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How to Manage Supply Chains Successfully in Transport Infrastructure Projects

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Abstract: The objective of this research is to assess the influence of effective supply chain management on the success of transport infrastructure projects, considering the moderating effects of building information modeling (BIM) and environmental factors. Data were collected through questionnaires from construction projects and subjected to analysis to gain insights into the contributions of various supply chain management strategies to the overall performance of transport infrastructure projects, as well as how the presence of BIM and environmental considerations affect this relationship. The data were subjected to analysis using partial least squares structural equation modeling (PLS-SEM). The results of this investigation revealed a significant impact of supply chain management practices in the construction industry on the performance of transport infrastructure projects, with BIM and environmental considerations acting as moderators in this association. This study holds both practical and theoretical significance, as it contributes to the existing body of knowledge by shedding light on the role of supply chain management in construction and its influence on the success of transport infrastructure projects while also exploring the moderating influence of BIM and environmental factors. The findings provide valuable perspectives for improving supply chain management practices in construction, thereby enhancing the outcomes of transport infrastructure projects.

Keywords: environmental considerations; supply chain management; transport infrastructure; projects performance; construction industry; building information modeling

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1. Introduction

As the major industry that creates jobs and is essential to the economic growth of Pakistan, construction is of utmost significance there [1]. Construction has boomed in several economic sectors, including Energy, Architecture and Planning, Industrial, and Transportation [2]. As a result, these sectors have seen significant advancements.

This study addresses the need to comprehensively assess how effective supply chain management practices impact the outcomes of transport infrastructure projects. The complexity and scale of such projects demand efficient supply chain management. However, what makes this research significant is its focus on understanding how two specific factors, namely building information modeling (BIM) and environmental considerations, may moderate or influence the relationship between supply chain management and project success. As BIM continues to transform the construction and infrastructure sectors and environmental concerns play a growing role in project decision-making, it is essential to explore how these factors interact with supply chain practices. This study aims to provide insights into these dynamics, offering valuable guidance for professionals and researchers in infrastructure project management. Despite the growing importance of supply chain management in construction projects, limited research explores the intersection of supply chain management practices and the outcomes of transport infrastructure projects. Maqsoom, Charoenngam [1] explored that although the sector is expanding, the rate and scope of development are still unsatisfactory. There are still problems with project quality and achieving success criteria [3]. As a result, many projects go over budget and on schedule, making it difficult for businesses to achieve government development goals [4]. Shehu, Endut [5] both emphasize the importance of the construction industry in a country's social and economic development and how it affects other industrial sectors. The economy, ecology, and society are all significantly impacted by construction projects [6]. Infrastructure-related projects are particularly vulnerable to several risks that might harm their performance [7]. Previous studies focused on studying the major industry that creates jobs and is essential to the economic growth of Pakistan; construction is of extreme significance there [8]. The timely and cost-effective completion of projects is difficult for Pakistan's construction business, just like for construction industries in other nations [2,9]. Stroumpoulis and Kopanaki [10] explored the reputation of the construction business in a country's social and efficient development and how it affects other industrial sectors. Construction projects all significantly impact the economy, ecology, and society. Infrastructure-related projects are particularly vulnerable to several risks that might harm their performance [11].

Concerns regarding reduced productivity and efficiency have been documented at various stages of construction projects [12]. BIM stands out as a highly promising recent innovation in architecture, engineering, and construction (AEC) [13]. Additionally, in the realm of building, off-site manufacturing has been validated as an effective alternative to the conventional on-site construction approach [14]. Most recent research has primarily concentrated on qualitative examinations of the amalgamation of BIM and OSM in specific areas of enhancement. For instance, these studies have explored improved construction efficiency using graph-based methodologies [15], enhanced energy consumption management through operational performance [16], the development of a simulation game to enhance the learning process [17], the establishment of a framework for information delivery in modular construction [18], heightened visibility and traceability in prefabricated construction [19], and augmented productivity resulting from BIM-based multitrade prefabrication via a case study analysis of complex building projects [20]. Additionally, these studies have explored improved collaboration and information exchange facilitated by a BIM-based interdisciplinary approach [12], the optimization of assembly sequences in concrete construction projects [20], and the development of an initial framework for integrating the last planner system with BIM and OSM [21]. It is worth noting that the focus of these prior studies has been primarily on the technological aspects of BIM integration.

The study's knowledge gap relates to integrating BIM and EI's potential to modify the link between construction supply chain management responsibilities and the performance of transportation infrastructure projects (TIP). While there is literature on supply chain management in construction and its effect on project performance [22], comprehensive research examining the combined influence of supply chain management, BIM, and environmental considerations on TIP is lacking. Studying this subject is important for several reasons. To pinpoint crucial elements and tactics that result in more successful and efficient projects, it is important to first comprehend the function of supply chain management roles in construction with TIP. Second, with an increased emphasis on sustainability and environmental responsibility, research is being conducted to determine how BIM and environmental issues affect supply chain management methods that support using eco-friendly and sustainable practices in building projects. Third, the study's findings give contractors, designers, and government organizations useful information about improving supply chain management procedures and producing better project results. Fourth, the relevance of technology adoption in contemporary construction methods is shown by the study's focus on incorporating BIM as a moderator. Additionally, it motivates the sector to use cutting-edge digital technologies for improved project management and teamwork. Finally, by examining novel viewpoints and connections that have not been thoroughly studied, this research adds to the knowledge already known in construction and supply chain management [21]. The study's practical applications can help guide decision-making in actual construction projects, resulting in more effective supply chain management and improved overall performance of transportation infrastructure.

Balancing economic interests with environmental responsibilities in information modeling and environmental considerations in transportation supply chain management is a nuanced challenge. Integrating environmental considerations can yield benefits such as cost savings, improved brand reputation, regulatory compliance, risk mitigation, increased customer loyalty, innovation, collaboration, and long-term value creation. However, achieving the optimal balance between economic and environmental goals poses difficulties involving trade-offs, uncertainties, and the involvement of multiple stakeholders [23]. The use of information modeling proves beneficial in optimizing transportation routes, inventory management, and risk mitigation for enhanced project outcomes. Integrating environmental considerations into flexible supply chains aids in mitigating negative environmental impacts while maintaining cost-effectiveness. Stakeholders must navigate these complexities to achieve comprehensive and effective sustainability outcomes in the transportation sector [24].

The integration of information modeling and environmental considerations in supply chain management faces some potential limitations, such as increased costs for sustainable practices, a lack of a well-defined sustainability framework leading to inconsistencies, and difficulties in uniformly implementing practices across the supply chain. Additionally, limited awareness, lack of regulations, and the need for transparency pose obstacles. Despite these challenges, integrating these elements holds the potential to reduce environmental impact, enhance sustainability, and create long-term value. Overcoming these limitations is essential for contributing to environmental preservation and fulfilling social responsibility objectives [23].

This study aims to evaluate the impact of efficient supply chain management on the success of transport infrastructure projects, particularly with regard to project timelines, budgets, and quality. Additionally, it investigates how the integration of BIM technology enhances supply chain coordination, information sharing, and decision-making. Furthermore, the research assesses how environmental factors, including sustainability and regulations, influence and potentially modify traditional supply chain practices within these projects.

Effective supply chain management is essential for the timely and cost-effective completion of transport infrastructure projects. Key research areas encompass supply chain optimization, risk management, sustainability, information technology adoption, procurement strategies, collaboration, infrastructure resilience, logistics modes, regulatory compliance, best practices, cost management, human resources, international projects, and technological trends.

The study of effective supply chain management in transport infrastructure projects offers significant contributions, including enhanced project efficiency, cost savings, risk mitigation, sustainability, innovation, stakeholder collaboration, regulatory compliance, human resource development, a global perspective for international projects, and the derivation of best practices. These contributions collectively ensure timely, cost-effective, and environmentally friendly project completion while improving collaboration and compliance, benefiting stakeholders, the environment, and the broader community.

The investigation of how building supply chain management positions affects TIP, together with the moderation study of BIM adoption and EI, is supported by some ideas. Supply chain management theory emphasizes the necessity of effective supply chain management in raising project performance. It implies that well-coordinated supply chain roles can favor the overall effectiveness and timely completion of building projects, including transport infrastructure [25]. These roles can involve suppliers, contractors, and other stakeholders. Building information modeling (BIM) theory is a collaborative method that uses digital depictions of a project's structural and functional elements. The adoption of BIM is anticipated to boost supply chain participant decision-making, project coordination, and performance in building projects, particularly transportation infrastructure projects [26].

Environmental impact theory emphasizes the importance of considering environmental considerations while planning building projects. The goal of environmental impact moderation analysis is to understand how sustainability practices and considerations affect the link between supply chain management responsibilities and the performance of the transportation infrastructure [27]. By incorporating these theories, the study seeks to shed light on the intricate connections between the management of the supply chain for building materials, the adoption of BIM, environmental impact, and the performance of the transportation infrastructure, ultimately assisting in the improvement of construction practices for the efficient and sustainable development of infrastructure.

Key objectives of this study were to:

1. Evaluate the impact of effective supply chain management practices on the overall success of transport infrastructure projects.
2. Identify the critical success factors in transport infrastructure projects, such as project scope, cost control, quality, and time management, and understand how supply chain management practices influence these factors.
3. Investigate the moderating role of BIM in the relationship between supply chain management and project success.
4. Explore how environmental factors, such as sustainability initiatives, regulations, and resource constraints, may influence the relationship between supply chain management and project success.

Supply chain management and networks are strategic frameworks employed to optimize the flow of products or services from suppliers to end customers. This process comprises planning, sourcing, production, distribution, logistics, and information systems [28]. Effective management of these components ensures the seamless movement of goods and information within the supply chain, contributing to timely, cost-efficient deliveries, quality assurance, and sustainability efforts [21]. Moreover, risk management is crucial for identifying and mitigating potential disruptions, such as natural disasters or economic fluctuations, while globalization necessitates adapting to the complexities of international operations and regulations. Collaboration, as emphasized by [13], fosters coordination and communication with partners, suppliers, and customers, enhancing visibility and overall supply chain performance. These principles collectively underpin the dynamic field of supply chain management, continually evolving in response to technological advancements and shifting global market dynamics.

The integration of information modeling and supply chain management in transportation infrastructure has been exemplified by key entities such as the Karachi Port Trust (KPT) and Port Qasim Authority (PQA), as well as projects like the Karachi–Lahore Motorway (M-9) and the Allama Iqbal International Airport [29]. These initiatives aimed to optimize operations and enhance environmental sustainability. For instance, the Pakistani authorities are urged to implement green packaging, transportation, and supply chain design to promote green economic growth [30]. Additionally, research has analyzed the impact of different transport infrastructure types on industrial output in Pakistan, contributing to the understanding of the country's transportation dynamics [29].

2. Literature Review and Hypotheses Development

This study is structured with a dual framework, incorporating both a hypothetical and theoretical foundation. Hypothetical framing primarily deals with formulating research questions, hypotheses, and predictions. It focuses on developing testable statements or educated guesses about the relationships or outcomes you expect to find in your research. It is about creating a structure for empirical investigation and experimentation. Theoretical framing, on the other hand, revolves around establishing the intellectual context and grounding for a research study. It involves delving into existing theories, models, and concepts in the field to understand how your research fits within a broader academic discourse.

2.1. Linking Reducing Cost of Site Activities and Transport Infrastructure Projects Success

According to [31], supply chain management comprises a range of organizational efforts to achieve diverse objectives, such as lowering costs, reducing lead times, enhancing profitability, and ensuring customer satisfaction. In response to challenges related to lead times, delivery uncertainty, and logistics expenses, the construction sector anticipates a growing need for logistics centers. [32]. Cost overrun is the word used when the actual cost of a project is higher than the initial projections [33]. Cost overruns are major obstacles to project development, and they are especially common in the building sector, especially in developing nations [34]. Project costs increase due to overruns, harming customers and contractors [35]. According to Saidu and Shakantu [36], the construction sector suffers several difficulties, including poor financial performance, high project delivery costs, delays, and material waste. Pakistani infrastructure projects frequently incur debts double what they originally cost [37]. Due to societal sustainability difficulties, such as land issues, the China–Pakistan Economic Corridor (CPEC) project under the one belt, one road (OBOR) plan is experiencing cost inflation and delays [38]. By increasing productivity, meeting deadlines, and producing effective results, cutting expenses in site activities improves project performance [38]. These academic works offer actual data supporting the claim that improving TIP performance is associated with cost-cutting in site operations. Effective cost control may result in better financial results, the prevention of cost overruns, increased project efficiency, and the successful completion of projects [18]. Based on the literature mentioned above, we may hypothesize that:

Hypothesis 1 (H1). *Reducing the cost of site activities has a positive relationship with the success of transport infrastructure projects.*

2.2. Linking Reducing Cost of Logistics Activities Lead Time and Inventory with Transport Infrastructure Projects' Success

Logistics expenses impact a nation's national, regional, and business GDP [39]. According to IT management, the entire logistics cost should be reduced before specific activity expenses. Lead time is now used to qualify orders and is critical to how customers see a company's performance [40]. Logistics performance includes logistics productivity and service performance [41]. The primary goals of evaluating logistics performance are to reduce operational expenses, stimulate revenue growth, and enhance shareholder value [42]. The incoming logistics chain should evaluate factors including manufacturing, shipping, customs brokerage, and delivery in terms of overall lead time to increase efficiency [14]. Project failures in Pakistan's construction sector result from time and expense overruns, which impede development by government goals [43]. Lead time efficiency may be increased by better coordination across supply chain activity phases. According to research by [44], which looked at the effect of logistics performance on the success of construction projects, effective logistics operations favorably impact project performance and enhance overall project outcomes. Major transportation infrastructure projects' performance is heavily influenced by lead time. Reducing lead time can lead to greater resource utilization, on-time project completion, and increased project efficiency. According to [45], good inventory control benefits project outcomes, including cost, schedule, and quality. The study looked at the effect of inventory management on construction project performance. Based on the above, we can hypothesize the following.

Hypothesis 2 (H2). *Reducing the cost of logistic activities, lead time, and inventory has a positive relationship with the success of transport infrastructure projects.*

2.3. Linking Transferring Activities from the Site to Earlier Stages of the Supply Chain and Transport Infrastructure Projects Success

Coordination, cooperation, and agility must be prioritized by businesses to improve their supply chain capabilities [18]. This will boost performance and lead time efficiency [46]. The client/owner, designer, general contractor, subcontractor, and suppliers are just a few stakeholders responsible for the construction process [47]. Although supply chain management may be employed on a project-by-project basis, it offers its greatest potential gains when used throughout several projects, at the enterprise level, and with the participation of numerous companies [31]. Project results can be improved in terms of cost, time, and quality by moving tasks from the site to earlier phases of the supply chain, such as pre-construction planning and design. According to research by [7], engaging the supply chain at an early stage positively influences project success factors, encompassing cost management, adhering to schedules, and mitigating risks. The research investigated how early supply chain involvement affects project performance, indicating that major transportation infrastructure projects could achieve better outcomes by shifting operations from the construction site to the pre-construction planning phase. The study also explored the effectiveness of design optimization in enhancing the performance of substantial infrastructure projects [48], and it was discovered that early design optimization had a favorable impact on project success variables, including cost savings, increased project delivery, and improved project quality. We can propose the following hypothesis.

Hypothesis 3 (H3). *Transferring activities from the site to earlier stages of the supply chain has a positive relationship with the success of transport infrastructure projects.*

2.4. Linking Management and Improvement of Supply Chain and Site Production with the Success of Transport Infrastructure Projects

Clients, suppliers, or contractors may adopt this emphasis and incorporate the site's output into supply chain management [49]. Supply chain integration improves cooperation, resource allocation, and responsiveness, contributing to total project performance. It helps businesses respond to shifting consumer needs and market conditions, boosting customer happiness and competitiveness [50]. The coordination of information, materials, funds, and services is performed by several parties and organizations, including the owner, general contractor, subcontractors, and suppliers. This network experiences several information transformations [51]. Open buildings and sequential processes have been suggested as new methods for integrated management of the construction site and supply chain [52]. Effective supply chain management is a prerequisite for the success of major transportation infrastructure projects. It enhances project performance by optimizing cost control, ensuring timely delivery, and facilitating the use of higher-quality materials and components [14]. According to [53], efficient supply chain management enhances project outcomes by reducing expenses, optimizing resource utilization, and improving project coordination. According to [54], effective on-site production management contributes positively to project success factors, such as labor efficiency, cost-efficiency, and meeting project schedule milestones. Furthermore, [55] found that successful supply chain integration positively impacts key success factors in construction projects, including cost control, adherence to project schedules, and stakeholder satisfaction. We can hypothesize the following statement according to above mentioned literature.

Hypothesis 4 (H4). *Management and improvement of the supply chain and site production have a positive relationship with the success of transport infrastructure projects.*

2.5. Linking Building Information Modeling, Supply Chain Management, and Transport Infrastructure Projects Success

BIM enhances collaboration and inter-professional teamwork, reducing the likelihood of conflicts and errors during design and construction [19]. Improved communication can lead to more effective project coordination and planning, ultimately reducing the necessity for rework and associated expenses [56]. BIM enables the early identification of conflicts between various building components and infrastructure systems in the design phase. This early conflict detection helps reduce costs and delays by avoiding expensive modifications during the construction phase [57]. BIM enhances building operation visualization and coordination, integrating logistics planning [12]. BIM fosters collaboration between manufacturers, suppliers, and transportation companies, providing valuable insights for streamlining operations, reducing expenses, and improving the performance of transport infrastructure [58]. BIM assists in lowering transportation costs, fuel consumption, and emissions related to site delivery and garbage collection by simulating and optimizing transportation routes and timetables [59]. Enhanced coordination positively impacts transportation infrastructure performance by streamlining operations and reducing delays [60]. There is a chance for cost savings through economies of scale and resource efficiency by moving operations from the site to earlier supply chain stages. BIM eliminates waste and enhances resource usage by allocating materials, equipment, and personnel [61]. This has a favorable effect on the entire supply chain and transportation infrastructure performance. The possibilities of BIM go beyond the realm of construction to enable asset management across the course of an infrastructure's lifetime. According to [62], BIM plays a moderating role in enhancing the relationship between supply chain management practices and the performance of transport infrastructure projects. BIM helps optimize supply chain activities, improves coordination, and ultimately positively influences the overall performance of transport infrastructure projects [14]. We can hypothesize the following statement according to above mentioned literature.

Hypothesis 5 (H5). *Building information modeling moderates the relationship between supply chain management and the success of transport infrastructure projects.*

2.6. Linking Environmental Consideration, Supply Chain Management, and Transport Infrastructure Projects' Success

According to the study [63], the environmental aspects of the infrastructure project play a moderating role in the extent to which cost savings in site operations lead to performance enhancements. Shifting supply chain operations positively influences the effectiveness of logistics and transportation systems, according to a previous study by [64], focusing on transportation infrastructure's efficiency and effectiveness. According to [65], numerous environmental factors pose greater organizational structure and project management challenges. These factors encompass political, legal, institutional, cultural, sociological, technical resources, economic, financial, and physical (infrastructure) dimensions. As mentioned by [66], it is essential to engage in activities that improve resource management, including reducing environmental impact [67]. Reducing carbon emissions, energy use, and waste production can be accomplished by including environmental considerations in supply chain choices [68]. An efficient transportation infrastructure, such as well-maintained highways, railroads, and ports, is essential for supply chain management and on-site production. Lead times are shortened, logistics costs are decreased, and supply chain efficiency is generally improved by high-quality infrastructure [69].

Additionally, timely delivery of building supplies is made possible by improved transportation infrastructure, lessening transportation operations' carbon footprint [70]. The environmental effect of supply chain operations has been studied, emphasizing sustainable packaging, eco-friendly transport methods, and route optimization [71]. We can hypothesize the following statement according to above mentioned literature.

Hypothesis 6 (H6). *Environmental considerations moderate the relationship between supply chain management and the success of transport infrastructure projects.*

Table 1 below summarizes and lists some theories connected to this study.

Table 1. Supportive Theories [72].

Theory	Description	Link with This Study
Resource-Based View (RBV)	This theory emphasizes the role of resources in achieving a competitive advantage. Effective supply chain management can be seen as a valuable resource contributing to project success [73].	Explains how supply chain management as a resource impacts the success of infrastructure projects.
Transaction Cost Economics (TCE)	TCE focuses on minimizing transaction costs. Efficient supply chain management can reduce costs and positively influence project success [74].	Shows how efficient supply chain management can lead to cost reduction and project success.
Innovation Diffusion Theory	This theory can be used to study the spread and adoption of BIM within the construction sector and its impact on supply chain practices and project outcomes [75].	Examines the diffusion of BIM, another moderating factor, and its impact on supply chain and project success.
Institutional Theory	Environmental factors often include regulatory and institutional aspects. Institutional theory helps explore how these factors shape supply chain practices and project success [76].	Investigates how external factors, such as regulations, influence supply chain practices and project success.
Resource Dependency Theory	This theory highlights how organizations depend on their environment for resources. It helps discuss how environmental factors influence the resources available for supply chain management in infrastructure projects [77].	Explores the interplay between environmental factors and the availability of resources for supply chain management.
Contingency Theory	Contingency theory emphasizes the importance of matching management practices to the specific context. This theory can be used to explore how supply chain management practices might need to be adapted in response to the moderating effects of BIM and environmental factors [78].	Investigates how supply chain management practices should be tailored to the specific context, considering BIM and environmental factors as moderators.

Figure 1 presents our proposed hypothesis and the underlying theoretical framework. This model has been developed by the authors and is based on comprehensive elaboration.

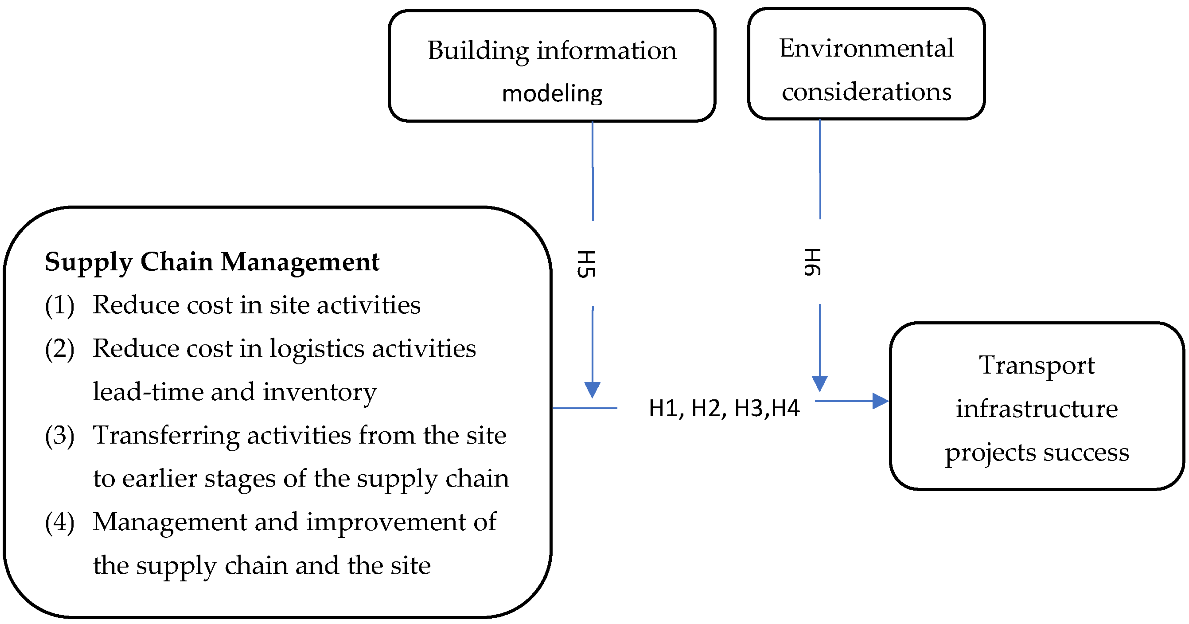

Figure 1. Theoretical Framework.

3. Methodology

3.1. Study Design

This study used a research approach focused on collecting and analyzing numerical data. The research was structured to test specific hypotheses, allowing for investigations from the relevant industry.

3.2. Study Participants

The research involved individuals employed at construction companies. The study's participants were also individuals working on projects related to transportation infrastructure. Addresses were acquired through participants who voluntarily supplied their social media information when choosing to engage in surveys, demonstrating their readiness to be contacted for research purposes. Online panels, frequently employed by research organizations, involved individuals signing up for various studies, with panel members offering their social media participants' information as part of their profiles.

3.3. Data Collection Tool

Data were gathered through an adopted structured questionnaire administered to the participants. Incorporating an adopted questionnaire, the researcher initiated the process by conducting a comprehensive literature review to find a questionnaire that suited this research's needs. The researcher delved deeply into the original context and purpose of the questionnaire, assessing its alignment with this research objective. Customization and adjustments were made as necessary, followed by a pilot test for clarity. The researcher also ensured the questionnaire's validity and reliability before administering it to the intended participants. To ensure valid questionnaire responses, the researcher defined clear research objectives, conducted a pretest to identify and resolve issues, used clear language to minimize misinterpretation, and avoided leading questions. These steps collectively enhance response validity and data quality. RCSA, with 6 associated items; RCLATI, with 5 associated items; TASC, with 5 associated items; MISCSP, with 5 associated items; TIP, with 5 associated items; BIM, with 8 associated items; and EC, with 5 associated items were scored on a 5-Point Likert scale (from "1—strongly disagree" to "5—strongly agree"). The survey used a scale to assess the participants' responses, ranging from strongly disagree to strongly agree. This instrument is appropriate for research objectives and aligns with the constructs intended to measure. Researchers demonstrated that the selected questionnaire has been used in prior research and cited studies that have successfully employed a similar instrument. Tools and instruments used for data measurement are explained in Table 2.

The questionnaire includes vital components: a clear title defining its purpose, an introduction explaining objectives and ensuring anonymity, precise instructions for completion, a demographic data section, structured main questions tailored to research objectives, well-defined response options, closing remarks expressing gratitude and contact details, and an informed consent statement for sensitive data.

3.4. Data Collection Procedure

The potential respondents for the study were selected from a roster comprising individuals and entities directly engaged in or impacted by transport infrastructure projects in Pakistan. Random sampling methodology was selected to collect data. Different construction companies and transport infrastructure projects operating in Pakistan were chosen for study. Participants were selected randomly to ensure the sample was representative of the population. To generate a randomized sample, all projects in Pakistan were precisely delineated to form a comprehensive understanding of the population. Subsequently, a thorough list of these projects was developed, serving as the sampling frame. The sample size was determined by establishing the number of projects for the study based on available resources and desired precision. Random sampling methods were employed for unbiased selection. Finally, the chosen method was implemented to systematically choose projects from the established frame, ensuring a representative and unbiased sample for further analysis. The survey questionnaires were sent to participants electronically via Google Forms, email, and WhatsApp. The survey contained detailed and specific questions relating to each variable under investigation. The participants were supply chain professionals, supply chain managers, supply chain directors, contractors, and suppliers.

Table 2. Survey Stats with Demographics Stats with Percentage.

Respondent's Profile	Construct and Items	Stats with Percentage
Questionnaire Response	Total Questionnaires Distributed	270 (100%)
	Total Questionnaires Received	245 (90.7%)
	Unusable/Incomplete Questionnaires	17 (6.9%)
	Total Useable Questionnaires	228 (84.4%)
Job Title	Supply Chain Professionals	
	Operations Development Manager	64 (28%)
	Business Architect	66 (28.9%)
	Director of Procurement and Logistics	45 (19.7%)
	Contractors	32 (14.1%)
	Suppliers	21 (9.3%)
Gender	Male	159 (69.7%)
	Female	69 (30.3%)
Respondent's Age	Less than 25	66 (28.9%)
	26–35	59 (25.8%)
	36–45	40 (17.5%)
	46–55	35 (15.4%)
	56 and above	28 (12.4%)
Job Experience	<5 years	57 (25%)
	5–10 years	45 (19.7%)
	11–15 years	55 (24.2%)
	16–20 years	44 (19.3%)
	More than 20 years	27 (11.8%)
Size of Company	Small (10–49 employees)	89 (39%)
	Medium (50–249 employees)	96 (42.2%)
	Large (250 or more)	43 (18.8%)
No. of Employees	Less than 30	86 (37.7%)
	31–50	60 (26.4%)
	51–70	35 (15.4%)
	71–90	27 (11.7%)
	More than 90 workers	20 (8.8%)

Random sampling was chosen because it ensures fairness by giving all population elements an equal chance in the sample, minimizes selection bias, leading to more impartial and less skewed results, supports the use of statistical methods for reliable population-wide conclusions, and is straightforward to implement, even when population details are limited. In survey research, preventing the completion of multiple questionnaires by the same respondent is a prevalent consideration to uphold data integrity and mitigate biases. It was crucial to transparently inform participants that their responses would be kept anonymous and confidential, ensuring that their individual answers remained unlinked to their identity. To further safeguard against duplicates, time constraints were imposed between survey submissions originating from the same IP address or device. Survey responses were regularly investigated for any discernible patterns or anomalies that might have suggested repeated submissions from a single individual, and subsequently, any identified duplicate entries were investigated and eliminated.

Participants were given prior notice regarding the expected duration for completing the questionnaire. The anticipated completion time was communicated as being approximately 10 to 15 min, offering prospective respondents transparency and the opportunity to plan accordingly. There was no incentive provided for participants in this study because of budgetary limitations, and participation was ensured through multiple requests.

All potential respondents were ensured anonymity; various steps were taken to safeguard the privacy and identity of each participant. Measures included identifying responses, assuring confidentiality, implementing robust data security, and undergoing ethical review to align with privacy standards. Participants were granted the freedom to stop or discontinue their involvement in the survey at any stage without facing any negative consequences or penalties. This flexibility acknowledges and respects the autonomy of respondents, allowing them to select out without being subject to adverse actions or repercussions. This practice is often employed to ensure a voluntary and non-coercive survey experience for participants.

3.5. Data Quality Check Procedure

The study began with an initial group of 245 participants. Efforts were made to encourage participants to provide accurate and complete information. Data collection between January and March 2023 resulted in the acquisition of 245 questionnaires. Among these, 17 were deemed incomplete, leading to 228 valid questionnaires. Within the 17 incomplete questionnaires, 6 outlier responses were identified and subsequently excluded, as these incomplete forms accounted for over 5% of the missing data. Consequently, our final data set consists of 228 fully completed and accurate questionnaires.

When comparing the characteristics outlined in this study to the broader SCM industry in Pakistan, it is crucial to recognize industry norms. The SCM sector in Pakistan, aligning with global standards, prioritizes efficient goods and services management, cost reduction, and product delivery. Professionals in Pakistan's SCM industry likely share similar skills and engage in analogous activities to those in the study. However, the representativeness of the sample depends on the study's focus, sample size, sector representation, and geographic distribution, influencing the findings' generalizability to the entire SCM industry in Pakistan.

An applied *t*-test yielded no significant differences ($p < 0.05$) in industry-based responses, indicating that the type of industry had no discernible impact. Employing the method outlined by [79], no significant differences were observed between early and late respondents, suggesting the absence of systematic non-response bias. To mitigate social desirability response bias, the research team utilized anonymous questionnaires to encourage candid responses. The questions were framed as impartial and non-leading, and confidentiality was guaranteed. The study also refrained from discussing socially desirable answers and conducted pilot testing to address potential bias issues. To evaluate the presence of common method variance, the recommendations put forth by [80] were followed. The results indicated that no single factor could explain variance in the variables, suggesting the absence of significant common method variance.

Furthermore, a thorough assessment was carried out to address multicollinearity, adhering to the criteria outlined by [81]. The results revealed that the model was free from multicollinearity, as all variance inflation factor (VIF) values fell below the established threshold of 3.3. The VIF values are presented in Table 3.

Table 3. Descriptive Statistics.

Variables	Mean	Standard Deviation	N
RCSA	3.36	0.054	228
RCLATI	4.38	0.061	228
TASC	3.19	0.072	228
MISCSP	4.28	0.081	228
TIP	4.12	0.063	228
BIM	3.59	0.069	228
EC	4.48	0.076	228

3.6. Data Analysis

The data were analyzed using the partial least squares method, chosen for its suitability with small sample sizes and its ability to work with various measurement scales. PLS was chosen because it can effectively analyze data despite a limited sample size. PLS does not assume that data need to be measured on a particular scale. PLS was employed to test hypotheses and clarify relationships between different variables.

Demographic statistics and data evaluations are presented in Table 2 of the study for a comprehensive understanding of the data.

Table 3 provides summary statistics for each variable, including the mean, standard deviation, and sample size. The mean is a measure of central tendency that represents the average value of the variable. For example, RCSA has a mean of 3.36, RCLATI has a mean of 4.38, TASC has a mean of 3.19, and so on. The standard deviation measures the dispersion or variability of the data points around the mean. It indicates how much the values deviate from the average. For instance, RCSA has a standard deviation of 0.054, RCLATI has a standard deviation of 0.061, TASC has a standard deviation of 0.072, and so forth.

Table 4 explains the source of measurement instruments and detailed questions used for various variables. The abbreviations in the table represent the latent constructs being studied: reduce cost in site activities (RCSA); reduce cost in logistics activities, lead time, and inventory (RCLATI); transfer activities from the site to earlier stages of the supply chain (TASC); management and improvement of the supply chain and the site production (MISCSP); transport infrastructure performance (TIP); building information modeling (BIM); and environmental consideration (EC).

Table 4. Source of measurement instruments.

Constructs	Item	Description	Source
RCSA	RCSA1	To what extent do you agree with the statement: Reducing cost in site activities is crucial for transport infrastructure projects?	[82,83].
	RCSA2	Reducing costs in site activities, such as construction materials, labor, and equipment, is crucial for completing major transport infrastructure projects.	
	RCSA3	Lowering site activity costs positively impacts major transport infrastructure projects' overall performance and efficiency.	
	RCSA4	Implementing cost reduction measures in site activities can result in better financial outcomes for major transport infrastructure projects.	
	RCSA5	Adequate cost management in site activities is a key factor in the timely completion of major transport infrastructure projects.	
	RCSA6	Minimizing costs in site activities is essential for maximizing the value and benefits of major transport infrastructure projects.	
RCLATI	RCLATI1	Reducing costs in logistic activities is essential for improving the performance of major transport infrastructure projects.	[84,85].
	RCLATI2	A shorter lead time in logistic activities positively affects the performance of major transport infrastructure projects.	
	RCLATI3	Efficient inventory management is crucial for enhancing the performance of major transport infrastructure projects.	
	RCLATI4	There is a direct relationship between reducing costs in logistic activities, lead time, inventory, and the performance of major transport infrastructure projects.	
	RCLATI5	Lead time reduction in logistic activities is crucial for the successful performance of major transport infrastructure projects.	

Table 4. *Cont.*

Constructs	Item	Description	Source
TASC	TASC1	Transferring activities from the site to earlier supply chain stages can improve project scheduling and timeliness in major transport infrastructure projects.	[86,87].
	TASC2	Transferring activities from the site to earlier supply chain stages can enhance coordination and communication among project stakeholders in major transport infrastructure projects.	
	TASC3	Transferring activities from the site to earlier supply chain stages can result in better quality control and risk management in major transport infrastructure projects.	
	TASC4	Transferring activities from the site to earlier supply chain stages can increase overall project performance and success in major transport infrastructure projects.	
	TASC5	Transferring activities from the site to earlier supply chain stages can lead to cost savings in major transport infrastructure projects.	
MISCSP	MISCSP1	To what extent do you agree with the statement: Effective supply chain management is essential for the transport infrastructure project.	[88,89].
	MISCSP2	Managing the supply chain and site production effectively is crucial for completing major transport infrastructure projects.	
	MISCSP3	Improved supply chain and site production processes can positively impact the performance of major transport infrastructure projects.	
	MISCSP4	Effective coordination among stakeholders in the supply chain and site production can enhance the overall performance of major transport infrastructure projects.	
	MISCSP5	Continuous improvement of supply chain and site production management can lead to better project outcomes for major transport infrastructure projects.	
TIP	TIP1	Our transport infrastructure projects' construction supply chain management is well-coordinated and efficient.	[89,90].
	TIP2	There is effective collaboration and communication among various stakeholders in the construction supply chain in our transport infrastructure projects.	
	TIP3	The construction supply chain management in our transport infrastructure projects ensures the timely delivery of materials and resources.	
	TIP4	Our transport infrastructure projects' construction supply chain management practices promote cost-effectiveness and resource optimization.	
	TIP5	Our transport infrastructure projects' construction supply chain management effectively addresses potential risks and uncertainties.	
BIM	BIM1	BIM technology enhances stakeholder collaboration in the construction and transport infrastructure supply chain.	[91,92].
	BIM2	BIM can mitigate risks in supply chain disruptions and unexpected changes during construction and infrastructure projects.	
	BIM3	BIM integration optimizes coordination between SCM activities and project design, improving performance outcomes.	

Table 4. *Cont.*

Constructs	Item	Description	Source
BIM	BIM4	Integrating supply chain management practices with BIM can lead to better project outcomes.	
	BIM5	BIM implementation leads to better decision-making within the supply chain management of construction and transport projects.	
	BIM6	BIM effectively moderates communication between different supply chain participants, enhancing information flow.	
	BIM7	BIM facilitates better visualization of project components, leading to improved decision-making in supply chain management.	
	BIM8	BIM improves the accuracy and quality of project documentation, reducing errors and rework.	
EC	EC1	Environmental impact considerations should be central to the decision-making process throughout the construction and transport project life cycle.	[93].
	EC2	Integrating environmental impact assessment into SCM processes enhances overall project sustainability.	
	EC3	Effective supply chain management can significantly minimize the environmental impact of construction and transport infrastructure projects.	
	EC4	The awareness and commitment of senior management within construction and transport infrastructure companies greatly influence the extent to which environmental impact is considered in supply chain decisions.	
	EC5	Environmental considerations should be given equal importance to cost and time factors in construction and transport infrastructure project decision-making.	

4. Results and Discussions

Partial least squares structural equation modeling (PLS-SEM) is a statistical method used in social sciences, business, and related disciplines to analyze and model complex relationships between variables. It is particularly valuable when dealing with small sample sizes, non-normal data, and complex models. PLS-SEM combines elements of partial least squares regression and structural equation modeling to examine the measurement (reflective and formative) and structural relationships between latent constructs and observed variables.

Below, in Table 5, is a breakdown of the key steps involved in partial least squares structural equation modeling (PLS-SEM), from data preprocessing to reporting findings.

PLS-SEM differs from other structural equation modeling techniques, such as covariance-based SEM.

PLS-SEM is considered more flexible and versatile in terms of model specification, allows for both reflective and formative measurement models, employs a non-parametric method to estimate path coefficients, is more tolerant of missing data and can handle missing values through techniques such as mean imputation, and is often chosen when the primary focus is on predictive modeling, model development, and exploring relationships between variables.

CB-SEM is often used for confirmatory research where a priori models with well-established relationships are tested, mainly uses reflective measurement models, uses maximum likelihood estimation to estimate path coefficients, typically requires complete data for each case, and CB-SEM is often chosen when the focus is on model validation and hypothesis testing within well-established theoretical frameworks.

PLS-SEM excels in scenarios where sample sizes are limited, and data do not meet multivariate normality assumptions. Researchers are exploring complex or evolving models when predictive modeling is the primary objective. Its flexibility, robustness, and applicability across various domains make it a preferred choice.

Table 5. Key Steps in PLS-SEM.

Step	Description
Step 1: Data Prepossessing	Prepare data by handling missing values, outliers, and quality issues. Normalize or standardize data if necessary.
Step 2: Specify the Measurement Model	Define the relationships between latent variables (constructs) and their observed indicators. Indicate the model's reflective or formative nature.
Step 3: Indicator Weighting	Using the PLS algorithm, assign weights to indicators based on their relationships with constructs.
Step 4: Assess Measurement Model	Evaluate the measurement model's reliability and validity. Examine factor loadings, composite reliability, and average variance extracted (AVE).
Step 5: Specify the Structural Model	Define the relationships between latent variables in the structural model. Indicate hypothesized paths and expected effects.
Step 6: Path Coefficient Estimation	Use PLS-SEM to estimate path coefficients, representing the strength and direction of relationships between latent variables.
Step 7: Bootstrapping Analysis	Perform bootstrapping to assess the significance of path coefficients and their confidence intervals.
Step 8: Assess the Structural Model	Evaluate the goodness of fit of the structural model, considering metrics like R-squared and Q-squared.
Step 9: Model Validation	Assess the model's predictive validity through holdout samples or cross-validation techniques.
Step 10: Report Findings	Present results of the PLS-SEM analysis, including path coefficients, significance levels, model fit statistics, interpretations, and insights.

4.1. Composite Reliability and Cronbach's Alpha

The questionnaire instrument's robustness was evaluated using Cronbach's alpha and composite reliability. The lowest acceptable value for both factors was usually between 0.70 and 0.95 [94]. Using Smart PLS 3.0, the findings of the composite reliability testing and the results of determining Cronbach's alpha value for the four constructs evaluated in this study are shown in Table 6. The table displays the results of composite reliability testing for the variables in the study. Composite reliability and Cronbach's alpha were calculated to assess each construct's internal consistency and reliability. All constructs achieved satisfactory levels of reliability.

Table 6. Composite Reliability Test Results.

Variables	Composite Reliability	Cronbach's Alpha
RCSA	0.91	0.878
RCLATI	0.912	0.881
TASC	0.914	0.86
MISCSP	0.89	0.85
TIP	0.84	0.718
BIM	0.938	0.923
EC	0.899	0.86

4.2. Average Variance Extracted (AVE)

By looking at the AVE values in Table 7, it is possible to evaluate the convergence validity. A strong level of convergent validity is indicated by an AVE score of greater than 0.5, which implies that latent variables often explain more than half of the variation in the indicators. The table presents the results of the convergent validity assessment using average variance extracted (AVE) for the variables in the study. The AVE values were computed to evaluate the convergent validity of each construct. All constructs achieved good convergent validity.

Table 7. Convergent Validity Assessment Using Average Variance Extracted (AVE).

Variables	AVE	Validity
RCSA	0.669	Good
RCLATI	0.675	Good
TASC	0.783	Good
MISCSP	0.634	Good
TIP	0.639	Good
BIM	0.684	Good
EC	0.691	Good

4.3. Discriminant Validity

Discriminant validity is important in research and statistical modeling as it guarantees the differentiation of various constructs or variables within a study. It involves evaluating how effectively the items intended to measure one specific construct can be distinguished from those designed for other constructs. Multiple techniques can be applied to assess discriminant validity, including correlation analysis, the Fornell-Larcker criterion, and the heterotrait–monotrait ratio (HTMT). Below, in Tables 8–10, are the findings of the discriminant validity test. When evaluating discriminant validity, the Fornell-Larcker criteria compares the square root of each construct's average variance extracted (AVE) to correlations between that construct and every other construct in the model. According to the Fornell-Larcker criterion, each construct's square root of the AVE needs to be higher than the correlation between it and all other constructs [95].

Table 8. Correlation Matrix.

	BIM	EC	MISCSP	RCLATI	RCSA	TASC	TIP
BIM	1						
EC	0.389	1					
MISCSP	0.571	0.459	1				
RCLATI	0.541	0.389	0.392	1			
RCSA	0.458	0.441	0.473	0.54	1		
TASC	0.592	0.54	0.596	0.586	0.407	1	
TIP	0.543	0.358	0.415	0.421	0.55	0.437	1

Table 9. Discriminant Validity (Fornell-Larcker) Test Results.

	BIM	EC	MISCSP	RCLATI	RCSA	TASC	TIP
BIM	0.827						
EC	0.626	0.831					
MISCSP	0.103	0.078	0.796				
RCLATI	0.296	0.368	0.389	0.822			
RCSA	0.367	0.408	0.441	0.524	0.818		
TASC	0.072	0.277	0.54	0.579	0.373	0.883	
TIP	0.21	0.358	0.358	0.357	0.488	0.42	0.799

In structural equation modeling (SEM), the heterotrait–monotrait ratio (HTMT) is a statistical tool for evaluating discriminant validity. The HTMT ratio contrasts the mean correlation of items measuring many constructs (heterotrait) with the mean correlation of items measuring a single construct (monotrait).

Table 10. Heterotrait–Monotrait Ratio (HTMT) as a Measure of Discriminant Validity.

	BIM	EC	MISCSP	RCLATI	RCSA	TASC
BIM						
EC	0.741					
MISCSP	0.148	0.108				
RCLATI	0.344	0.436	0.437			
RCSA	0.414	0.485	0.477	0.608		
TASC	0.151	0.304	0.616	0.646	0.417	
TIP	0.257	0.238	0.441	0.435	0.566	0.531

4.4. Cross Loading

The cross-loading test results table shows the correlation coefficients between different variables and their respective indicators. VIF values below 5 suggest no significant multicollinearity issues in our estimation model. The table appears to be part of a factor analysis or structural equation modeling (SEM) analysis. The results of the cross-loading test and VIF are shown in Table 11 below.

Table 11. Cross-Loading Test and VIF Results.

Variables	Indicators	BIM	EC	MISCSP	RCLATI	RCSA	TASC	TIP	VIF
BIM	BIM1	0.811	0.488	0.097	0.297	0.28	0.077	0.229	2.204
	BIM2	0.864	0.555	0.059	0.274	0.373	0.027	0.202	3.001
	BIM3	0.855	0.549	0.031	0.217	0.281	0.074	0.266	2.829
	BIM4	0.823	0.504	0.067	0.146	0.265	0.057	0.253	2.47
	BIM5	0.85	0.502	0.087	0.3	0.247	0.097	0.23	2.478
	BIM6	0.821	0.489	0.135	0.259	0.278	−0.06	0.191	1.007
	BIM7	0.762	0.451	0.091	0.247	0.317	0.009	0.174	2.876
	BIM8	0.699	0.459	0.1	0.161	0.166	−0.017	0.05	2.234
EC	EC1	0.444	0.777	0.069	0.267	0.271	0.207	0.217	1.616
	EC2	0.56	0.843	0.085	0.364	0.377	0.261	0.2	2.424
	EC3	0.705	0.808	0.022	0.325	0.394	0.156	0.16	2.51
	EC4	0.514	0.824	0.067	0.302	0.359	0.315	0.197	2.381
	EC5	0.176	0.594	0.176	0.14	0.181	0.262	0.193	1.978
MISCSP	MISCSP1	0.095	0.059	0.746	0.288	0.304	0.422	0.215	1.883
	MISCSP2	0.003	0.184	0.816	0.295	0.421	0.506	0.374	2.428
	MISCSP3	0.146	0.072	0.875	0.343	0.335	0.505	0.362	1.772
	MISCSP4	0.049	0.049	0.811	0.354	0.473	0.499	0.403	1.895
	MISCSP5	0.172	0.046	0.703	0.238	0.247	0.388	0.116	2.349
RCLATI	RCLATI1	0.319	0.378	0.261	0.791	0.523	0.368	0.272	2.344
	RCLATI2	0.316	0.311	0.327	0.824	0.428	0.483	0.325	2.401
	RCLATI3	0.283	0.33	0.315	0.853	0.458	0.483	0.343	2.484
	RCLATI4	0.292	0.328	0.279	0.875	0.446	0.514	0.414	1.774
	RCLATI5	0.022	0.164	0.426	0.765	0.388	0.536	0.356	1.888
RCSA	RCSA1	0.32	0.3	0.331	0.392	0.789	0.27	0.442	2.421
	RCSA2	0.304	0.371	0.412	0.386	0.845	0.357	0.503	2.036
	RCSA3	0.293	0.358	0.423	0.472	0.845	0.37	0.57	2.153
	RCSA4	0.25	0.296	0.342	0.42	0.778	0.274	0.32	2.307
	RCSA5	0.333	0.357	0.295	0.492	0.791	0.291	0.34	2.159
	RCSA6	0.112	0.23	0.423	0.423	0.68	0.352	0.342	2.506
TASC	TASC1	0.2	0.361	0.422	0.579	0.406	0.855	0.459	2.025
	TASC2	0.044	0.216	0.509	0.53	0.316	0.867	0.377	1.393
	TASC3	0.099	0.217	0.531	0.399	0.3	0.862	0.355	1.751
	TASC4	0.239	0.069	0.52	0.383	0.237	0.71	0.181	2.227
	TASC5	0.039	0.321	0.48	0.398	0.335	0.682	0.258	1.159

Table 11. *Cont.*

Variables	Indicators	BIM	EC	MISCSP	RCLATI	RCSA	TASC	TIP	VIF
TIP	TIP1	0.238	0.129	0.255	0.285	0.387	0.233	0.717	2.532
	TIP2	0.223	0.276	0.301	0.308	0.496	0.378	0.858	2.325
	TIP3	0.025	0.028	0.34	0.252	0.235	0.354	0.649	1.695
	TIP4	0.103	0.185	0.254	0.24	0.26	0.271	0.558	1.729
	TIP5	0.316	0.239	0.347	0.399	0.512	0.334	0.773	2.983

4.5. Evaluation of Structural Model (Inner Model)

The R^2 test findings are shown in Table 12 below, showing how much external influences can explain the variability of the endogenous variable. Changes in the R^2 value can be used to detect significant effects of external latent factors on endogenous latent variables.

Table 12. Coefficient Determination.

Variable	R^2 Adjusted
TIP	0.422

The R^2 value in the table shows that factors such as "reduce cost in logistics activities and inventory", "transfer activities from the site to earlier stages of the supply chain", and "management and improvement of the supply chain and the site production" have an impact on 42.2% of TIP in construction companies. However, additional factors not investigated in this study are responsible for 57.8% of TIP in construction enterprises.

4.6. Path Coefficients

Direct and moderation effect analysis yielded the results shown in Table 13 below.

Table 13. Direct and Moderation Effect Analysis.

Direct Effect	Hypothesis	Coefficient	STDEV	t-Value	Supported
RCSA -> TIP	H1	0.200	0.037	16.224	Yes
RCLATI -> TIP	H2	0.107	0.031	6.454	Yes
TASC -> TIP	H3	0.321	0.035	5.391	Yes
MISCSP -> TIP	H4	0.171	0.037	5.636	Yes
Moderation Effect					
BIM × SCM -> TIP	H5	0.631	0.028	4.169	Yes
EC × SCM -> TIP	H6	0.640	0.037	3.475	Yes

The table presents the results of the direct and moderation effect analysis, which explores the relationships between different variables and examines the moderating influences on these relationships.

According to the direct effect analysis findings, the independent variables RCSA, RCLATI, TASC, and MISCSP all appear to have a statistically significant effect on the dependent TIP, shown in Figure 2.

According to the results of the moderation effect study, the moderator variables (BIM and EC) strongly moderate the interactions between the independent factors and the dependent variable, providing new information about the model's overall impact, as shown in Figure 3. This study includes six proposed hypotheses, and their associated discussions are shown below.

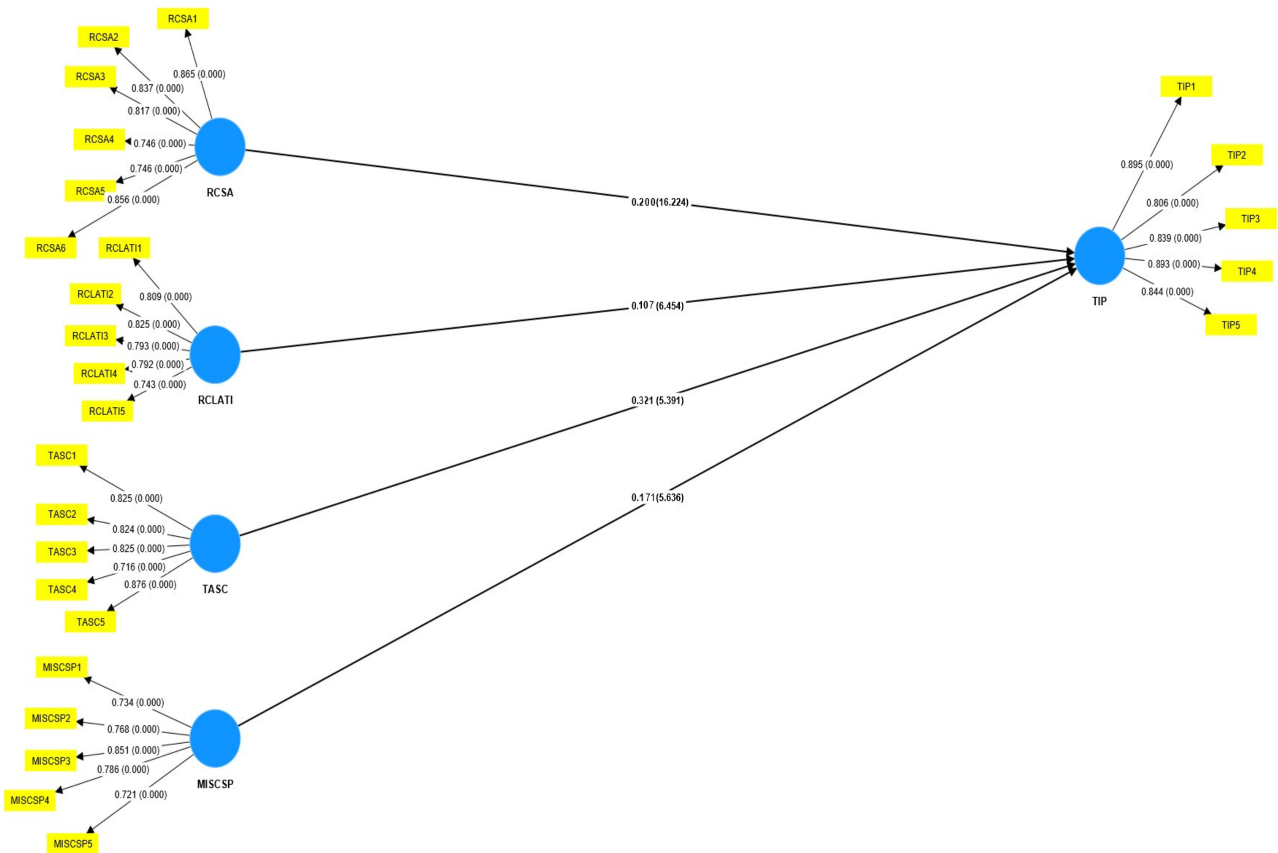

Figure 2. Path Coefficients Test Results (Direct Effect).

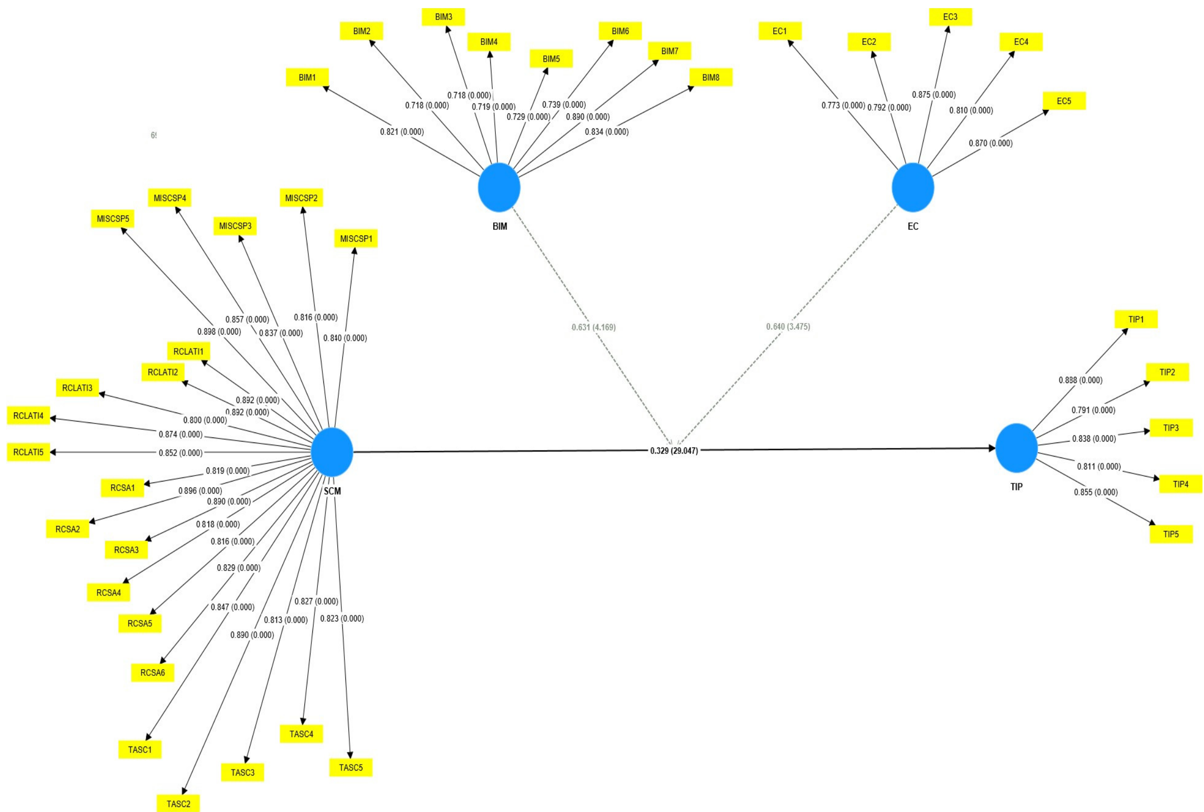

Figure 3. Path Coefficients Test Results (Moderation Effect).

4.7. Critical Analysis

The examination of the interconnection between reducing the costs of site activities, logistic activities, and the success of transportation infrastructure projects reveals noteworthy insights. The reduction in site activity costs exhibits a positive correlation with project success, emphasizing the importance of efficient site management for favorable outcomes and stakeholder satisfaction. Similarly, lowering the costs associated with logistic activities is positively linked to project success, achievable through route optimization, inventory management, and shipment consolidation, ultimately enhancing project efficiency. The positive relationship between transferring activities to earlier stages of the supply chain and project success underscores the advantages of early engagement with supply chain partners in identifying risks and streamlining processes. Additionally, the effective management and improvement of the supply chain and site production demonstrate a positive influence on project success by fostering coordination, waste reduction, and improved outcomes. Building information modeling acts as a moderating factor in the relationship between supply chain management and project success, offering optimization tools for transportation routes, inventory management, and risk mitigation. In conclusion, the critical analysis affirms the positive relationship between reducing site and logistic activity costs, transferring activities to earlier supply chain stages, and the success of transport infrastructure projects, with the management and improvement of the supply chain and site production, along with BIM, exerting a moderate influence on this relationship.

The decision not to implement demographic and behavioral characteristics from the study's model was influenced by factors such as the unavailability or difficulty in obtaining relevant data. Avoiding overfitting, where including too many variables could hinder the generalization to new data, may also drive the exclusion of certain characteristics. Additionally, ethical considerations regarding the collection and use of demographic and behavioral information could lead researchers to limit the scope of variables in the study.

4.8. Discussions

The findings of the hypothesis test showed that RCSA significantly and favorably affects TIP, as indicated by the *t*-value of 16.224. The findings of this study are consistent with those of [96,97]; efficient site activity cost management in transportation infrastructure projects offers several key advantages. It enhances project efficiency by streamlining construction processes, ensuring smoother execution and quicker progress. Effective cost control optimizes resource allocation, boosting productivity and overall project performance. Additionally, it leads to substantial cost reductions by monitoring and implementing cost-saving measures, reducing the project's financial burden. These benefits highlight the significance of cost control in ensuring the efficiency and financial sustainability of transportation infrastructure projects.

RCLATI and TIP have a 6.454 *t*-value association. The findings of this study run counter to research by [97,98], which revealed that efficient cost reduction in logistics operations offers significant advantages. It shortens project lead times, ensuring quicker completion and minimizing costly delays. It also optimizes resource management, enhancing productivity and project progress. Additionally, reduced logistics expenses lead to substantial cost savings, promoting financial efficiency and contributing to the project's overall success.

TASC and TIP are correlated, with a *t*-value of 5.391. According to [99], transferring tasks from the construction site to earlier supply chain stages positively impacts transportation infrastructure projects. This strategic shift enhances project efficiency, optimizes resource allocation, shortens construction timelines, and leads to cost savings, all collectively contributing to project success. This reorganization streamlines processes, improves productivity, accelerates project completion, and ensures financial efficiency.

TIP and MISCSP have a 5.636 *t*-value association. The findings of this study are consistent with studies by [100,101], which discovered that effective supply chain management and improved site manufacturing processes yield several key benefits in transport infrastructure projects. Firstly, operations become more efficient, ensuring smoother material and information flow, resulting in quicker task completion and shorter project timelines. Secondly, there are fewer delays, as effective supply chain management and enhanced manufacturing processes minimize potential bottlenecks, keeping projects on schedule and avoiding costly disruptions. Furthermore, resource utilization is optimized, enhancing productivity and project progress. Lastly, cost savings are realized through efficient supply chain management and improved manufacturing processes, reducing labor, materials, and logistics expenses, ultimately bolstering the project's financial efficiency and sustainability.

The findings indicate that BIM significantly moderates the association between SCM and TIP. This shows that the availability of efficient risk control self-assessment methods affects how BIM impacts TIP. According to earlier research [102,103], combining BIM with effective risk management methods may enhance project results, reduce uncertainty, and improve decision-making; how well logistical operations are handled and regulated impacts how successful BIM is at improving TIP performance. Prior studies have shown that BIM-based logistics optimization may increase project efficiency, decrease delays, and cut transportation costs [56]. According to [103,104], early integration of supply chain operations with BIM integration offers multiple advantages in construction and infrastructure projects. It simplifies project execution by providing a comprehensive understanding of project components, streamlining planning and execution for smoother implementation. BIM enhances stakeholder coordination, reducing errors and rework, resulting in seamless project alignment. It often leads to shorter project durations through efficient planning and visualization, meeting timelines effectively. When combined with efficient project management, BIM optimizes resource allocation, reduces costs, and ensures on-time and on-budget projects. This efficient coordination and resource management improves financial performance. Additionally, BIM and efficient management practices yield higher-quality results by preventing errors and aligning project components with design and performance standards, emphasizing the pursuit of quality in construction and infrastructure projects [105].

The findings demonstrate the statistical significance of the moderating impact of EC on the association between SCM and TIP. EC plays a significant role in shaping how SCM impacts TIP. This suggests that environmental considerations are not just a passive factor but actively affect and potentially enhance or diminish the relationship between supply chain management practices and the overall performance of transport infrastructure projects. According to an earlier study, using environmentally friendly techniques at construction sites can result in cost savings, resource efficiency, and enhanced project results [106]. EC on TIP may be contingent on how well logistical activities related to cost, lead time, and inventory management are managed. In simpler terms, the extent to which environmental considerations influence the performance of transport infrastructure projects could be linked to how efficiently logistics operations, such as managing costs, reducing lead times, and optimizing inventory, are carried out. In other words, the success of environmental initiatives in transportation projects may depend on how effectively logistics and supply chain practices are executed in terms of cost, time, and resource management. Efficient logistics operations can amplify the positive impact of environmental considerations on project performance. According to prior studies, effective logistics procedures can result in lower project costs, shorter lead times, and better inventory management, improving overall project performance [107]. Earlier research demonstrated how early supply chain integration may enhance project results by improving resource allocation, reducing site-related effects, and reducing project costs [108]. Strong supply chain and production management techniques may enhance project performance, resource efficiency, and environmental sustainability [109]. That research has validated this result. The research results highlight the significance of well-organized collaboration and resource allocation, which substantially impact project success. Integration of BIM was crucial in improving project visualization and teamwork, which led to better results [104,110]. Project performance was improved by considering environmental effects, in line with sustainability principles.

Organizations face several challenges when implementing environmental considerations in transportation supply chain management, including inadequate resources, a lack of technical and process expertise, limited knowledge and experience in sustainable practices, difficulties in managing standard environmental control policies, and the complexity of global supply chains [111]. Additionally, resistance to change among employees and stakeholders, often driven by cost concerns, and the significant environmental impact of the transportation industry pose obstacles to achieving sustainability goals. These multifaceted challenges underscore the importance of addressing resource, knowledge, and process-related barriers for the successful integration of environmental considerations in transportation supply chain management [112].

Organizations can seize various opportunities in implementing environmental considerations in transportation supply chain management. These include optimizing transportation routes, employing fuel-efficient vehicles, and exploring alternative modes of transportation to reduce emissions and enhance logistics efficiency. Promoting collaboration and information sharing among supply chain partners fosters sustainability while ensuring transparency and measuring environmental performance. Adhering to environmental regulations and standards mitigates legal risks, and efficient ordering practices reduce transportation emissions. Partnering with sustainable suppliers and prioritizing eco-friendly packaging contributes to environmental stewardship. Leveraging these opportunities enables organizations to minimize their environmental impact, improve operational efficiency, cut costs, and contribute to a cleaner and more sustainable future [112].

5. Conclusions

Efficient cost management of site activities significantly enhances project performance, underscoring the critical role of effective cost control measures in project management. In contrast to previous research, this study establishes that reducing logistic activity costs, especially lead times and inventory management, positively correlates with the success of transport infrastructure projects. This relationship is substantiated by a coefficient of 0.107 and a t-value of 6.454. Streamlined logistics operations lead to shorter lead times, fewer delays, optimized resource utilization, and cost savings, ultimately improving project outcomes. Shifting activities from on-site construction to earlier stages in the supply chain is positively linked to the success of transport infrastructure projects. This strategic shift is supported by a substantial coefficient of 0.321 and a moderately high t-value of 5.391. It enhances efficiency, resource allocation, and overall project performance, resulting in shorter construction timelines and significant cost reductions.

The study confirms that managing and enhancing supply chain and on-site production has a positive relationship with the success of transport infrastructure projects, as indicated by a coefficient of 0.171 and a t-value of 5.636. Effective supply chain management practices and improved on-site manufacturing processes lead to increased efficiency, reduced delays, optimal resource utilization, cost savings, and overall project success. The role of BIM in moderating the relationship between supply chain management and the success of transport infrastructure projects is pivotal, supported by a substantial coefficient of 0.631 and a t-value of 4.169. This suggests that the combination of BIM and SCM enhances transport infrastructure performance (TIP). Effective risk management and BIM integration enhance project outcomes by reducing uncertainty and improving decision-making. Well-managed logistics operations maximize the impact of BIM, resulting in increased efficiency, fewer delays, and reduced transportation costs. Furthermore, environmental considerations act as a significant moderator in the relationship between supply chain management and project success, as evidenced by a substantial coefficient of 0.640 and a t-value of 3.475. This implies that considering environmental factors within SCM positively influences TIP. Implementing eco-friendly practices at construction sites leads to cost savings, resource efficiency, and improved project outcomes. Effective logistical operations, especially in terms of cost, lead time, and inventory management, are crucial to ensuring that environmental considerations positively impact project success, resulting in cost reductions and shorter lead times.

The vital role of information modeling in enhancing supply chain management within the transportation sector is evident through its contributions, such as real-time data visibility, decision-making support, and optimization of transportation routes and inventory. This integration fosters improved coordination, efficiency, and customer satisfaction. Additionally, combining information modeling with environmental considerations yields various benefits, including reduced environmental impact, cost savings, enhanced brand reputation, regulatory compliance, risk mitigation, increased customer loyalty, and long-term value creation. Together, these approaches create a comprehensive strategy for organizations to achieve sustainability, efficiency, and positive environmental and business outcomes in their supply chain management practices.

The integration of environmental considerations and information modeling has significant impacts on supply chain management. Environmental considerations in supply chain management practices, such as lean, resilient, and green practices, can improve supply chain sustainability. The integration of environmental considerations across supply, production, and distribution chains emerged as a much more effective strategy in the 1990s. A sustainable supply chain model emphasizes ethical, environmental, and economic considerations and requires transparency and traceability throughout the supply chain. BIM is one of the tools in advancing construction technology today and has the potential to be applied to construction supply chain management. Activity analysis-based modeling approaches can facilitate spatially differentiated sustainability assessments of global supply chains.

This research's originality lies in its unique focus on supply chain management in the context of transport infrastructure projects, technology integration, environmental considerations, and its interdisciplinary approach. Its value is evident in the practical applications that can improve project efficiency, reduce costs, promote sustainability, and advance our understanding of supply chain management in complex construction projects.

5.1. Implications of the Study

This study has significant theoretical implications in multiple key areas. It advances supply chain theory by applying it to transport infrastructure projects, offering insights into adapting supply chain management principles to the industry's unique challenges. Additionally, it enhances our understanding of supply chain roles, emphasizing the need for more comprehensive theories that address construction and transportation complexities. The research highlights the moderating role of technology, specifically BIM, underscoring the importance of technology in supply chain management models. It also brings environmental considerations to the forefront, prompting the inclusion of sustainability in supply chain models, reflecting the industry's green practices. Furthermore, the study uncovers complex relationships between supply chain roles and project performance, laying the foundation for more nuanced models that account for diverse factors influencing project success in infrastructure settings. Lastly, it underscores the value of an interdisciplinary approach, merging supply chain management with construction, transportation, technology, and sustainability, encouraging the development of holistic theoretical frameworks recognizing the intersections of these fields.

Managing supply chains in transport infrastructure projects has various practical implications. The study provides tangible benefits for the construction industry, enabling experts to fine-tune supply chain management. Understanding the roles of different supply chain components in infrastructure performance paves the way for informed decision-making, effective strategies, and the streamlining of supply chains. Implementing best practices and utilizing tools like BIM can expedite project completion, reduce delays, improve quality, and lower costs. Furthermore, prioritizing sustainability through environmental considerations promotes the adoption of eco-friendly construction techniques and adherence to sustainability goals. The emphasis on technology integration, particularly with BIM, enhances project coordination and decision-making. It is important to note that contextual elements such as project location and regulations influence the relationship between supply chain management and infrastructure performance. Supply chain optimization is crucial in minimizing waste, resource allocation, and financial efficiency.

Additionally, stakeholder collaboration is essential for facilitating better communication and knowledge transfer. This collaboration can influence policymakers and promote environmentally friendly practices in the construction sector. Therefore, incorporating supply chain management into transport infrastructure projects is a practical approach that can lead to more efficient, cost-effective, and environmentally sustainable construction practices, benefiting project stakeholders and the broader society.

Incorporating information modeling and environmental considerations in transportation supply chain management offers numerous benefits, including enhanced operational efficiency, cost reduction, and environmental impact reduction. Efficient information flow enables real-time coordination and communication, optimizing routes and streamlining processes. Improved data utilization leads to resource efficiency, lowering costs in fuel consumption, maintenance, and inventory management. Environmental considerations identify eco-friendly transportation options, aligning with sustainability goals and reducing carbon emissions. Information modeling aids in risk mitigation by identifying and addressing disruptions and delays. This fosters a resilient supply chain. Regulatory compliance is ensured through alignment with environmental standards, reducing legal and reputational risks. Accurate tracking enhances customer satisfaction and loyalty. Information modeling promotes technology adoption, fostering continuous innovation. Additionally, integrating environmental considerations encourages long-term sustainability by incorporating eco-friendly practices into strategic planning, including renewable energy investments and sustainable packaging initiatives.

5.2. Limitations and Future Research

Limitations of this study include potential constraints on generalizability due to the specific context, the need for robust data and sample quality, limitations in measurement and variables capturing complex constructs, potential time-related factors not accounted for within the study's timeframe, and challenges in establishing causality and directionality. To address these limitations and further advance research in this field, future studies should consider longitudinal research to track long-term effects, conduct comparative analyses across various regions and project types, employ qualitative research methods for a deeper contextual understanding, investigate the specific technological aspects of BIM that impact project success, explore standardized sustainability metrics, study government policies and regulations' influence, and leverage advanced analytics and machine learning for more comprehensive insights into complex relationships within infrastructure projects.

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