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Developing a Formative Construction Supply Chain Resilience Index to Improve Cost and Schedule Stability in Post-Disaster Projects

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Abstract

Background: Construction material supply chain resilience has emerged as a critical determinant of infrastructure project success in disaster-prone regions; however, its quantitative measurement at the post-disaster project level remains limited, particularly at the district scale. Despite East Lombok being an earthquake-affected area with intensive reconstruction activities, no empirical model has systematically quantified supply chain resilience and tested its influence on project cost and schedule performance.
Aims: This study aimed to identify priority factors of construction material supply chain resilience and to examine the effect of a resilience index on post-earthquake project performance.
Methods: An explanatory quantitative approach was applied to 25 reconstruction projects in East Lombok, involving eight experts for AHP weighting and multiple regression analysis of CPI and SPI using SPSS/Stata.
Result: The results indicated that supplier diversification was the dominant factor (weight = 0.32) with acceptable consistency (CR = 0.069), while the average resilience index reached 0.64. The resilience index explained 46% of cost performance variance and 52% of schedule performance variance, demonstrating significant positive relationships ($p < 0.05$).
Conclusion: These findings confirm that supply chain resilience functions as a risk-buffering mechanism for cost and schedule stability in post-disaster projects. The study provides an empirical operationalization of Supply Chain Resilience into a measurable AHP-based index.

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1. Introduction

The resilience of the construction supply chain has evolved from a risk mitigation instrument to a strategic variable that determines the stability of infrastructure systems in disaster-prone areas. Global disruptions ranging from pandemics to international logistics disruptions suggest that delays in material distribution are triggering cost escalations and slowing regional economic recovery (Bruckler *et al.,* 2024). In prefabricated construction, resilience is modeled through cost-resilience tradeoffs (Zhang & Yu, 2021), whereas the latent-construct approach emphasizes its multidimensional nature in complex systems (Lin *et al.,* 2024). Artificial Intelligence integration increases adaptive capacity to external pressures (Belhadi *et al.,* 2024), and supply chain effectiveness correlates with the productivity of material-intensive projects (Awaad *et al.,* 2024). However, the theoretical position of resilience in the post-disaster project domain, particularly its relationship to cost and time performance, has not been explicitly formulated in a tested operational framework at the project level.

In post-disaster projects, material supply resilience is no longer a purely logistical issue, but a systemic determinant of cost stability and timeliness. The aid distribution optimization model shows the tradeoff between unmet demand, emergency costs, and environmental risks (Cao *et al.,* 2021), while multi-stakeholder coordination strengthens adaptive capacity (Xu *et al.,* 2021). Adoption of Industry 4.0 and AI increases visibility and velocity (Ahmed *et al.,* 2023; Spieske & Birkel, 2021), which contribute to resilience and performance (Sadha *et al.,* 2024). Prepositioning inventory also increases service levels with cost implications (Moosavi & Hosseini, 2021). However, these studies have not directly explained how resilience at the construction project level translates into improved cost and time performance in the context of a district-scale post-earthquake as a specific theoretical constraint.

Post-earthquake material supply disruptions trigger a nonlinear cross-echelon ripple effect involving the interactions among production capacity, inventory policy, and network configuration (Katsaliaki *et al.,* 2022; Rahman *et al.,* 2021). Supply-demand imbalance increases contractual uncertainty and drives emergency procurement (Chen *et al.,* 2021; Guo *et al.,* 2025). The simulation shows how reorder points and production reliability interact with profitability (Shahed *et al.,* 2021), while network restructuring can reduce adaptive redundancy (Son *et al.,* 2021). This literature confirms the systemic complexity of resilience. Still, it does not answer the problematic question: why is it that, in some post-disaster projects, resilience capacity is not always translated into cost and time stability in proportion?.

This complexity is evident in East Lombok Regency, an area affected by the earthquake and experiencing a high level of reconstruction. BIM–GIS Integration (Cao *et al.,* 2023) and circular economy (Papamichael *et al.,* 2023) have been adopted, but validation of regional distribution capacity remains limited. Experimentally robust materials and technology research have not yet fully translated to local logistics capacity (Cao *et al.,* 2023; Liu *et al.,* 2024; Rahimpour *et al.,* 2024). Global assumption-based analysis is often out of sync with geological variation and regional distribution capacity (D'Amico *et al.,* 2021; Valente, 2021). This discrepancy establishes a clear theoretical boundary condition, whereby resilience is examined at the district-scale post-disaster project level, where logistical constraints, institutional capacity, and supply network structure differ fundamentally from national or industrial systems.

The Supply Chain Resilience literature can be mapped into four clusters. HR–SNA-based technical-dynamic model and digital twin explain vulnerabilities–capabilities (Ekanayake *et al.,* 2021; Ivanov & Dolgui, 2022), but are dominant in manufacturing. The absorptive adaptive restorative indicator provides comprehensive quantification (Yang *et al.,* 2025). However, it does not test the causal relationship to project performance. The MCDM framework prioritizes robustness and adaptability (Liu *et al.,* 2023), while SEM emphasizes multidimensional flexibility (Piprani *et al.,* 2022). Although reconfiguration enablers are consistent (Al Naimi *et al.,* 2022), no explicit testing of the proposition that Supply Chain Resilience affects Project Performance in the post-disaster construction domain has been conducted, thereby extending theoretical boundaries.

The cross-sectional SEM paradigm assumes latent relational stability, but it does not capture it at the district level. Resilience-security integration is still conceptual (Hong *et al.,* 2025), two-echelon models simplify multi-tier complexity (Yan *et al.,* 2025), and the digital twin has not been operationalized at the project level (Guo & Mantravadi, 2025). Thus, an epistemological weakness emerges: previous approaches have not explained the mechanism by which absorptive and adaptive capacity are converted into project cost and time stability.

Methodologically, SEM (Kamal *et al.,* 2021), Network simulation (Habibi *et al.,* 2023), and fuzzy MCDMs such as OPA-F and IFAHP (Mahmoudi *et al.,* 2022; Xie *et al.,* 2023) have not been integrated into an index-based operating model that can be causally tested. This study overcomes this gap by operationalizing resilience as a formative construct, in which dimensions such as supplier diversification, transportation flexibility, and information coordination together form a composite index rather than reflecting a single latent construct. Thus, changes in one dimension directly affect the index's value. Importantly, This study conceptualizes Supply Chain Resilience as a formative composite construct, in which multiple operational dimensions collectively define resilience capacity rather than reflect a single latent variable.

Based on these gaps, this study develops an AHP-based construction material supply chain resilience index (SCRI) using data from 25 post-earthquake projects in East Lombok Regency and empirically examines its effects on cost and schedule performance through regression analysis within the framework of Supply Chain Resilience Theory. The SCRI is conceptualized as a formative composite construct, in which multiple operational dimensions collectively define resilience capacity at the project level. This study formulates two theoretical propositions: (P1) Supply Chain Resilience positively influences project cost stability, and (P2) Supply Chain Resilience positively influences project schedule performance. These propositions position the study not merely as an empirical application, but as a domain extension and mechanism clarification of Supply Chain Resilience Theory within construction project systems characterized by temporal urgency, contractual rigidity, and localized logistics constraints. Accordingly, this study delineates the boundary conditions of district-scale post-disaster construction projects, clarifies the mechanism through which absorptive and adaptive capacities are translated into measurable project performance outcomes, and proposes a formative, empirically testable index model for resilience assessment.

2. Methods

This study adopts an explanatory quantitative approach to examine the causal relationship between Construction Supply Chain Resilience and post-disaster project performance. The research design is structured into three sequential and integrated stages: (1) determining the priority weights of resilience factors using the Analytical Hierarchy Process (AHP); (2) constructing and measuring the Supply Chain Resilience Index (SCRI) across sampled projects; and (3) assessing the effect of SCRI on cost and schedule performance using two separate simple linear regression models estimated via Ordinary Least Squares (OLS). In this context, the term "multiple regression models" refers to the use of two independent regression equations rather than a single multivariate regression model with multiple predictors. The research workflow begins with variable identification grounded in Supply Chain Resilience Theory, followed by instrument development, expert validation, field data collection, numerical processing, and inferential statistical analysis. This structured design ensures methodological transparency and enables replication in comparable post-disaster construction contexts.

The study was conducted in East Lombok Regency, West Nusa Tenggara Province, Indonesia, an area significantly affected by the 2018 earthquake and characterized by intensive reconstruction activities. The research sample consists of 25 post-earthquake construction projects that have been completed or have reached at least 90% physical progress, allowing accurate measurement of cost and schedule performance indicators. These projects include the construction of educational, healthcare, and public infrastructure facilities, with contract values ranging from IDR 2 billion to IDR 25 billion. Primary data were collected from contractors, Commitment-Making Officers (PPK), and project supervisors through structured questionnaires and confirmation interviews. Secondary data, including contract documents, physical progress reports, and budget realization records, were used to calculate the Cost Performance Index (CPI) and Schedule Performance Index

(SPI). The district-level context is explicitly framed as a theoretical boundary condition, representing medium-scale, resource-constrained post-disaster construction systems where resilience dynamics differ from large-scale industrial or national contexts.

The AHP stage involved eight experts selected through purposive sampling based on three criteria: (1) a minimum of 10 years of experience in construction projects, (2) direct involvement in post-earthquake reconstruction projects, and (3) familiarity with construction supply chain management. The expert panel comprised senior contractors, PPKs, civil engineering academics, and material distributors. Each expert completed a pairwise comparison matrix using the Saaty scale (1–9). For SCRI measurement and project performance analysis, a total sampling approach was applied to the 25 eligible projects. Each resilience dimension was evaluated using a Likert scale (1–5) based on operational indicators validated by experts. Data collection combined questionnaire responses, interview confirmations, and project document reviews to ensure consistency between perceived resilience conditions and actual project performance.

The AHP hierarchy consists of a single goal (Construction Supply Chain Resilience) and five criteria: Supplier Diversification, Transportation Flexibility, Material Stock Availability, Information Coordination, and Local Policy Support. Pairwise comparison matrices were aggregated and normalized to derive priority eigenvectors. Consistency was assessed using the Consistency Index (CI) and Consistency Ratio (CR), with an acceptance threshold of CR < 0.10. The resulting weights represent the relative importance of each resilience dimension and are used as coefficients in constructing the SCRI.

SCRI is calculated using weighted linear aggregation:

$$SCRI = \sum (w_i x s_i)$$

where w_i represents the AHP-derived weight and s_i represents the standardized score of each dimension. The weights (w_i) satisfy $\sum w_i = 1$, ensuring proportional contribution of each criterion. Epistemologically, SCRI is conceptualized as a formative composite construct, in which each dimension contributes to the formation of resilience capacity rather than reflecting an underlying latent variable. Consequently, indicators are not required to covary, and changes in any dimension directly influence the composite index value. This implies that the regression models assess the effect of an operationally constructed resilience capacity on project performance outcomes, rather than relationships among reflective latent constructs.

Although supply chain systems are inherently nonlinear and complex, the linear-additive formulation is adopted as an operational simplification at the project level, where decision-making occurs within relatively short-term contractual and logistical horizons. This approach assumes relative independence among criteria and prioritizes interpretability and practical applicability over dynamic system modeling, making it suitable for empirical analysis and policy-relevant decision support. SCRI values are classified into low, moderate, and high resilience categories based on predefined thresholds.

The effect of SCRI on CPI and SPI is analyzed using two separate simple linear regression models estimated through OLS. Model evaluation includes the coefficient of determination (R^2), F-test for overall model significance, and t-test for individual parameter significance. Instrument validity is established through expert-based content validation, while internal reliability is assessed using Cronbach's Alpha with a threshold of ≥ 0.70. To ensure robustness, regression models are re-estimated using Stata software to verify parameter stability and consistency across computational platforms.

Classical assumption tests include normality (Kolmogorov–Smirnov test), heteroscedasticity (Breusch–Pagan test), and multicollinearity (Variance Inflation Factor, VIF < 5). Outliers are identified using standardized residuals and Cook's Distance. Statistical significance is evaluated at $\alpha = 0.05$. Missing or incomplete observations are handled using listwise deletion to maintain consistency in OLS estimation.

Ethical approval for the study was obtained from the relevant academic institution, and all respondents provided informed consent prior to participation. Project data were anonymized to ensure confidentiality. Despite its methodological rigor, the study is subject to limitations, including a relatively small sample size (n = 25) and a focus on a single district, which constrains generalizability. Additionally, the linear regression framework does not capture potential nonlinear relationships or moderating effects. Nevertheless, the integration of AHP and regression within a systematic explanatory design provides a transparent, replicable, and empirically grounded framework for assessing supply chain resilience in post-disaster construction projects.

3. Result and Discussion

The first stage of the analysis aims to determine the priority weight of the Construction Supply Chain Resilience factor using *the Analytical Hierarchy Process* (AHP). The hierarchical structure consists of one main goal (Construction Supply Chain Resilience) and five criteria, namely Supplier Diversification (C1), Material Stock Availability (C2), Transportation Flexibility (C3), Information Coordination (C4), and Local Policy Support (C5). This structure represents the dimensions of absorptive and adaptive capacity at the project level. The paired comparison matrix obtained from the average assessment of 8 experts is presented in Table 1. Then, Matrix normalization yields the priority eigenvectors presented in Table 2.

Table 1. Paired Comparison Matrix (Average Expert Rating)

Criteria	**1**	**2**	**3**	**4**	**5**
C1	1.00	1.50	2.00	3.00	4.00
C2	0.67	1.00	1.50	2.00	3.00
C3	0.50	0.67	1.00	1.50	2.00
C4	0.33	0.50	0.67	1.00	1.50
C5	0.25	0.33	0.50	0.67	1.00

Table 2. Weight of Priority Factors Construction Supply Chain Resilience

Criteria	**Weight (Eigenvector)**	**Ranking**
Supplier Diversification (C1)	0.32	1
Stock Availability (C2)	0.24	2
Transportation Flexibility (C3)	0.19	3
Information Coordination (C4)	0.15	4
Policy Support (C5)	0.10	5

A maximum eigenvalue of 5.31 results in a Consistency Index (CI) of 0.0775. With a Random Index (RI) for n = 5 of 1.12, a Consistency Ratio (CR) of 0.069 was obtained. A CR value of < 0.10 indicates that the comparison matrix meets the consistency criteria and can be used as a basis for index weighting.(λ_{max}).

The AHP weights are used to calculate the Supply Chain Resilience Index (SCRI) for 25 post-earthquake projects via weighted linear aggregation. Operationally, a linear-additive approach is used to represent the structural capacity of a project in the face of disruptions to short-term contractual horizons. This model assumes relatively independent contributions of criteria at the project level, so that an increase in one dimension increases the composite score without modeling nonlinear interactions between criteria. Thus, the SCRI is positioned as an indicative composite index, rather than a dynamic system simulation model.

The use of a linear-additive SCRI reflects an aggregated representation of structural resilience capacity, rather than modeling nonlinear interdependencies, thereby supporting empirical testing of resilience-performance relationships at the project level. Descriptive SCRI statistics are presented in Table 3.

Table 3. SCRI Descriptive Statistics (n = 25 Projects)

Parameter	Score/ Value
Minimum	0.47
Maximum	0.78
Mean	0.64
Standard Deviation	0.09

The category distribution showed that 8 projects (32%) were in the high category (>0.70), 13 projects (52%) in the medium category (0.50 - 0.70), and 4 projects (16%) in the low category (<0.50). Moderate variability between projects shows differences in structural capacity in the face of supply disruptions.

The effect of SCRI on the Cost Performance Index (CPI) was tested using simple linear regression. A summary of the models is presented in Table 4.

Table 4. Model Summary SCRI to CPI

R	R²	Adjusted R²	Std. Error
0.678	0.460	0.438	0.032

A coefficient of determination (R^2) of 0.460 indicates that SCRI explains 46.0% of the variation in the CPI. The results of ANOVA are presented in Table 5.

Table 5. ANOVA – Model CPI

Source	Sum of Squares	df	Mean Square	F	Sig
Regression	0.048	1	0.048	19.62	0.003
Residual	0.059	23	0.0026		
Total	0.107	24			

An F value of 19.62 with p = 0.003 indicates a statistically significant model. The regression coefficient is shown in Table 6.

Table 6. Regression Coefficient – CPI

Variable	B	Std. Error	Beta	t	Sig
Constant	0.512	0.074	—	6.92	0.000
SCRI	0.580	0.131	0.678	4.43	0.003

Regression equations:

$$\boldsymbol{CPI = 0.512 + 0.580(SCRI)}$$

This positive coefficient indicates that improvements in composite resilience capacity systematically enhance cost stability through reduced exposure to supply disruption risks. The second model tested the influence of SCRI on the Schedule Performance Index (SPI). A summary of the models is presented in Table 7.

Table 7. Summary Model – SCRI on SPI

R	R²	Adjusted R²	Std. Error
0.721	0.520	0.500	0.029

An R^2 value of 0.520 indicates that SCRI explains 52.0% of the SPI variation. The ANOVA results are shown in Table 8, and the regression coefficients are presented in Table 9.

Table 8. ANOVA – Model SPI

Source	Sum of Squares	df	Mean Square	F	Sig
Regression	0.061	1	0.061	24.89	0.002
Residual	0.056	23	0.0024		
Total	0.117	24			

Table 9. Regression Coefficient – SPI

Variable	B	Std. Error	Beta	t	Sig
Constant	0.401	0.069	—	5.81	0.000
SCRI	0.610	0.122	0.721	4.99	0.002

Regression equations:

$$\boldsymbol{SPI = 0.401 + 0.610(SCRI)}$$

The stronger coefficient suggests that resilience capacity more directly influences temporal recovery dynamics than financial adjustments. The higher Beta coefficient in the SPI model indicates a stronger linear association than in the CPI model in the context of the sample project. The statistical results above establish the empirical relationship between SCRI and project performance. The following section interprets these findings within the framework of Supply Chain Resilience Theory.

The stronger influence of SCRI on SPI compared to CPI can be explained through three structural mechanisms. First, in post-disaster public projects, budget structures are relatively rigid due to fixed contracts and regulatory constraints, limiting cost variability. In contrast, project schedules are inherently more elastic, as material disruptions directly affect activity sequencing and critical path continuity. Second, time performance is more sensitive to flow disruptions because delays propagate immediately through construction dependencies, whereas cost impacts can often be partially absorbed through administrative adjustments or resource reallocation. Third, public reconstruction contracts tend to tolerate schedule extensions more readily than cost escalations, making temporal performance more responsive to supply chain conditions.

Within Supply Chain Resilience Theory, this indicates that adaptive and restorative capacities manifest more rapidly in temporal recovery than in financial stabilization, thereby clarizing the differential pathways through which resilience influences project performance.

As shown in Table 2, Supplier Diversification has the highest weight (0.32), followed by Stock Availability (0.24) and Transportation Flexibility (0.19). These findings suggest that supply source redundancy is a key structural determinant of Supply Chain Resilience at the project level.

This finding indicates that supply redundancy is the most critical structural determinant of resilience at the project level. Within Supply Chain Resilience Theory, redundancy represents a core component of absorptive capacity, enabling systems to absorb disruptions without failure. This mechanism reduces single-point dependency risks and enhances supply continuity. These results are consistent with Ivanov & Dolgui (2022), which demonstrate higher performance stability in multi-sourcing networks, and Ekanayake *et al.* (2021), which emphasize supplier density as a robustness factor.

In contrast to Piprani *et al.* (2022), who identify flexibility as the dominant factor in national industrial systems, this study shows that in district-scale post-disaster construction contexts, absorptive capacity through redundancy is more influential than adaptive flexibility. This finding provides a context-specific domain extension of Supply Chain Resilience Theory. The average SCRI value of 0.64 indicates a moderate level of resilience, with 16% of projects categorized as low. This suggests that resilience capacity has developed partially but remains structurally incomplete.

In Supply Chain Resilience Theory, adaptive processes evolve through post-disruption learning cycles. The moderate SCRI value indicates that absorptive capacity is relatively established, while adaptive and restorative capacities are still consolidating. This aligns with Katsaliaki *et al.* (2022), which describes the transition phase of the post-disaster system, and with Rahman *et al.* (2021), which shows the dynamics of the nonlinear ripple effect on the regional network.

Compared with Chen *et al.* (2021), who observe increased resilience after repeated disruption cycles, these findings suggest that East Lombok remains in a structural consolidation phase. The contribution of this research lies in providing quantitative measures of resilience at the district level that have not previously been documented in the construction literature.

The regression results indicate that SCRI explains 46% of CPI variation, confirming a substantial relationship between resilience and cost performance. Mechanistically, absorptive capacity and redundancy reduce cost volatility through: (1) price stabilization via alternative suppliers, (2) reduced emergency logistics costs, and (3) minimized crashing costs due to fewer delays.

These findings are consistent with Cao *et al.* (2021) and Mahmoudi *et al.* (2022), and reinforce Sadha *et al.* (2024) who identify resilience as an economic shock absorber. This demonstrates that absorptive capacity operates as a risk-buffering mechanism that stabilizes cost fluctuations under disrupted supply conditions, rather than eliminating cost impacts entirely.

The influence of SCRI on SPI ($R^2 = 0.52$) was stronger than on CPI ($R^2 = 0.46$). A comparison of the power of such influence is shown in the following graph.

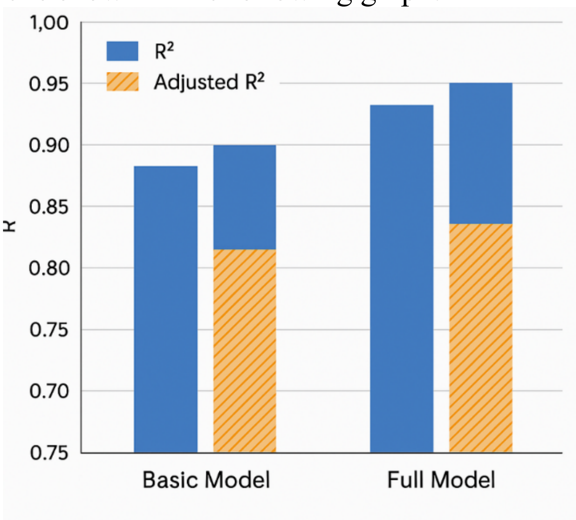

Figure 1. The influence of SCRI on SPI and CPI

As illustrated in Figure 1, the slope of the SCRI–SPI relationship is steeper than that of SCRI–CPI, indicating greater temporal elasticity of project performance with respect to resilience capacity.

Conceptually, this difference can be explained through three structural mechanisms. First, in post-disaster public projects, the budget structure is relatively more rigid due to limited contracts and procurement regulations, so cost deviations are often controlled through internal reallocation or scope adjustments. In contrast, project schedules are more elastic to material disruptions because distribution delays directly affect the sequence of construction activities and create *idle time* on critical lines. Second, time is more sensitive to *flow disruption* than costs that can be absorbed through administrative mechanisms. Third, the characteristics of public reconstruction contracts tend to tolerate greater time adjustments than changes in contract value.

Within the framework *of Supply Chain Resilience Theory*, these findings show that the adaptive and restorative capacity dimensions are more quickly reflected in temporal stability than in financial stability. The study by Son *et al.* (2021) asserts that reconfiguration ability determines recovery duration, whereas Spieske & Birkel (2021) emphasize the role of visibility in maintaining a smooth schedule. Thus, this study enriches the literature by providing a differential explanation of the elasticity of time and cost to logistical disruptions in the context of district projects.

Simultaneous findings from CPI and SPI indicate that SCRI is a significant empirical determinant of project performance, providing measurable evidence of Supply Chain Resilience mechanisms. This is consistent with Bruckler *et al.* (2024), which places resilience as a pillar of regional economic stability.

The contribution of this research is proportionate and measurable: (1) expanding the theoretical domain to the context of district-scale post-disaster construction projects; (2) empirically test the relationship between SCRI and project performance; and (3) integrating priority weighting and causal testing in a single operational framework. This integration addresses the criticism by Kamal *et al.* (2021) that SEM's limitations prevent it from producing an operational weight that is applicable.

Theoretically, this study does not claim a global reformulation, but rather provides a context-specific domain extension and mechanism clarification within district-scale post-disaster construction systems. It demonstrates that absorptive and adaptive capacities can be operationalized as a formative composite index and empirically linked to project performance outcomes.

Methodologically, integrating AHP with simple linear regression provides an operational approach that bridges priority evaluation and cause-and-effect testing. Empirically, this study presents quantitative evidence from real projects that enriches the literature, which manufacturing studies or conceptual models previously dominated. Thus, the contribution of this study is both contextual and measurable, as it extends the theory's application to the post-disaster construction domain at the district level.

4. Conclusion

This study aims to identify the priority factors of Construction Supply Chain Resilience using the Analytical Hierarchy Process (AHP) and test the influence of the resilience index on post-earthquake project cost and time performance in East Lombok Regency. The results show that supplier diversification is the main determinant of supply chain resilience, followed by stock availability and transportation flexibility. The level of project resilience is generally in the moderate category, reflecting the adaptive capacity that has developed but is not yet fully consolidated. Linear regression analysis shows that the resilience index has a positive and significant influence on the Cost Performance Index (CPI) and Schedule Performance Index (SPI), with stronger explanatory power for time performance than for cost performance.

Theoretically, this study does not reformulate Supply Chain Resilience Theory, but rather provides a domain-specific extension and empirical clarification of causal mechanisms linking resilience capacity to project performance in district-scale post-disaster construction contexts. The findings demonstrate that absorptive capacity—primarily reflected through supplier diversification—functions as a structural buffering mechanism, while adaptive capacity contributes to recovery speed, thereby influencing both cost stability and schedule performance through distinct pathways. Methodologically, the integration of AHP-based weighting and simple linear regression offers a transparent and operational framework that connects multi-criteria prioritization with causal analysis at the project level. From a practical perspective, the SCRI developed in this study can serve as a decision-support instrument for evaluating supply chain risks in project planning, cost estimation (RAB), schedule control, and procurement strategies, particularly in disaster-prone regions where logistical uncertainty is high.

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