, 2014.

Gruzauskas, V., Gimzauskiene, E. and Navickas, V. Forecasting accuracy influence on logistics clusters activities: The case of the food industry. Journal of Cleaner Production 240 (2019.) 1182.25, 2019.

Guoqing Zhao, Shaofeng Liu, Yi Wang, Carmen Lopez, Nasiru Zubairu, Xiaoning Chen and Xiaotian, X.ie & Jinhua Zhang. Modelling enablers for building agrifood supply chain resilience: insights from a comparative analysis of Argentina and France, Production Planning & Control, DOI: 10.1080./0953.7287.2022.2078.246, 2022.

Hamidu, Z., Boachi, F. and Issau, K. Supply chain resilience and performance of manufacturing firms: role of supply chain disruption. Journal of Manufacturing, 2023.

Hamidu, Z., Issau, K. and Boachie, F. On the interplay of supply chain network complexity on the nexus between supply chain resilience and performance. Benchmarking: An International Journal. Emerald Publishing Limited 1463.-5771. DOI: 10.1108./BIJ-09-2022.-0551, 2023.

Hamidu, Z., Mensha, B., Issau, K. and Asado, E. Does technological innovation matter in the nexus between supply chain resilience and performance of manufacturing firms in a developing economy?. Journal of Manufacturing Technology Management. Emerald Publishing Limited 1741.-038X DOI: 10.1108./JMTM-11-2022.-0384, 2023.

Hsu, C.-H., Li, M.-G., Zhang, T.-Y., Chang, A.-Y., Shangguan, S.-Z., Liu and W.-L. Deploying Big Data Enablers to Strengthen Supply Chain Resilience to Mitigate Sustainable Risks Based on Integrated HOQ-MCDM Framework. Mathematics, 10, 1233. DOI: 10.3390./math1008.1233, 2023.

Hsu, C.-H., Yu, R.-Y., Chang, A.-Y., Chung, W.-H., Liu and W.-L. Resilience-Enhancing Solution to Mitigate Risk for Sustainable Supply Chain–An Empirical Study of Elevator Manufacturing. Processes, 9, 596. DOI: 10.3390./pr9040.596, 2021.

Hsu, Ch., Zeng, J., Chang, A. and Cai, S.h. Deploying Industry 4.0 Enablers to Strengthen Supply Chain Resilience to Mitigate Ripple Effects: An empirical study of Top Relay manufacturer in China. Digital Object Identifier 10.1109./ACCESS.2017, 2017.

Huang, D., Delang, C. O., Wu, Y. and Li, S. An Improved Lotka–Volterra Model Using Quantum Game Theory. Mathematics, 9, 2217. DOI: 10.3390./math9182.217, 2021.

Hui Shan Loh & Vinh and V. Thai. Managing port-related supply chain disruptions (PSCDs): a management model and empirical evidence, Maritime Policy & Management, DOI: 10.1080./0308.8839.2015.1107.921, 2015.

Huma, Sehrish & Siddiqui and Danish. Impact of Lean and Agile, S.trategies on Supply Chain Risk Management. SSRN Electronic Journal. 10.2139./ssrn.3384.808, 2019.

Irfan, I., Sumbal, M. S.U. K., Khurshid and F. and Chan, F. T.S. Toward a resilient supply chain model: critical role of knowledge management and dynamic capabilities", Industrial Management & Data Systems, Vol. 122 No. 5, pp. 1153.-1182. is published by Emerald and is available at https://dx.DOI: 10.1108./ IMDS-06-2021.-0356, 2022.

Ivanov and D. Exiting the COVID-19 pandemic: after-shock risks and avoidance of disruption tails in supply chains. Annals of Operations Research DOI: 10.1007./s1047.9-021-0404.7-7, 2021.

Ivanov and D. Supply Chain Simulation and Optimization with anyLogistix. Berlin School of Economics and Law. Recuperado de https://blog.hwr-berlin.de/ivanov/wp-content/uploads/2020./09/Update_ALX-Book-2020.pdf, 2021.

Ivanov and D. Supply Chain Viability and the COVID-19 Pandemic: A. Conceptual and Formal, G.eneralisation of Four Major Adaptation Strategies. International Journal of Production Research, 2021.

Jafar Namdar, Xueping Li and Rupy, S.awhney & Ninad Pradhan. Supply chain resilience for single and multiple sourcing in the presence of disruption risks, International Journal of Production Research, DOI: 10.1080./0020.7543.2017.1370.149, 2017.

Jamali, M., Rasti, M. and Atltmann, J. A. game-theoretic approach for investigating the competition between energy producers under the energy resilience index: A. case study of Iran. Sustainable Cities and Society 95 (2023.) 1045.98, 2023.

Jao-Hong Cheng and Kuo-Liang Lu. Enhancing effects of supply chain resilience: insights from trajectory and resourcebased perspectives", Supply Chain Management: An International Journal, Vol. 22 Issue: 4, pp.329-340, DOI: 10.1108./SCM-06-2016.-0190, 2017.

Jiang, Ch., Wan, Y. and Zhang, A. Internalization of port congestion: strategic effect behind shipping line delays and implications for terminal charges and investment. Taylor & Francis in Maritime Policy & Management. available at: http://www.tandfonline.com/10.1080./0308.8839.2016.1237.783. 2016.

Joshi, S. and Sharma, M. Sustainable Performance through Digital Supply Chains in Industry 4.0 Era: Amidst the Pandemic Experience. Sustainability, 14, 1672.6. DOI: 10.3390./su1424.1672.6, 2022.

Kazemian, I., Torabi, S., Zobel, Ch., Li, Y. and Baghersad, M. A. multi-attribute supply chain network resilience assessment framework based on SNA-inspired indicators. Operational Research DOI: 10.1007./s1235.1-021-0064.4-3, 2021.

Khan, S., Piprani, A. and Yu, Z. Supply chain analytics and postpandemic performance: mediating role of triple-A. supply chain strategies. International Journal of Emerging Markets. Emerald Publishing Limited 1746.-8809. DOI: 10.1108./IJOEM-11-2021.-1744, 2022.

Kim and W. C., & Mauborgne, R. Blue Ocean Strategy: How to Create Uncontested Market Space and Make the Competition Irrelevant. Harvard Business Review Press. 2005.

L. Geng, R. Xiao, Outer synchronization and parameter identification approach to the resilient recovery of supply network with uncertainty, Physica, A., http://dx.DOI: 10.1016./j.physa.2017.04.025, 2017.

Liang, D., Bhamara, R., Liu, Z. and Pan, Y. Risk Propagation and Supply, C.hain Health Control Based on the SIR Epidemic Model. Mathematics, 10, 3008. DOI: 10.3390./math1016.3008, 2022.

Lohmer, J., Bugert, N. and Lasch, R. Analysis of resilience strategies and ripple effect in blockchain-coordinated supply chains: An agent-based simulation study. Int. J. Production Economics 228 (2020.) 1078.82, 2020.

Luo, Y. and Zhu, J. Resilience Strategy Optimization for Large Aircraft Supply Chain Based on Probabilistic Language QFD. International Journal of Information Systems and Supply, C.hain Management Volume 13 • Issue 4 • October-December 2020, 2020.

Maslak, K., Franz, B. and Leicht, R. Framework for assessing resilience in the communication networks of AEC Teams. 15th Engineering Project Organization Conference with 5th International Megaprojects. Workshop Stanford Sierra Camp, California, 2017.

Massari, G. and Giannoccaro, I. Investigating the effect of horizontal coopetition on supply chain resilience in complex and turbulent environments. Int. J. Production Economics 237 (2021.) 1081.50, 2021.

Mikhail, M., Beheiry, M. and Afia, N. Incorporating resilience determinants in supply chain network design model. Journal of Modelling in Management Vol. 14 No. 3, 2019. pp. 738-753. Emerald Publishing Limited 1746.-5664. DOI: 10.1108./JM2-05-2018.-0057, 2019.

Misbauddin, S. M., Alam, M. J., Karmaker, C. L., Nabi, M. N.U., Hasan and M. M. Exploring the Antecedents of Supply Chain Viability in a Pandemic Context: An Empirical Study on the Commercial Flower Supply Chain of an Emerging Economy. Sustainability, 15, 2146. DOI: 10.3390./su1503.2146, 2023.

Mohammed, T., Mustapha, K., Godsell, J., Adamu, Z., Babatunde, K., Akintade, D., Acquaye, A., Fujii, H., Ndiaye, M., Yamoah, F. and Koh, S. A. critical analysis of the impacts of COVID-19 on the global economy and ecosystems and opportunities for circular economy strategies. Resources, Conservation & Recycling 164 (2021.) 1051.69, 2021.

Mohammed and A. Al-Hakimi, Dileep, B. Borade, Moad Hamod Saleh & Mohsen, A. A. Nasr . The moderating role of supplier relationship on the effect of postponement on supply chain resilience under different levels of environmental uncertainty, Production & Manufacturing Research, 10:1, 383-409, DOI: 10.1080./2169.3277.2022.2089.264, 2022.

Moreno-Baca, F.; Veloz, T.; Cano-Olivos, P.; Sanchez-Partida, D.; Martínez-Flores, J.L. Forecasting Supply Chain Resilience: A Multi-Effect Analytical Approach with Hybrid Optimization. Journal IISE Transactions. Under Review. 2025.

Mubarik, M., Bonrtis, N., Mubarik, Mo., Mahmood and T. Intellectual capital and supply chain resilience. Journal of Intellectual Capital. Emerald Publishing Limited 1469.-1930. DOI: 10.1108./JIC-06-2020.-0206, 2021. Naimi, M., Faisal, M., Sobh, R., Uddin, S. Antecedents and consequences of supply chain resilience and reconfiguration: an empirical study in an emerging economy. Journal of Enterprise Information Management. Emerald Publishing Limited 1741.-0398. DOI: 10.1108./JEIM-04-2020.-0166, 2020.

Nikian, A., Zare, H., Lofti, M. and Nezhad, M. Redesign of a sustainable and resilient closed-loop supply chain network under uncertainty and disruption caused by sanctions and COVID-19. Operations Management Research DOI: 10.1007./s1206.3-022-0033.0-3, 2022.

Ning, Y., Li, L., Xu, S. and Yang, S.h. How do digital technologies improve supply chain resilience in the COVID-19 pandemic? Evidence from Chinese manufacturing firms. Front. Eng. Manag. 2023, 10(1): 39–50 DOI: 10.1007./s4252.4-022-0230.-4, 2023.

Nowak and M. A. Five Rules for the Evolution of Cooperation. Science 314, 1560. (2006.). AAAS. DOI: 10.1126./science.1133.755. 2006.

Ozdemir, D., Sharma, M., Dhir, A. and Daim, T. Supply chain resilience during the COVID-19 pandemic. Technology in Society 68 (2022.) 1018.47, 2022.

Paul, S., Chowdhury, P., Chakrabortty, R., Ivanov, D. and Sallam, K. A. mathematical model for managing the multi-dimensional impacts of the COVID-19 pandemic in supply chain of a high-demand item. Annals of Operations Research DOI: 10.1007./s1047.9-022-0465.0-2, 2022.

Prataviera, L. B., Creazza, A., Melacini, M. and Dallari, F. Heading for Tomorrow: Resilience Strategies for Post-COVID-19 Grocery Supply Chains. Sustainability. 2022, 14, 1942. DOI: 10.3390./su1404.1942, 2022.

Prataviera, L. B., Creazza, A., Melacini, M. and Dallari, F. Heading for Tomorrow: Resilience Strategies for Post-COVID-19 Grocery Supply Chains. Sustainability, 14, 1942. DOI: 10.3390./su1404.1942, 2022.

Qazi, A. and Quigley, J. and Dickson, A. Supply chain risk management: systematic literatura review and a conceptual framework for capturing interdependencies between risks. 5th International Conference on Industrial Engineering and Operations, M.anagement, 2015.

Qi, F., Zhang, L., Zhuo, K. and Ma, X. EarlyWarning for Manufacturing Supply Chain Resilience Based on Improved Grey Prediction Model. Sustainability, 14, 1312.5. DOI: 10.3390./su1420.1312.5, 2022.

Rahman, Agarwal, N., Seth, N. and Agarwal, A. Evaluation of supply chain resilience index: a graph theory based approach. Benchmarking: An International Journal. Emerald Publishing Limited 1463.-5771. DOI: 10.1108./BIJ-09-2020.-0507, 2021.

Rajesh and R. A. grey-layered ANP based decision support model for analyzing strategies of resilience in electronic supply chains. Engineering Applications of Artificial Intelligence 87 (2020.) 1033.38, 2020.

Rajesh and R. A. novel advanced grey incidence analysis for investigating the level of resilience in supply chains. Annals of Operations Research DOI: 10.1007./s1047.9-020-0364.1-5, 2020.

Rehman, O. and Ali, Y. Enhancing healthcare supply chain resilience: decision-making in a fuzzy environment. The International Journal of Logistics Management. Emerald Publishing Limited 0957.-4093. DOI: 10.1108./IJLM-01-2021.-0004, 2021.

Saberifard, N. and Zinati, B. Evaluation and Ranking the Resilient Suppliers with the Combination of Decision Making Techniques. Management and Production, E.ngineering Review Volume 12 _ Number 3 _ September 2021. _ pp. 129–140 DOI: 10.2442.5/mper.2021.1376.85, 2021.

Shi, J., Che, J., Xu, L., Di, Z. and Qu, Q. Improving the resilience of maritime supply chains: the integrations of ports and inland transporters in duopoly markets. Front. Eng. Manag. DOI: 10.1007./s4252.4-022-0231.-3, 2022.

Singh, N. and Singh, S.h. Building supply chain risk resilience Role of big data analytics in supply chain disruption mitigation. Benchmarking: An International Journal Vol. 26 No. 7, 2019. pp. 2318.-2342. Emerald Publishing Limited 1463.-5771. DOI: 10.1108./BIJ-10-2018.-0346, 2019.

Suryadi, A. and Rau, H. Considering region risks and mitigation strategies in the supplier selection process for improving supply chain resilience. Computers & Industrial Engineering 181 (2023.) 1092.88, Technology Management Vol. 34 No. 3, 2023. pp. 361-382. Emerald Publishing Limited 1741.-038X DOI: 10.1108./JMTM-08-2022.-0307, 2023.

Tukamuhabwa Rwakira, B. and Stevenson, M. and Busby, J. S. Supply chain resilience in a developing country context: A. case study on the interconnectedness of threats, strategies and outcomes. Supply Chain Management: An International Journal, 2017.

Um, J. and Han, N. Understanding the relationships between global supply chain risk and supply chain resilience: the role of mitigating strategies. Supply Chain Management: An International Journal 26/2 (2021.) 240–255, Emerald Publishing Limited [ISSN 1359.-8546.][DOI: 10.1108./SCM-06-2020.-0248.], 2020.

Vann Yaroson, E., Breen, L. and Hou, J. and Sowter, J. Examining the impact of resilience strategies in mitigating medicine shortages in the United Kingdom's (UK) pharmaceutical supply chain (PSC)", Benchmarking: An International Journal, Vol. ahead-of-print No. ahead-of-print. DOI: 10.1108./BIJ-07-2022.-0460, 2023.

Vipul Jain, Sameer Kumar and Umang, S.oni & Charu Chandra. Supply chain resilience: model development and empirical analysis, International Journal of Production Research, DOI: 10.1080./0020.7543.2017.1349.947, 2017.

Wang, M. and Pan, X. Drivers of Artificial Intelligence and Their, E.ffects on Supply Chain Resilience and Performance: An Empirical Analysis on an Emerging Market. Sustainability, 14, 1683.6. DOI: 10.3390./su1424.1683.6, 2022.

Wang, X., Herty, M. and Zhao, L. Contingent rerouting for enhancing supply chain resilience from supplier behavior perspective. Intl. Trans. in Op. Res. 23 (2016.) 775–796 DOI: 10.1111./itor.1215.1, 2016.

Wen Jun Tan, Wentong Cai & Allan and N. Zhang. Structural-aware simulation analysis of supply chain resilience, International Journal of Production Research, DOI: 10.1080./0020.7543.2019.1705.421, 2019.

Wheatley and M. J. Liderazgo y la nueva ciencia: Descubriendo el poder de la claridad. Berrett-Koehler Publishers, 1999.

Yadav, S., Luthra, S., Kumar, A., Agrawal, R. and Frederico, G. Exploring the relationship between digitalization, resilient agri-food supply chain management practices and firm performance. Journal of Enterprise Information Management. Emerald Publishing Limited 1741.-0398. DOI: 10.1108./JEIM-03-2022.-0095, 2023.

Yang, J., Liu, Y. and Kholaif, M. The impact of relationship management on manufacturer resilience in emergencies. Emerald Publishing Limited 0368.-492X DOI: 10.1108./K.-08-2022.-1198, 2022.

Yu, W., Chavez, R. and Jacobs. Openness to Technological Innovation, Supply Chain Resilience and Operational, P.erformance: Exploring the Role of Information Processing Capabilities. IEEE Transactions on Engineering Management. pp. 1-13. ISSN 0018.-9391, 2022.

Yu, W., Wong, CY, Chavez and R. How intellectual capital builds supply chain resilience? Exploring mediation and interaction effects from an intellectual capital based view. Supply Chain Management. ISSN 1359.-8546, 2023.

Yu, W., Jacobs, M., Chavez, R. and Yang, J. Dynamism, disruption orientation and resilience in the supply chain and the impacts on financial performance: A. dynamic capabilities perspective. International Journal of Production Economics 218 (2019.) 352–362, 2019.

Zhu, X. and Wu, Y. J. How Does Supply Chain Resilience Affect Supply Chain Performance? The Mediating Effect of Sustainability. Sustainability, 14, 1462.6. DOI: 10.3390./su1421.1462.6, 2022.

Biographies

Fabricio Moreno-Baca is currently running for PhD in Logistics & Supply Chain Management at the Popular Autonomous University of the State of Puebla (UPAEP), in Mexico. He earned PhD in Economics at the Autonomous University of Baja California (UABC); Master in Economics at Autonomous University of Coahuila (UAC); B.S. in

Logistics & Transport Engineering at Open and Distance National University of Mexico (UNADM) and B.S. in Enterprises Management at Technology of Monterrey (Tec de Monterrey).

Patricia Cano-Olivos is Industrial Engineer, Master of Science in Industrial Engineering and PhD in Logistics and Supply Chain Management from the Popular Autonomous University of the State of Puebla. She has been a professor of the degree in Industrial Engineering at the Technological Institute of Apizaco (2002-2003), as well as professor-researcher of the degree in Industrial Engineering and Master of Engineering at the Polytechnic University of Tlaxcala (2006-2015). From 2015 to date, he is a professor-researcher of the Postgraduate in Logistics and Supply Chain Management of the UPAEP. Additionally, Dr. Patricia obtained the Outstanding Research Award by The Institute for Business and Finance Research in January 2013 in Las Vegas, Nevada, USA.

Diana Sánchez-Partida has a PhD in Logistics and Supply Chain Management. Currently, she is a Professor-Researcher of the Postgraduate in Logistics and Supply Chain Management of the Popular Autonomous University of the State of Puebla (UPAEP) and is leader of the Humanitarian Logistics Group at the same institution. She has been awarded a scholarship in Doctorate and Postdoctoral studies by CONACyT. Her areas of interest are: Disaster Risk Reduction, Humanitarian Logistics, Resilience in economic activities, among others. He has participated in applied projects such as Schedule Scheduling for Schools, Inventory Levels and Control, Planning and Production Control. He is a Member of the National System of Researchers in the category (Level 1) from January 2018 to December 2021.

José-Luis Martínez-Flores has a Degree in Mathematics, Master's in administration sciences and PhD in Engineering from the Autonomous University of Nuevo León (UANL). He was Vice President of the Mexican Association of Logistics and Supply Chain in the period 2012-2015 and obtained the National Logistics Award 2013. He has directed research and consulting projects in different companies such as Nestlé and ECOPETROL. He has been a speaker at different international events and has published articles in different journals such as: International Journal of Production Research, Production Planning and Control, Transactions of the Society for Modeling and Simulation International, Mathematical Problems in Engineering. He currently directs logistics projects for The Dow Chemical Company. He is also a Level I National Researcher and member of international academic associations such as: Mexican Association of Logistics and Supply Chain, American Mathematical Society, Society for Industrial & Applied Mathematics, Mexican Society of Operations Research.

Algorithm 1 *Proposed Pseudocode Model for Strategic Supply Chain Analysis*

1. Notations:

i=1, 2, …, I (Set of nodes)

j= 1, 2, …, J (Set of identifications of nodes neighboring the study node).

2. Parameters:

   T = Number of simulation periods

   PR = Percentage of production reduction during disruptive period

3. Random variables (uniform distribution):

   Pv: Unit price of sale per ton sent to port

   Inf: Random inflation rate in each period t

   $Cp_{(i)}$: Port capacity and full ship service.

   $Ds_{(i,j)}$: Random distances between nodes i and j.

   $Cu_{(i)}$: Random unit costs of production per ton of cargo, carried out by the links in the supply chain.

4. Random variables (normal distribution):

   $CTonnage_{(i)}$: The port's customer portfolio (i) already established and based on its cabotage and location, represented in Tons.

   $Tonnage_{(i)}$: New tonnage to be shipped to the node (i).

5. Non-random variables:

   $EB_{(i,t)}$: Excess Vessels of a Node

6. Initialize graph:

   $G(N, E)$: $N_{(i)}$, E (Arch Set, undirected graph)

   $MCts_{(i,t)}$: Cost matrix initialized with zeros

7. Initialize Storage List for Overcapacity Vessel Transfers.

8. Simulation:

For every f (Sun Tzu, Musachi, Crhistensen, Wheatly, Kim & Mougborne) (See equations 3-11):

For every t:

For every $N_{(i)}$:

Calculate resilience effect during disruptive period:

- FR: 1.0 (Resilience factor)
- If Dti (Beginning of the disruptive period) <= t <= Dtf (End of the disruptive period), then $FR_{(t)}= FR_{(t-1)}*(1-(t-20)/10)$

Calculate Sales Before Production:

- $Vts_{(i,t)}$ = max($Ctonnage_{(i,t-1)}$, $Tonnage_{(I,t-1)}$)

Calculate tonnage considering costs and negative disruptive effect:

- If $Tonelaje_{(i,t-1)}$<=0.1*$Cp_{(i)}$, then $Tonelaje_{(i,t)}$= Normal random distribution ($Tonnage_{(I)}$, Standard deviation)
  - Else $Tonnage_{(i,t)}$<=max(0.1*$Tonnage_{(i,t-1)}$, Normal random distribution ($Ctonnage_{(I)}$, Standard deviation)

Apply inflation effect on sales:

- $Vts_{(i,t)}= Vts_{(i,t-1)}*(1-Inf_{(t)})$

Calculate vessels considering costs

- $CTonnage_{(i-t)}=CTonnage_{(i,t-1)}+Tonnage_{(i,t)}-Vts_{(i,t)}$

Check if it exceeds vessel capacity per node:

If $CTonnage_{(i,t)} > Cp_{(i)}$, then:

- $EB_{(i,t)}=CTonnage_{(i,t)}-Cp_{(i)}$
- $CTonnage_{(i,t)}=Cp_{(i)}$
- Find the nearest port to transfer $(i \neq j)$
- Sum the excess of ships transferred to the nearest node.

Calculate Cargo Investment and Opportunity Cost

- $IC_{(i,t)}=Tonnage_{(i,t)}*Cu_{(i)}$
- $CO_{(i,t)}=Vts_{(i,t)}-IC_{(i,t)}$

Generate matrix of results of transfers made by node(i)