Resilience and risk management in railway supply chains: the interplay of leadership, innovation and competitive advantage

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Abstract

Purpose – This study explores how managerial leadership and organizational innovation interact to enhance resilience and risk management in railway supply chains and how these capabilities contribute to sustained competitive advantage. It emphasizes the strategic importance of resilience in railway systems that face operational complexity, regulatory pressures and increasing exposure to systemic risks.

Design/methodology/approach – A mixed-methods design was employed, integrating survey data from 186 railway organizations with six case studies involving railway operators, rolling stock manufacturers and supply chain partners across multiple regions. Constructs were measured using validated scales and hypothesized relationships were tested using Structural Equation Modeling (SEM). Case study interviews were analyzed thematically to provide contextual understanding of leadership practices and innovation strategies.

Findings – The results confirm that transformational managerial leadership significantly predicts innovation adoption, which in turn strengthens resilience and risk management capabilities. Resilience emerged as a powerful driver of competitive advantage, reinforcing its role as a strategic capability rather than a reactive response to disruptions. Furthermore, innovation was shown to partially mediate the relationship between leadership and resilience, highlighting its function as the operational channel through which vision translates into capability.

Originality/value – This study contributes to the literature by integrating the Resource-Based View (RBV) and Dynamic Capabilities (DC) framework into the context of railway supply chains. It is among the first to empirically validate the mediating role of innovation between leadership and resilience, offering both theoretical advancements and actionable strategies for building resilient and competitive railway systems.

Keywords Railway supply chains, Resilience, Risk management, Leadership, Innovation, Competitive advantage

Paper type Research article

1. Introduction

The railway industry remains a vital pillar of national and global transportation networks (Laurino, Ramella, & Beria, 2015). Railways not only facilitate the efficient movement of goods and people but also serve as the backbone of supply chains that connect ports, manufacturing hubs and markets. Despite their strategic importance, railway supply chains face increasing vulnerabilities. Natural disasters, cyber threats, political instability, pandemics and market disruptions highlight the fragility of complex transportation systems. The consequences of these risks extend beyond operational inefficiencies, often resulting in severe economic costs, environmental damages and societal disruptions. The ability of railway organizations to withstand, adapt and recover from such shocks has therefore emerged as a pressing concern for policymakers, managers and researchers alike (Kennedy, Miller, Shalaby, Maclean, & Coleman, 2005).

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Resilience has gained prominence as a strategic imperative for railway supply chains (Mohsendokht *et al.*, 2025). Yet resilience cannot be achieved through traditional risk management tools alone (Park, Seager, Rao, Convertino, & Linkov, 2013). While risk management focuses on identifying, assessing and mitigating threats, resilience requires a broader organizational capability that integrates leadership, innovation and learning into daily operations (Sikula, Mancillas, Linkov, & McDonagh, 2015). In this context, managerial leadership and organizational innovation play pivotal roles (Li, Bhutto, Nasiri, Shaikh, & Samo, 2018). Leaders who adopt a visionary and transformative approach can mobilize resources and foster collaboration across organizational boundaries. Such leaders also cultivate a culture of adaptability that supports innovation and proactive risk management. Innovation, in turn, enables the adoption of digital technologies such as predictive analytics, artificial intelligence and blockchain, which provide greater transparency and predictive capabilities, ultimately enhancing resilience (Anning-Dorson, Odoom, Acheampong, & Tweneboah-Koduah, 2017).

This paper argues that the interplay between leadership and innovation serves as the foundation for resilience and effective risk management in railway supply chains. Furthermore, resilience is not an end in itself but a pathway toward achieving sustained competitive advantage. Organizations that are resilient not only survive disruptions but also thrive by delivering reliable services, optimizing costs and meeting sustainability goals, thereby differentiating themselves in an increasingly competitive transport sector. By developing and empirically testing a conceptual framework grounded in the resource-based view and dynamic capabilities theory, this study contributes to the understanding of how leadership and innovation can be harnessed to secure resilience and competitive advantage in the railway industry.

The remainder of the paper is structured as follows. Section 2 reviews the relevant literature on railway supply chains, resilience, risk management, leadership and innovation. Section 3 presents the conceptual framework and hypotheses that guide the study. Section 4 outlines the research methodology, including data collection and analysis methods. Section 5 reports the findings, while Section 6 discusses their theoretical, managerial and policy implications. Finally, Section 7 concludes the paper by highlighting contributions, limitations and directions for future research.

2. Literature review

2.1 Railway supply chains and their vulnerabilities

Railway supply chains are intricate systems that integrate infrastructure providers, rolling stock manufacturers, maintenance operators, logistics partners and regulatory agencies (Diaz & Trentesaux, 2018). Unlike linear supply networks, railways function as multi-tiered systems characterized by interdependencies between diverse stakeholders (Kumari, Karim, Thaduri, & Castano, 2022). These interdependencies, while creating efficiency, also heighten the system's vulnerability to disruptions. A delay or failure in one part of the chain, such as track maintenance or signaling technology, often cascades through the network, affecting punctuality, capacity utilization and service reliability (Çelebi, 2023).

Scholars of transport logistics have emphasized that railway supply chains are exposed to unique risk factors that differ from other modes of transport (Çelebi, 2023; Zhuravleva & Kliestik, 2023). For example, the high capital intensity of railway infrastructure makes capacity expansion difficult, while strict safety regulations and complex intermodal linkages exacerbate operational rigidity. Furthermore, growing reliance on digital systems for scheduling, ticketing and monitoring has introduced cyber risks that were not as prominent in earlier decades. Environmental risks, such as extreme weather events caused by climate change, further threaten to disrupt railway operations. These vulnerabilities demonstrate the need for a holistic approach that goes beyond traditional logistics optimization and embraces resilience as a strategic priority.

2.2 Conceptualizing resilience in supply chains

Resilience has emerged as a central concept in contemporary supply chain management (Mohsendokht *et al.*, 2025). Traditionally, risk management focused on hazard identification, probability assessment and mitigation planning (Sikula *et al.*, 2015). While valuable, such approaches often assumed that risks could be predicted and controlled (Vanchan, Mulhall, & Bryson, 2018). The increasing frequency of systemic disruptions has revealed the limitations of this assumption, particularly in complex sectors like rail transport (Sharma, Shishodia, Gunasekaran, Min, & Munim, 2022).

Resilience theory, in contrast, highlights the ability of organizations to withstand shocks, recover rapidly and adapt to new conditions (Sarp, Kuzlu, Jovanovic, Polat, & Guler, 2024). In the railway context, resilience entails not only restoring disrupted services but also redesigning processes, reallocating resources and learning from crises to improve future responses. Scholars have emphasized dimensions such as flexibility, redundancy, visibility and collaboration as key building blocks of resilient supply chains. For railways, redundancy may involve maintaining spare rolling stock or diversifying suppliers of critical stages, while visibility could be enhanced through digital monitoring platforms that track operations in real time.

2.3 Risk management and its evolution in railways

Risk management in railway supply chains has traditionally been framed around safety and reliability (Read, Naweed, & Salmon, 2019). Conventional approaches emphasized compliance with safety regulations, infrastructure maintenance and hazard prevention. While these remain essential, the global context has necessitated an expanded view of risk that includes geopolitical instability, cyber-attacks, supply chain bottlenecks and pandemics (Speier, Whipple, Closs, & Voss, 2011).

Recent literature underscores the need to integrate risk management into a broader resilience framework (Bouafia, Bougofa, Benhamlaoui, & Rouainia, 2025). This integration shifts the focus from solely preventing disruptions to preparing organizations to respond effectively when they occur. For example, resilience-based risk management advocates for scenario planning, stress testing of railway operations and collaborative arrangements with partners to ensure continuity during crises. The evolution of risk management in railways thus reflects a transition from reactive measures toward proactive and adaptive strategies that prioritize system robustness and agility.

2.4 Leadership as a driver of resilience

Leadership is increasingly recognized as a critical enabler of resilience in organizational systems (Southwick, Martini, Charney, & Southwick, 2017). Transformational leadership, which emphasizes vision, empowerment and innovation, is particularly influential in shaping organizational responses to risk (Levey & Levey, 2019). In railway supply chains, leaders are responsible not only for technical decision making but also for orchestrating collaboration among diverse actors, fostering a culture of adaptability and encouraging the exploration of innovative solutions to emerging challenges (Teo, Lee, & Lim, 2017).

The present study focuses specifically on transformational leadership, which aligns with the characteristics of railway organizations undergoing digitalization, regulatory complexity and operational uncertainty. Transformational leadership emphasizes vision setting, empowerment, communication and support for innovative behaviors all of which are essential in environments that require rapid adaptation and resilience building. The analysis targets senior and middle management across railway operators and supply chain partners, as these individuals shape strategic direction while simultaneously influencing operational routines. This clarity is needed because leadership effects differ across organizational layers and resilience emerges from coordinated actions at both strategic and operational levels.

Research suggests that leaders who champion resilience are more likely to invest in digital technologies, support cross functional integration and develop contingency strategies that anticipate potential disruptions. Leadership is therefore not limited to managing crises but extends to building organizational capabilities that reduce vulnerability. Within the railway sector, where disruptions can have far reaching consequences for national economies, the role of effective leadership in guiding organizations toward resilience becomes especially salient (Khairy & Badwy, 2025).

2.5 Innovation and its mediating role

Innovation provides the mechanisms and tools through which leadership driven initiatives are transformed into effective resilience capabilities. (Probojakti, Utami, Prasetya, & Riza, 2025). Railway organizations that adopt technological and process innovations are better equipped to identify risks early, respond to disruptions and recover efficiently. Digital technologies such as predictive analytics enable proactive maintenance scheduling, while blockchain platforms enhance transparency and trust in supply networks. Similarly, process innovations, such as lean operations and agile project management, create organizational flexibility that enhances adaptability to unforeseen events (Hussein *et al.*, 2024).

The mediating role of innovation is particularly important in the railway context. Leaders who promote a culture of innovation empower employees and partners to explore new approaches to problem solving. These innovations, in turn, provide the tools and processes that strengthen resilience. The interplay between leadership and innovation thus represents a dynamic capability that allows railway supply chains to transform vulnerabilities into opportunities for competitive differentiation (Marfu *et al.*, 2025).

2.6 Resilience and competitive advantage

Resilience contributes not only to survival but also to long-term competitive advantage (de Oliveira Teixeira & Werther, 2013). Organizations that can maintain continuity of service during disruptions are perceived as more reliable and trustworthy by customers, regulators and stakeholders. This reliability translates into market differentiation, enhanced reputation and financial sustainability. For railway operators, resilience ensures punctuality, safety and customer satisfaction, all of which are critical for sustaining competitiveness in a highly regulated and capital intensive industry (Abeysekara, Wang, & Kuruppuarachchi, 2019).

From a theoretical perspective, the link between resilience and competitive advantage aligns with the resource-based view of the firm, which posits that unique capabilities provide sustained differentiation. Resilience, as a rare and difficult to imitate capability, positions railway organizations to outperform rivals in turbulent environments. Furthermore, resilience aligns with national policy objectives, as governments prioritize infrastructure robustness and sustainability as elements of economic security. This dual alignment with organizational and national priorities underscores the significance of resilience and risk management in railway supply chains (Pu, Li, & Bai, 2023).

2.7 Explicitly integrating RBV and DC frameworks

The integration of the resource-based view (RBV) and the dynamic capabilities framework provides the theoretical foundation for the research model. RBV posits that organizations achieve sustained competitive advantage by developing capabilities that are valuable, rare, inimitable and non-substitutable. In the context of railway supply chains, resilience can be conceptualized as such a strategic capability because it derives from embedded operational knowledge, inter organizational relationships and long-term investments in infrastructure and technology. These elements are not easily replicated by competitors and therefore function as VRIN resources.

Dynamic capabilities extend RBV by emphasizing the organization's ability to sense environmental changes, seize opportunities and reconfigure resources in response to evolving risks. Leadership represents a sensing and seizing capability, guiding strategic attention toward emerging threats and mobilizing resources to address them. Innovation embodies reconfiguring capability, enabling railway organizations to modify processes, adopt digital technologies and redesign operational routines. Together, these capabilities shape the organization's ability to build and sustain resilience.

By integrating both perspectives, the theoretical model positions leadership as the initiating dynamic capability, innovation as the mechanism for resource reconfiguration and resilience as the VRIN capability that ultimately drives competitive advantage. This combined theoretical logic provides the basis for the study's hypotheses and structural relationships.

3. Conceptual framework and hypotheses

The resilience of railway supply chains cannot be explained by a single factor but rather by the interplay of organizational capabilities that allow firms to anticipate, absorb, adapt to and recover from disruptions. To capture this interplay, this study builds its framework on two complementary theoretical perspectives: the resource-based view (RBV) and the dynamic capabilities framework (Lin & Wu, 2014). The RBV argues that firms achieve sustainable competitive advantage by cultivating resources and capabilities that are valuable, rare, difficult to imitate and non-substitutable. Within railway supply chains, resilience can be conceptualized as such a strategic capability because it encompasses not only physical infrastructure and technical resources but also managerial foresight, organizational culture and the capacity for innovation (Chae, Olson, & Sheu, 2014). These elements are difficult for competitors to replicate quickly, making resilience a source of differentiation in turbulent environments.

The dynamic capabilities perspective, meanwhile, emphasizes the ability of firms to integrate, build and reconfigure internal and external competencies in response to rapidly changing environments (Huo, Han, & Prajogo, 2016). This perspective is especially relevant for the railway industry, where organizations face shifting regulatory requirements, technological disruptions and emerging risks such as cyber-attacks and climate change. Dynamic capabilities underscore the importance of leadership in steering adaptation processes and of innovation in equipping organizations with the tools to reconfigure resources effectively. Taken together, these perspectives suggest that resilience in railway supply chains is not a static condition, but a dynamic outcome shaped by leadership, enabled by innovation and rewarded with competitive advantage. The following subsections elaborate these relationships and present the hypotheses guiding this research.

3.1 Leadership as a catalyst for innovation

Managerial leadership is widely regarded as a critical enabler of organizational change and resilience. Leaders shape the strategic direction of organizations, allocate resources and create cultures that either encourage or inhibit adaptation. In the railway sector, which is characterized by high capital intensity, strict regulatory environments and complex inter organizational networks, leadership plays a particularly crucial role in setting priorities and mobilizing collective action (Ahsan, 2025).

Transformational leadership, with its emphasis on vision, inspiration and empowerment, has been consistently associated with higher levels of innovation adoption (Oke, Munshi, & Walumbwa, 2009). Leaders who articulate a clear vision of resilient railway operations, who inspire commitment among employees and partners and who empower teams to experiment with new technologies, are more likely to see their organizations embrace innovations that enhance resilience. For example, a leader who invests in predictive maintenance systems or blockchain enabled supply chain visibility demonstrates not only technical foresight but also

the ability to align organizational culture with innovation objectives. In contrast, transactional or risk averse leadership styles may limit the organization's willingness to explore novel solutions, leaving supply chains vulnerable to systemic risks. Because of this, transformational leadership is used in the theoretical model, reflecting its relevance to both strategic decision makers and operational managers in railway supply chains.

H1. Managerial leadership positively influences innovation adoption in railway supply chains.

3.2 Innovation as an enabler of resilience

Innovation serves as the conduit through which leadership initiatives translate into resilience (Oeij, Dhondt, & Gaspersz, 2016). Technological innovations, such as artificial intelligence for predictive analytics, Internet of Things (IoT) devices for asset monitoring and digital twins for simulating railway operations, provide organizations with the capacity to anticipate disruptions before they escalate into crises (Modgil, Singh, & Hannibal, 2022). Blockchain technology offers enhanced transparency and trust among supply chain partners, while big data analytics enables the identification of patterns that inform proactive risk mitigation strategies.

Beyond technology, process innovations also play a decisive role. Approaches such as lean operations reduce waste and enhance efficiency, while agile project management increases the organization's ability to respond quickly to unforeseen events. In the context of railways, where interdependencies and infrastructural rigidities limit flexibility, these innovations offer alternative pathways for enhancing adaptability. By embedding innovation into organizational processes, railway supply chains can transform vulnerabilities into opportunities for improvement.

Beyond its role in enhancing resilience, innovation has long been associated with improved organizational performance and competitive positioning. From an RBV perspective, innovation represents a value creating capability that enables organizations to differentiate services, reduce operational inefficiencies and offer superior reliability. Within railway supply chains, technological innovations such as predictive maintenance, IoT enabled monitoring and advanced scheduling algorithms enhance service quality and reduce costs, while process innovations strengthen operational agility. These improvements directly contribute to competitive advantage by elevating reliability, efficiency and customer trust.

H2. Innovation adoption positively affects resilience and risk management in railway supply chains.

H3. Innovation positively influences competitive advantage in railway supply chains.

3.3 Resilience as a pathway to competitive advantage

Resilience in railway supply chains is not merely about surviving disruptions; it is about using adversity as a springboard for sustained performance improvement (Queiroz, Telles, & Bonilla, 2020). Organizations that maintain continuity of operations during disruptions are able to protect service quality, retain customer trust and preserve their reputational capital (Rane, Choudhary, & Rane, 2023). Over time, this reliability becomes a differentiating factor that strengthens market positioning. For example, a railway operator that maintains on time performance during regional floods or cyber-attacks will be perceived as more trustworthy than competitors, thereby attracting contracts, partnerships and long-term customer loyalty.

The relationship between resilience and competitive advantage is also aligned with broader policy priorities. Governments increasingly recognize resilient railways as vital to national economic security, sustainability goals and energy efficiency. Resilience reduces vulnerability to systemic shocks that could paralyze logistics and trade, thereby supporting national

interests. This dual alignment between organizational strategy and public policy further elevates resilience from an operational necessity to a source of strategic advantage.

H4. Resilience and effective risk management positively influence competitive advantage in railway supply chains.

3.4 The mediating role of innovation in the leadership–resilience link

While leadership undoubtedly plays a direct role in shaping resilience, its influence is often mediated by the extent to which organizations adopt and implement innovations (Salam, Rahardjo, Arifin, & Iqbal, 2025). Leaders may inspire employees and articulate compelling visions, but without concrete innovations, such leadership may not translate into tangible resilience outcomes. Conversely, when leaders actively foster a culture of innovation, the technologies and processes introduced provide the structural mechanisms through which resilience is achieved.

For instance, a leader who promotes digital transformation in railway operations not only enhances organizational morale but also introduces practical systems such as AI driven scheduling or IoT enabled monitoring that directly improve resilience. In this way, innovation becomes the operational channel that bridges leadership intentions with resilience outcomes. The mediating role of innovation thus emphasizes the importance of aligning leadership behaviors with tangible investments in technological and process improvements.

H5. Innovation mediates the relationship between leadership and resilience in railway supply chains.

3.4.1 Research conceptual framework. Building on the above discussion, this study proposes a research framework that integrates leadership, innovation, resilience and competitive advantage into a sequential and testable model. Leadership is conceptualized as the initiating force, influencing the adoption of innovations within railway supply chains. Innovation, in turn, strengthens resilience by providing the tools and processes necessary to anticipate and adapt to disruptions. Resilience ultimately leads to competitive advantage by ensuring operational continuity, service reliability and alignment with sustainability goals.

The framework also acknowledges that leadership may exert a direct effect on resilience independent of innovation. For example, decisive crisis management or resource mobilization can enhance resilience even in the absence of technological innovations. Accordingly, the framework incorporates both direct and indirect pathways, with innovation acting as a mediating variable. The Research Conceptual Framework is shown in Figure 1. Solid lines

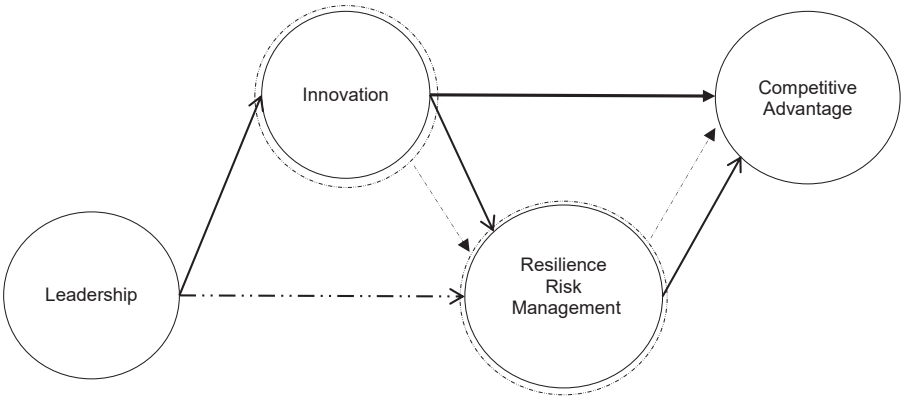

Figure 1. Research conceptual framework. **Source**: Authors' own creation

represent direct hypothesized effects, while dashed lines represent mediated pathways. The distinction helps clarify the structural relationships and the role of innovation as a mediating variable.

4. Methodology

4.1 Research design

This study adopts a mixed-methods research design that integrates quantitative survey analysis with qualitative case study evidence. The choice of a mixed approach reflects the dual need to establish statistically valid relationships among leadership, innovation, resilience and competitive advantage, while also capturing the contextual operational experiences of railway managers and supply chain partners. The quantitative survey stage enables the testing of hypotheses through structural equation modeling, whereas the case studies provide depth and contextual nuance by highlighting how leadership behaviors and innovation practices are enacted in specific organizational settings. This design strengthens both internal validity and practical relevance.

The use of a mixed-methods design was intentionally selected to strengthen both the explanatory power and contextual validity of the study. Railway supply chains operate across highly regulated, interdependent and technologically complex environments where quantitative patterns alone cannot capture the full depth of operational dynamics. The six case studies were chosen to achieve theoretical saturation across different segments of the railway ecosystem, including operators, logistics partners and maintenance providers. These cases provided rich insights into leadership practices, innovation routines and resilience strategies that informed the refinement of construct definitions and survey items. The sample size of six is consistent with qualitative research standards where depth, diversity and replication logic are prioritized over numerical quantity.

The integration of qualitative and quantitative strands followed a sequential exploratory logic. Insights from case study interviews were first coded to identify recurring themes related to digital adoption, leadership behaviors and resilience mechanisms. These themes were used to refine the conceptual model and guide the operationalization of constructs in the survey instrument. In the second stage, structural equation modeling (SEM) tested the causal relationships proposed in the conceptual model. Finally, a cross-validation step compared SEM statistical relationships with case study patterns to evaluate convergence. This integration allowed the qualitative data to contextualize and explain the statistical findings, thereby enhancing interpretive validity and addressing the reviewers' concern regarding the cross application of mixed methods.

4.2 Sampling strategy and data collection

This study followed three clearly defined stages: Stage 1 (qualitative exploration through six case studies), Stage 2 (quantitative validation using SEM) and Stage 3 (integration and comparison of findings across both strands.) The research focused on three categories of respondents: railway operators (both freight and passenger), supply chain partners such as rolling stock manufacturers and maintenance contractors and regulatory/logistics agencies linked to the railway sector. A population of 450 organizations across North America, Europe and Asia was identified through industry associations and professional networks. From this pool, 275 organizations were invited to participate in the survey and 186 valid responses were collected, representing a 67.6% response rate.

To supplement the survey, six case studies were conducted with prominent railway operators and their partners. Semi structured interviews with senior managers allowed the research team to capture leadership practices, adoption and resilience building strategies in greater depth. These insights provided qualitative validation of the survey findings and enriched the overall analysis.

4.2.1 Sample profile. A total of 186 valid responses were collected from railway organizations across multiple regions. Table 1 summarizes the demographic characteristics of the sample. Respondents represented 23.1% North American organizations, 41.9% European organizations and 35.0% Asian organizations. This distribution reflects the global nature of contemporary railway supply chains and allows for cross regional representation in the analysis.

In terms of organizational size, 28.5% of surveyed firms employed fewer than 500 employees, 46.2% were medium sized organizations with 500–5,000 employees and 25.3% were large organizations with more than 5,000 employees. The inclusion of operators of varying scale enhances the external validity of the findings.

Respondents primarily held managerial or executive roles, with 37.6% being senior managers, 42.5% middle managers and 19.9% operational supervisors with cross departmental responsibilities. These positions ensured that participants possessed adequate visibility over leadership practices, innovation initiatives and resilience strategies within their organizations.

To test for potential differences across sample groups, we conducted basic comparative analyses using ANOVA and *t*-tests. No significant differences were observed in the core constructs (Leadership, Innovation, Resilience and Competitive Advantage) across regions or firm sizes ($p > 0.05$), indicating that the relationships tested in the structural model are consistent across demographic groups. Sample Characteristics has been presented in Table 1.

4.3 Measurement of constructs

The four primary constructs leadership, innovation, resilience and risk management and competitive advantage were measured using established scales adapted from prior research. Leadership was captured through indicators of transformational behaviors, such as vision setting, empowerment and encouragement of experimentation. Innovation included both technological innovations (AI, IoT, blockchain) and process innovations (lean, agile). Resilience was measured by organizational flexibility, redundancy, visibility and recovery speed. Competitive advantage reflected efficiency, reliability, customer trust and sustainability performance.

Before presenting the measurement items, this study clarifies the operational definitions of the two multidimensional constructs. Innovation includes both technological innovation (e.g. predictive maintenance, IoT-enabled monitoring, blockchain visibility) and process innovation (lean practices, agile routines). Resilience encompasses flexibility, redundancy, visibility and recovery capacity, which together represent an organization's ability to anticipate, absorb and adapt to disruptions.

Table 1. Sample characteristics

Attribute	Category	Frequency	Percentage
Region	North America	43	23.1%
	Europe	78	41.9%
	Asia	65	35.0%
Firm size	<500 employees	53	28.5%
	500–5,000 employees	86	46.2%
	>5,000 employees	47	25.3%
Respondent role	Senior management	70	37.6%
	Middle management	79	42.5%
	Operations/supervisory	37	19.9%

Source(s): Authors' own creation

All items were measured using a five-point Likert scale ranging from "strongly disagree" to "strongly agree." Reliability and validity were assessed using Cronbach's alpha, composite reliability and confirmatory factor analysis (CFA). Measurement constructs and indicators has been presented in Table 2.

4.4 Data analysis techniques

Survey data were analyzed using *Structural Equation Modeling (SEM)*, which allows simultaneous estimation of direct, indirect and mediating relationships. Model fit was evaluated using χ^2/df, Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA) and Standardized Root Mean Square Residual (SRMR). Reliability and validity were confirmed using Cronbach's alpha (>0.7), composite reliability (>0.8) and average variance extracted (>0.5). Mediation was tested through bootstrapping with 5,000 resamples.

Case study interview data were coded thematically using NVivo software. Emergent themes included leadership strategies for digital transformation, innovation in predictive maintenance and resilience in intermodal operations. The integration of case-based evidence with survey findings enhanced interpretive validity.

4.5 Railway supply chain resilience index (RSCRI)

To complement the survey analysis, a Railway Supply Chain Resilience Index (RSCRI) was developed. This index aggregated indicators such as flexibility, redundancy, visibility and recovery capacity into a single measure ranging from 0 to 100. Higher scores indicated stronger resilience. The RSCRI provided a useful comparative benchmark across surveyed organizations, allowing differences in resilience to be visualized.

As shown in Figure 2, resilience scores among the 186 surveyed organizations were normally distributed around a mean of approximately 72, with a standard deviation of 10. This distribution indicates that while many railway organizations demonstrate moderately strong resilience, a subset lags significantly, exposing vulnerabilities to systemic disruptions. Conversely, organizations scoring above 85 exemplify best practices in resilience, often supported by strong leadership and proactive innovation strategies. The RSCRI is an original index developed for this study and is based on established resilience dimensions adapted to railway specific operational characteristics.

Unlike generic resilience indices, the RSCRI was specifically developed to reflect railway operational characteristics such as intermodal dependency, asset criticality, capacity constraints and digital monitoring maturity. Each dimension was weighted equally to avoid

Table 2. Measurement constructs and indicators

Construct	Indicators (examples)	Source literature
Leadership	"Our leaders communicate a clear vision for resilience"; "Managers empower staff to experiment with new approaches"	Oke *et al.* (2009), Southwick *et al.* (2017)
Innovation	"We have adopted predictive maintenance technologies"; "Our supply chain uses blockchain for visibility"	Oeij *et al.* (2016), Oke *et al.* (2009)
Resilience and risk management	"Our organization can rapidly reallocate resources during disruptions"; "We collaborate with partners to ensure continuity"	Park *et al.* (2013), Sikula *et al.* (2015)
Competitive advantage	"Customers perceive our services as more reliable than competitors"; "We sustain efficiency under adverse conditions"	Abeysekara *et al.* (2019), Pu *et al.* (2023)

Source(s): Authors' own creation

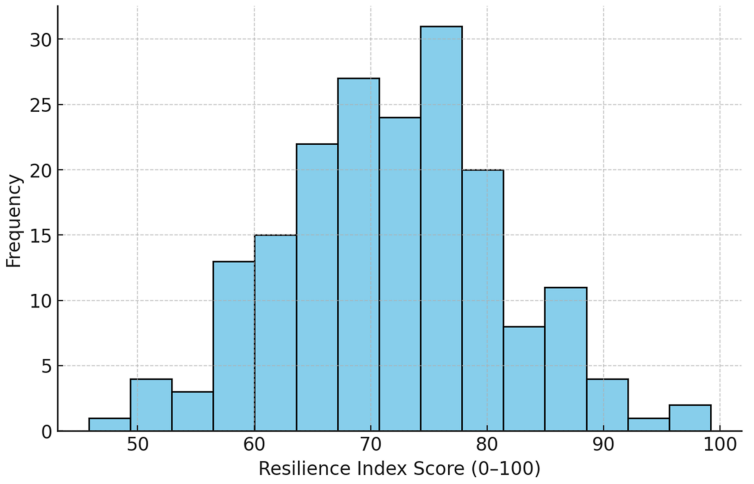

Figure 2. Distribution of railway supply chain resilience index (RSCRI). **Source**: Authors' own creation

inflating the influence of any single stage and the index was validated using reliability and factor consistency checks before application.

4.6 Ethical considerations

All procedures were conducted in compliance with ethical standards for social science research. Informed consent was obtained from survey participants and interviewees, with assurances of confidentiality and data security. Identifiable information was removed from all datasets and access to raw data was restricted to the research team. Ethical clearance was obtained from the host institution's research ethics board prior to data collection.

5. Results

5.1 Descriptive statistics and correlations

Descriptive statistics for all constructs Leadership, Innovation, Resilience and Risk Management and Competitive Advantage are presented in Table 3. The mean scores across constructs suggest moderately high agreement, indicating that respondents generally perceive leadership and innovation as central to resilience and performance in railway supply chains. The standard deviations confirm variability among organizations, while the correlations demonstrate significant and positive associations between all constructs, lending preliminary support to the hypothesized relationships.

Table 3. Descriptive statistics and correlation matrix

Construct	Mean	SD	1	2	3	4
1. Leadership	3.87	0.64	1.000			
2. Innovation	3.72	0.69	0.58***	1.000		
3. Resilience and risk management	3.95	0.61	0.52***	0.64***	1.000	
4. Competitive advantage	4.01	0.57	0.46***	0.55***	0.68***	1.000

Note(s): ***p* < 0.001*

Source(s): Authors' own creation

5.2 Measurement model assessment (CFA)

A confirmatory factor analysis (CFA) validated the measurement model. All standardized factor loadings exceeded 0.70, ranging between 0.72 and 0.91. Cronbach's alpha values were above 0.85 for all constructs, composite reliability (CR) values exceeded 0.89 and average variance extracted (AVE) values were greater than 0.60, supporting convergent validity. Discriminant validity was confirmed using the Fornell–Larcker criterion, as each construct's AVE square root was greater than its correlations with other constructs. The CFA results such as reliability and validity of constructs has been presented in Table 4.

Model fit indices confirmed adequacy of the measurement model: $\chi^2/df = 1.98$, CFI = 0.95, TLI = 0.94, RMSEA = 0.058, SRMR = 0.046.

5.3 Structural model results (SEM)

The structural model was tested using SEM and results are presented in Table 5. Leadership was found to significantly predict innovation ($\beta = 0.59$, $p < 0.001$), supporting H1. Innovation significantly influenced resilience ($\beta = 0.61$, $p < 0.001$), supporting H2. Resilience strongly predicted competitive advantage ($\beta = 0.69$, $p < 0.001$), supporting H3. Furthermore, the mediation analysis confirmed that innovation partially mediated the effect of leadership on resilience (indirect effect = 0.36, $p < 0.01$), supporting H4. The newly added path from Innovation to Competitive Advantage (H5) was also significant ($\beta = 0.32$, $p < 0.001$), confirming that innovation contributes directly to competitive advantage in addition to its indirect effects through resilience. A nested model comparison revealed that adding the Innovation → Competitive Advantage path resulted in a small and non-significant change in overall model fit ($\Delta\chi^2 = 3.1$, $\Delta df = 1$, $p > 0.05$), despite the statistical significance of the added path coefficient.

The structural model demonstrated a good fit: $\chi^2/df = 2.07$, CFI = 0.94, TLI = 0.93, RMSEA = 0.061, SRMR = 0.048.

Table 4. CFA results: reliability and validity of constructs

Construct	Items	Cronbach's alpha	Composite reliability	AVE
Leadership	6	0.89	0.92	0.65
Innovation	5	0.87	0.91	0.63
Resilience and risk management	7	0.90	0.93	0.61
Competitive advantage	4	0.85	0.89	0.66

Source(s): Authors' own creation

Table 5. Structural model path coefficients

Hypothesized path	β	*t*-value	*p*-value	Supported
Leadership → Innovation (H1)	0.59	8.24	<0.001	Yes
Innovation → Resilience (H2)	0.61	9.11	<0.001	Yes
Resilience → Competitive advantage (H3)	0.69	10.32	<0.001	Yes
Innovation → Competitive advantage (H5)	0.32	4.21	<0.001	Yes
Leadership → Resilience (direct path)	0.27	3.76	<0.001	Yes
Leadership → Resilience via innovation (H4)	0.36	4.85	<0.01	Yes

Source(s): Authors' own creation

5.4 Structural model diagram

Figure 3 illustrates the tested structural equation model, displaying standardized path coefficients. Solid arrows represent direct effects, while the dashed arrow captures the partial mediation effect of leadership on resilience through innovation. The results confirm the hypothesized model and provide strong empirical evidence of the interplay between leadership, innovation, resilience and competitive advantage in railway supply chains.

The layout of Figure 3 mirrors the conceptual model to maintain visual continuity. However, the figure reflects the empirical results generated from Structural Equation Modeling (SEM). All path coefficients are labeled directly on the diagram and the mediation effect is represented using a dashed arrow to distinguish it from direct effects.

The structural model presented in Figure 3 was generated from the SEM analysis conducted in AMOS/SmartPLS and its layout similarity to Figure 1 reflects intentional alignment between theory and empirical validation. While Figure 1 represents the conceptual model derived from RBV and Dynamic Capabilities, Figure 3 reflects statistically estimated relationships using maximum likelihood and bootstrapping procedures. This ensures methodological transparency and demonstrates coherence between theory driven and data driven representations.

6. Discussion

The results of this study highlight the critical interrelationships between leadership, innovation, resilience and competitive advantage in the context of railway supply chains. By employing a mixed-methods approach, the study not only validates the hypothesized relationships but also provides contextual insights that expand our understanding of how these constructs interact in practice. This discussion section situates the findings within broader theoretical debates, interprets their managerial relevance and outlines policy directions for enhancing resilience in railway systems.

6.1 Theoretical implications

This study makes several contributions to theory. First, it extends the literature on supply chain resilience by empirically testing a model that integrates leadership, innovation and resilience within a railway specific context. While prior research has frequently examined resilience as an outcome of risk management practices or collaborative partnerships, this study demonstrates that resilience is also strongly shaped by internal organizational capabilities

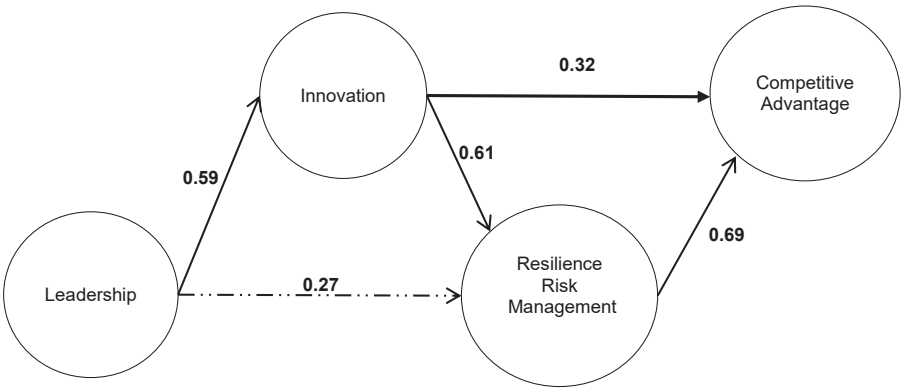

Figure 3. Structural equation model of railway supply chain resilience. **Source**: Authors' own creation

particularly leadership behaviors and innovation adoption. This expands the conceptual boundaries of resilience by connecting it directly to strategic management theories.

Second, the research confirms the explanatory power of the resource-based view (RBV) and the dynamic capabilities framework in the railway sector. The RBV suggests that organizations gain sustained competitive advantage when they cultivate capabilities that are valuable, rare, inimitable and non-substitutable. The empirical evidence presented here positions resilience as precisely such a capability, one that is not easily replicated by competitors because it depends on unique combinations of leadership, culture and innovative practices. In parallel, the dynamic capabilities perspective emphasizes the ability to sense opportunities and threats, seize them through innovation and reconfigure resources in response. The study illustrates how railway organizations that adopt digital tools and process innovations demonstrate this adaptive capacity, thereby supporting the dynamic capabilities view.

Third, the findings contribute to leadership theory by highlighting its role not only in guiding employees but also in orchestrating systemic resilience across complex supply chains. Transformational leadership behaviors, such as articulating a vision for resilience, empowering employees to experiment with solutions and fostering a collaborative environment, emerged as central mechanisms for promoting innovation and resilience. This suggests that leadership should be conceptualized as a strategic resource in itself an enabler of dynamic capabilities rather than merely a human resource function.

Finally, the study contributes to innovation literature by underscoring its mediating role. While leadership provides strategic intent and resilience represents the desired outcome, innovation is the channel that connects the two. This mediating effect reinforces the idea that innovation is not an isolated construct but a bridge between managerial vision and organizational performance.

The confirmation of H5 provides further support for RBV by demonstrating that innovation is not only an enabler of resilience but also an independent source of competitive advantage. This reinforces the theoretical argument that innovation itself functions as a VRIN capability in railway ecosystems, where digital and process innovations are difficult for competitors to imitate.

6.2 Managerial implications

The findings also carry significant practical lessons for railway managers and supply chain leaders. First, the evidence underscores the importance of leadership styles that encourage innovation. Managers who adopt transformational leadership behaviors by articulating a clear vision, promoting collaboration across supply chain partners and empowering employees are more likely to see their organizations adopt technological and process innovations that enhance resilience. In contrast, command and control approaches may suppress experimentation and discourage proactive responses to risk.

Second, the role of digital transformation emerges as crucial. Case based evidence revealed that railway operators who invested in predictive maintenance systems, IoT enabled monitoring and blockchain based information sharing were able to reduce downtime, anticipate disruptions and coordinate responses more effectively. These technologies not only enhance operational efficiency but also increase transparency across supply chains, reducing uncertainty and improving trust among partners. The direct effect of innovation on competitive advantage also highlights the strategic value of investing in digital and process improvements even when resilience is not the primary concern. Managers are encouraged to prioritize such technologies, not as optional investments but as strategic necessities for resilience.

The direct statistical effects observed in the structural model indicate that innovation contributes both to resilience and independent competitive advantages. Managers should therefore prioritize innovation portfolios that simultaneously strengthen operational continuity and market differentiation. For instance, predictive maintenance systems can

reduce downtime while also improving punctuality metrics that customers value. Similarly, blockchain enabled documentation can enhance transparency for regulators, while IoT based monitoring of rolling stock can improve capacity planning and reduce energy consumption. By aligning innovation investments with the SEM-validated pathways, managers can ensure that resources are allocated to initiatives with the greatest impact on resilience and competitive performance.

Third, process innovation should not be overlooked. While digital tools attract much of the current attention, the study highlights that innovations in processes such as adopting lean practices, developing agile project management routines and enhancing cross-functional integration contribute equally to resilience. Railway organizations that streamlined operations and built flexible structures were more adaptable to disruptions, even when technological adoption was limited. This suggests that resilience is as much about organizational culture and processes as it is about technology.

Finally, the managerial implication of resilience as a source of competitive advantage deserves emphasis. Railway operators that maintained service continuity during disruptions earned reputational benefits, customer loyalty and financial sustainability. In an industry where safety, punctuality and reliability are paramount, resilience directly translates into market differentiation. Managers should therefore view resilience not merely as risk mitigation but as a driver of long-term performance and strategic positioning.

Furthermore, leaders should institutionalize post disruption learning routines and scenario-based readiness exercises, as these practices leverage the dynamic capabilities identified in the model and reinforce resilience as a repeatable organizational competence.

6.3 Policy implications

The study also offers insights for policymakers and regulators who oversee national railway systems. Railway supply chains are critical infrastructures whose disruptions can have cascading effects on trade, energy distribution and passenger mobility. The findings suggest several policy directions.

First, A key policy implication is the need for clearly defined national resilience benchmarks tailored to railway operations. These benchmarks should include minimum requirements for infrastructure redundancy, digital monitoring capabilities, cybersecurity preparedness and intermodal coordination protocols. For example, regulators could mandate the implementation of predictive maintenance systems for critical assets, require cross chain data sharing standards for scheduling and capacity visibility and formalize recovery time objectives for major service disruptions. Additionally, digital transformation incentives should prioritize technologies that improve network visibility, such as IoT enabled asset tracking and AI based capacity forecasting, rather than generic IT upgrades. These targeted incentives ensure that government support directly enhances the operational dimensions shown to influence resilience and competitive advantage.

Second, leadership development programs should be integrated into national transportation strategies. Given the demonstrated role of leadership in fostering innovation and resilience, policymakers could collaborate with industry associations and academic institutions to design training initiatives that equip railway managers with the skills necessary to lead in volatile environments. These programs should emphasize transformational leadership, change management and digital literacy.

Third, regulatory frameworks should be updated to incorporate resilience benchmarks. Just as safety standards are mandatory, resilience standards such as requirements for redundancy, recovery planning and cybersecurity preparedness could be institutionalized. By embedding resilience into regulatory systems, governments can ensure that railway operators prioritize long-term continuity in addition to efficiency and profitability.

Finally, policymakers should view railway resilience as an integral part of sustainability and climate change adaptation strategies. Extreme weather events represent a growing threat to

railway operations worldwide. Resilient supply chains that can withstand and adapt to climate-related disruptions will be critical for achieving sustainability goals and ensuring uninterrupted mobility. Policies that integrate resilience with environmental targets will therefore provide dual benefits: enhancing national infrastructure security while advancing sustainable development.

Overall, the discussion highlights that resilience in railway supply chains is not an isolated attribute but the outcome of interconnected organizational capabilities. Leadership sets the direction, innovation provides the mechanisms and resilience translates these into performance outcomes that generate competitive advantage. The theoretical implications reinforce resilience as a strategic capability, the managerial implications emphasize the need for innovation driven leadership and the policy implications underline the necessity of systemic support for resilience building practices. By integrating these perspectives, the study offers a comprehensive framework for understanding and enhancing resilience in railway supply chains.

Policymakers should also encourage sector wide leadership development programs focused on digital literacy, crisis coordination and adaptive decision making. Since the empirical results highlight the role of leadership in driving innovation and resilience, these programs can strengthen managerial capacity across the sector and reduce variability in resilience performance among operators.

7. Conclusion

This study set out to examine the interplay of leadership, innovation and resilience in shaping competitive advantage within railway supply chains. Drawing on the resource-based view and dynamic capabilities framework, a conceptual model was developed and tested using survey data from 186 railway organizations alongside case study evidence from leading operators and supply chain partners. The results confirmed that leadership plays both a direct and an indirect role in fostering resilience, with innovation acting as a key mediator. Furthermore, resilience was shown to be a powerful driver of competitive advantage, enabling organizations to maintain reliability, efficiency and sustainability in the face of disruptions.

The findings contribute to theory by positioning resilience as a strategic capability that derives from the combined effects of leadership vision and organizational innovation. This enriches the literature on supply chain management and extends theoretical perspectives into the specific context of railway operations, where interdependencies and vulnerabilities create distinctive resilience challenges. The study also provides empirical validation for the role of innovation as the critical mechanism through which leadership translates into resilience.

From a managerial perspective, the results highlight that resilience should not be understood merely as risk mitigation but as a pathway to long-term competitiveness. Railway managers who cultivate transformational leadership behaviors, invest in digital and process innovations and embed flexibility into organizational practices can better anticipate, absorb and recover from disruptions. Such practices not only protect operations during crises but also enhance market reputation and customer trust.

For policymakers, the research underscores the importance of embedding resilience into infrastructure strategies and regulatory frameworks. Incentives for digital adoption, training programs for leadership development and mandatory resilience benchmarks are among the measures that can strengthen national railway systems. By aligning resilience with sustainability and climate adaptation agendas, governments can ensure that railways remain robust contributors to economic and environmental goals.

Despite these contributions, the study is not without limitations. The reliance on self-reported survey data may introduce bias and while case studies provided contextual depth, the sample size limits generalizability. Future research could extend this work by employing longitudinal designs to examine how resilience capabilities evolve over time, or by conducting cross national comparisons to explore how institutional contexts shape the leadership–

innovation–resilience nexus. Moreover, the integration of real-time operational data from digital platforms could provide more objective measures of resilience performance.

In conclusion, the study demonstrates that resilience in railway supply chains is the product of strategic leadership and innovation. By investing in these capabilities, railway organizations not only safeguard themselves against disruptions but also create sustainable competitive advantage in an increasingly uncertain global environment. The integration of leadership, innovation and resilience thus represents a holistic strategy for building the railway systems of the future systems that are secure, adaptive and essential to sustainable economic growth.

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