

Enhancement of the Project Cost by Mapping the Influence of the Supply Chain Attributes

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Abstract

Controlling construction project costs is a critical factor in achieving project success, particularly in complex construction environments. Previous studies have shown that weaknesses in supply chain management are among the primary causes of cost overruns. Accordingly, this study investigates the impact of supply chain attributes (SCA) on construction project costs by identifying key characteristics through a comprehensive review of prior literature and developing a framework to evaluate their influence on cost outcomes.

Data were collected from construction projects and analyzed using statistical techniques, including correlation analysis and Structural Equation Modeling (SEM). The results reveal a statistically significant negative correlation between project costs and SCA, indicating that improved supply chain performance contributes to cost reduction. The SEM results validate the proposed framework, with a chi-square value of $\chi^2 = 9.865$ and a probability value of $p = 0.275$, which exceeds the acceptable threshold of 0.05 and confirms an adequate model fit.

Further findings demonstrate that supply chain functions, quality management, and human resource management (HRM) significantly enhance project cost efficiency. Among these factors, HRM plays a pivotal role in strengthening supply chain functions and improving overall performance, highlighting its strategic importance within construction organizations. By statistically modeling the relationships and pathways between SCA and project costs, this study provides a systematic approach to understanding how effective supply chain management can improve cost efficiency in construction projects.

Keywords: enhancement; framework; function of supply chain; project's costs; structural equation modeling; supply chain attributes.

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1. Introduction

Controlling construction project costs is a fundamental factor in achieving project success. However, cost overruns remain a persistent and widespread problem across construction projects worldwide. Previous studies have consistently reported that cost overruns occur in both developing and developed countries, indicating that this issue is systemic within the construction industry [1-4].

Despite extensive research efforts, cost overruns continue to pose serious challenges, highlighting the need for further investigation to better understand their underlying causes and mitigation strategies.

The literature identifies numerous factors contributing to construction cost overruns, including shortages in material supply, poor coordination among project participants, inadequate monitoring and control, weak management practices, ineffective

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material planning, and unclear scheduling [5-7]. A substantial portion of these factors is directly or indirectly associated with supply chain management practices. Consequently, understanding supply chain characteristics and their influence on construction project costs has become increasingly important. Previous research has emphasized that effective supply chain management plays a vital role in improving project performance and enhancing overall project success [8] and [9].

Several studies have identified key supply chain attributes (SCA) that influence project success and cost performance, such as supply chain functions, human resource management (HRM), quality, sustainability, and coordination. Structural Equation Modeling (SEM) has been recognized as a powerful analytical technique for examining both direct and indirect relationships among these attributes and project cost outcomes[10]. However, despite these advances, empirical evidence quantifying the magnitude and pathways of SCA impacts on construction project costs remains limited. The lack of measurable and statistically validated models represents a critical research gap.

To address this gap, the present study aims to systematically map and quantify the impact of supply

chain attributes on construction project costs. The study develops an integrated assessment framework based on literature review, expert input, and empirical project data. It applies SEM to evaluate the strength and significance of relationships between SCA and cost performance. By doing so, this research provides a clearer scientific contribution to the understanding of cost control mechanisms through supply chain optimization.

2. Methodology

A collection of impact coefficients will be used to analyze the SCA's impact on costs. To determine the coefficients, the next process must be completed:

1. Identify the SCA by review of the previous literature.
2. Create a framework for assessing the impact of SCA management on the costs of projects, and define which variables impact outcomes.
3. Data from the projects is collected, and statistical processing is performed.
4. Choose a technique to test the framework, and compute the impact coefficients.
5. Analyze and evaluate the outcomes.

The process of research is shown in Fig. 1.

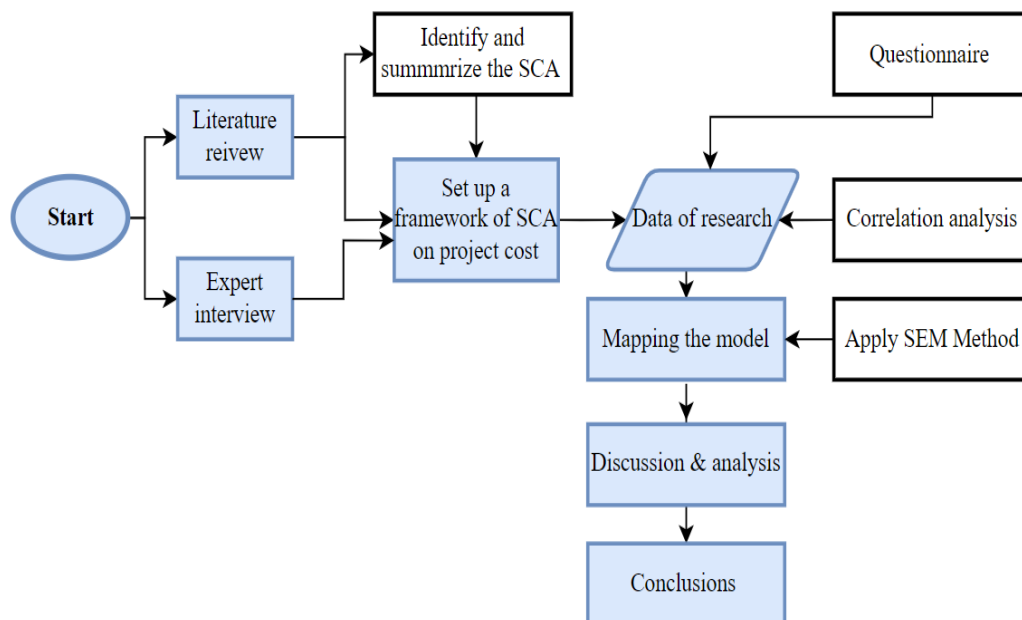


Fig. 1. Flowchart of Research.

2.1. Design of Questionnaire.

Through the literature review, the attributes of the supply chain that affect the cost of construction

projects were identified. Data on these attributes and cost efficiency were collected from a group of companies operating in the construction sector in Iraq. These companies include government and private companies, contractors, and suppliers. The questionnaire was conducted for only those working in the construction sector. The survey included 63 company owners and managers, 48 contractors, and 32 suppliers, all of whom work in the construction sector.

The questionnaire involves two parts; the first deals with descriptive data about the nature of projects and respondents. The second part evaluates supply chain attributes by asking respondents to select from a list of options, such as "strongly agree, agree, neutral, disagree, strongly disagree." The responses were analyzed using a scale ranging from (+5) to (-5), where +5 means it has a very positive effect, while -5 means it has a very negative effect.

2.2. Principal Component Analysis and Correlation Analysis.

Based on the literature review, the relationship between SC function and the cost of the project was studied. The relationship between SC functions was studied by classifying them into four types of activities: operations, logistics, resource management, and information workflow. The relationship between these activities was tested quantitatively using Pearson correlation analysis. The results of the statistical analysis of the data showed that the relationship between SC functions is strongly correlated. By using principal components analysis, the four functions of SC have been replaced with independent variables.

2.3. Interview with an Expert.

The framework for a relational model was developed based on the relationship between SCA and project cost. In addition to the survey questionnaire, two consultants with extensive knowledge of project performance evaluation were interviewed to provide a broader understanding of the relationships between SCA and project costs. The relationships between the attributes and the relational framework have been discussed with experts, and they provided an in-depth insight into the relationship between them.

2.4. Structural Equation Modeling (SEM)

The validity of the framework's relational structure is checked from a statistical perspective by SEM, which is a means for testing theoretical or conceptual models [11]. SEM is a methodology to analyze structural theory and contains two elements. Firstly, the causal connections are illustrated by a sequence of structural equations. Secondly, modeled these relationships graphically to make the theories clearer. The SEM can statistically test the relationship between variables and determine the consistency of the data with models. [12]. In this study, it is essential to determine if the data is compatible with the relational framework. Thus, the framework validity was tested to define how the SCA affects the costs of projects.

3. Supply Chain Attributes (SCA)

3.1. Literature Review of SCA Affecting the Costs of Projects.

Project management involves utilizing knowledge, skills, tools, and procedures to accomplish specific project needs, as per PMI's 2004 guide. Project management comprises nine knowledge domains, including cost, scope, time, integration, risk, quality, communication, human resources, and procurement management, with cost objectives being a crucial project criterion. To determine the primary SCA elements influencing project cost, thorough literature research was carried out. The primary causes of SCA determined by the literature study are shown in **Table 1**. The pertinent reasons for cost overruns that were associated with (SC) were categorized under many attributes of (SC) based on the findings of the literature study. The SCA was set based on their availability and associated activities, and their definition. Each attribute is covered in further detail in the sections that follow. The several SCA-related reasons for cost overruns identified in the literature are grouped into 10 categories in **Table 1**, including operations, logistics, resource management, information workflow, human resource management (HRM), sustainable, quality, coordination, balance, and efficiency. SCA and definitions will be presented in the next section.

Table 1. A brief overview of studies on how SCA impacts project cost

No.	Reference	Supply Chain Attribute	Causes related to SC	Year
1	R. V. Altekar [13], and Manfredi, E., & Capik, P. [14]	Operations	Supply chain management and operations are two departments that frequently operate in tandem and share procedures within a company.	2023, 2022
2	Mangan, J., & Lalwani, C.[15]	Logistics	Logistics is a vital part of the supply chain, and failure in logistics can result in supply chain failure.	2016
3	Acquah et al. [16]	Resource Management	If resources are not managed properly, it can also slow the supply chain down.	2021
4	Núñez-Merino et al. [17]	Information Workflow	Information workflow is crucial for effective supply chain decisions at all levels, including strategy, planning, and operations.	2020
5	Jena & Ghadge [18]	(HRM)	Individual behaviors contribute to the success of SCM; HRM enhances SCM techniques.	2021
6	Bag et al. [19], Jarallah & Mahjoob [20]	Sustainable	Supply chain sustainability enhances productivity, optimizes costs, and promotes continuous improvement in the SC.	2021, 2022
7	Gunasekaran et al. [21]	Quality	Quality management throughout the supply chain is crucial for organizations to maintain a competitive edge and reduce costs.	2019
8	Wankmüller & Reiner [22]	Coordination	Supply chain coordination enhances inventory management, reduces delivery time, and reduces manufacturing costs.	2020
9	Wisner et al. [23]	Balance	A supply chain's cost, efficiency, and risk must be balanced via the application of best practices that maximize productivity.	2019
10	X. Meng [24]	Efficiency	Effective supply chains avoid both underproduction and overproduction, which can result in surplus inventory.	2019

3.2. The Definitions of Supply Chain Attributed (SCA).

Eight SCAs were ultimately chosen to be included in this study: Operations, Logistics, Resource Management, Information Workflow, Human Resource Management (HRM), Sustainable, Quality, and Coordination. The CII 10-10 Program involves polling project management team members on project performance, team dynamics, and organizational

relationships anonymously. During the project's development phase, ten input measures were surveyed and created to alert top management to potential issues. Project size and cost efficiency have a significant impact on the overall costs. Project cost efficiency is calculated by dividing the total estimated cost by the capacity. Best cost efficiency mentions spending less money on production units. Project cost efficiency was processed using logarithms to decrease

data diversity since various project types have different units of cost efficiency.

4. The Effect Framework of SCA on Costs

The study aims to map the relationship between the costs and SCA of the project. So, the study requires an appropriate framework model for this relationship.

4.1. Framework Structure.

The supply chain attributes (SCA) in this framework are employed in conjunction with the efficiency of cost. The relevance between the SCA and efficiency of cost was reanalyzed, and the outcomes are offered in part 6. According to the Association for Project Management (APM) in the UK, project management is a multidisciplinary leadership paradigm that attempts to solve a short-term problem [25]. Through examination of the definition of supply chain management (SCM), SCM involves managing operations involving raw material procurement, transformation into finished goods, and distribution to the end consumer. Effective supply chain management balances demand and supply, reducing waste, increasing profits, lowering costs, and ensuring timely product delivery, thereby enhancing efficiency.

This is why understanding attributes of supply chain management is essential for manufacturing organizations, as it will provide insight into how to improve the efficiency of your operations. The study of partnership and supply chain management looks at the tactics the project team uses to encourage improved collaboration amongst all project participants, including those in the supply chain. SCA are inseparable and overlap in nature, affecting each other's performance and blending into each other, despite their analytical distinctions. Fig. 2 shows how a preliminary framework might map the influence of SCA on project cost.



Fig. 2 Influence SCA framework on project cost.

4.2. An Influence of the SCA Framework

As Fig 2 illustrates, people are the engine that propels the transformation toward the transformation

variables and then the project cost goals, which are accomplished through supply chain activities. Managing people in companies is the main focus of human resources (HR). Operations, logistics, resource Management, and Information workflow are a part of the supply chain function leading to transformation variables such as sustainability, quality, and coordination. Cost efficiency is referred to as project cost in this research. The next section will discuss the connections between HRM, sustainability, quality, and coordination. The field of supply chain management in construction focuses on maximizing the flow of products, materials, services, and associated data from suppliers to consumers [26].

Managing the movement of materials from suppliers to the final consumer efficiently and effectively requires careful supply chain planning, design, and management. It provides chances for enhancing quality, reducing costs, and shortening lead times [27], and quick reaction to modifications or fresh advancements [28]. Each supply chain has a unique impact on prices and quality [29]. It is always possible to credit low costs to decision-making during the product design process. To better understand the connections between SCA and the costs, two experts were interviewed, and the link between the attributes and the rationality framework was debated. They agreed that the impact of sustainability and coordination on cost efficiency is not important, and it can cut the causal relationship between them. It is expressed by the dotted lines in the causal framework that was developed. The solid lines indicate that there is a causal relationship between the remaining factors. The causal framework was developed and shown in Fig. 3. Model A and Model B are the names of the frameworks with and without the dotted lines, respectively. The two models will be discussed in Section 6.1.

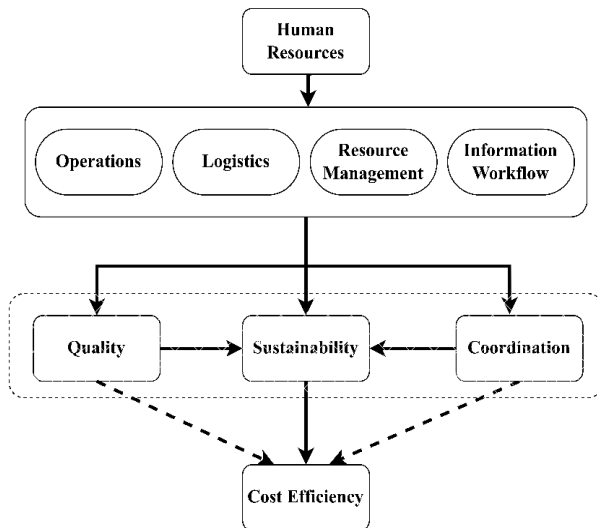


Fig. 3. The relationships between SCA and the costs of the projects

4.3. Hypotheses

The following seven hypothesized connections between attributes are supposed based on the model (A):

- H1:** HRM has a favorable connection with improved function of the SC.
- H2:** The SC function has been favorably connected with improved sustainability.
- H3:** The SC function has favorably connected with improved quality.
- H4:** The SC function has a favorable correlation with improved coordination.
- H5:** Sustainability has a favorable correlation with improved quality.
- H6:** Coordination is favorably connected with improved quality.
- H7:** Quality is negatively correlated with cost-efficiency.

5. Data of Research.

This section discusses the statistical and reliability tests on the project data that was gathered from construction companies. Operations, logistics, resource management, and information workflow are related to supply chain (SC) functions. The correlation between the SC functions was expected to be high theoretically. Correlation analysis was performed to determine the correlation coefficients between the SC function. The correlation between them was strong, so the principal component analysis (PCA) was used to minimize them and create

independent variables. In the later parts, the remaining SCA will be evaluated.

5.1. Data Gathering

The data was collected from 56 projects implemented mainly in Iraq's construction sector from 2012 to 2019. The questionnaire responses were collected about operations, logistics, resource management, information workflow, HRM, sustainability, quality, coordination, balance, efficiency, and cost efficiency. Despite providing data from 56 building projects, some of the projects' cost efficiency was absent. In the end, 48 projects' worth of data were used for the study, with the remaining projects' data being rejected since it was insufficient. The data was analyzed using version 26 of SPSS. The nature of the 48 projects has been determined, it sorted by location, kind, and size of the project. According to the project's size, 4.5% of the projects had a value of more than \$1000 M US, 24% had a value of between \$100 M and \$1000 M US, 32.2% had a value of between \$10 M and \$100 M US, and 39.3% had a value of less than \$10 M US. According to CII (2012), a project is considered large if its overall cost exceeds \$5 million. Since most of the projects are worth more than \$10 million US, they are considered large-scale initiatives. According to the construction project locations, all projects whose data was taken are in Iraq, and the time can also influence the costs of projects. The impact of time and place was minimal because all projects were constructed between 2012 and 2019.

5.2. Test of Reliability

Reliability testing shows how consistent the information gathered is. An indicator of internal consistency is the Cronbach α coefficient. When Cronbach's α is less than 0.3, reliability is low and cannot be accepted. When Cronbach's α is more than 0.7, it implies excellent reliability since it shows high and hence acceptable internal consistency. Alpha should have a range greater than 0.5 to 0.6 [30]. Since cost-effectiveness is an objective variable and the eight SCAs are subjective and related to attitude, the coefficient of Cronbach (α) was employed to check the internal consistency of the eight variables. **Table 2** displays the values of Cronbach's (α) for the SCA. It is evident from this table that all of the alpha values are more than 0.6, indicating that the eight SCAs have very satisfactory inner consistency. The Cronbach (α)

outcome for the entire study's index is 0.936, so the questionnaire is stable and reliable.

Table 2: the Cronbach (α) values for eight of the SCA

No.	SCA	α	N.	SCA	α
1	Operations	0.702	5	HRM	0.675
2	Logistics	0.731	6	Sustainability	0.841
3	Resource Management	0.689	7	Quality	0.622
4	Information Workflow	0.603	8	Coordination	0.654

5.3. Analysis of Correlation

The Pearson correlation coefficient is used to measure the strength between variables by dividing the (sample) covariance by the product of their standard deviations. It indicates the direction and degree of the linear relationship between two variables [31]. According to theory, the four primary functions of SC—operations, logistics, resource management, and information workflow—are related to each other and highly inseparable. A correlation analysis was performed on the four SC functions to create new independent variables. In **Table 3**, the correlation coefficient results are displayed. According to the results, the correlation between logistics and

information workflow is 0.765, while between logistics and resource management is 0.768, the highest of all. The correlation coefficients between resource management and information workflow, resource management and operations, operations and Logistics were 0.744, 0.727, and 0.686, respectively. Operations and information workflow had the lowest correlation coefficient (0.672). The findings demonstrate a strong association between operations, logistics, resource management, and information workflow, as seen by the extremely high correlation coefficients between them, which fall between 0.6 and 0.8. Correlation is significant at the 0.01 level (2-tailed)

Table 3: The value of Pearson correlation coefficients between operations, logistics, resource management, and information workflow.

	Operations	Logistics	Resource Management	Information Workflow
Operations	1	0.686**	0.727	0.672
Logistics	0.686	1	0.768	0.765
Resource Management	0.727	0.768	1	0.744
Information Workflow	0.672	0.765	0.744	1

5.4. Analysis of Principal Components

Since it was shown that operations, logistics, resource management, and information workflow were substantially connected, principal component analysis (PCA) is used to create a new independent variable instead of the four original components. PCA is a statistical technique that creates principal components—a collection of values of linearly uncorrelated variables—from a set of observations of potentially linked variables using an orthogonal transformation. **Table 4** displays the findings of the PCA utilizing information from 57 projects. Kaiser-Meyer-Olkin (KMO) and Bartlett's tests indicate that factor analysis has a favorable effect since the sample adequacy measure is 0.851, higher than 0.7. Given

that the $P = 0.000$ is less than 0.05 and Bartlett's test of sphericity is 155.194, the original hypothesis is rejected, allowing for factor analysis [32]. **Table 4** presents the whole variance and identifies one common component; its variance-contributed rate was 80.372%. The components' cumulative contribution rate exceeds 80% by using PCA [33], demonstrating that the principal component can account for 80% of the first four variables. The component matrix and eigenvalue are used to determine the principal component. Operations, logistics, resource management, and information workflow are the four variables replaced by a single major component known as the "Function of SC." Using the SEM to Map the SCA's Impact on Costs.

Table 4: The total variance explained

Component	of variance %	Cumulative %	Total
1 Principal Component	80.372	80.372	3.215
2 Principal Component	8.762	89.131	0.35
3 Principal Component	5.802	94.933	0.232
4 Principal Component	5.067	100	0.203

The next stage after setting up the impact framework is to evaluate the framework model's internal validity from a statistical standpoint. Based on the impact framework model, the SEM was used to statistically examine the hypotheses. There are two approaches for SEM analysis: partial least squares-based SEM (PLS-SEM) and covariance-based SEM (CB-SEM). PLS-SEM is more suited for exploratory work in identifying and assessing causal links, whereas CB-SEM is better suited for confirmatory factor analysis [34]. The relational framework model has been established, and its validity has to be verified. Thus, the influence of SCA on the costs was mapped using CB-SEM. CB-SEM on Amos 17.0 software was used to determine the significance of 57 samples. The test

of variables' normality was carried out because the greatest likelihood approach is used to assess the significance probability [35]. The outcome of a single-sample Kolmogorov-Smirnov test is displayed in **Table 5**. The findings show that the cost-efficiency data is not regularly distributed; the asymptotic significance for cost-efficiency is 0.000, which is less than 0.05. All other variables had asymptotic significance greater than 0.05, suggesting that they are regularly distributed. The result is normally distributed when the logarithm function is used to convert the cost-efficiency data. The data for function SC, HRM, sustainability, quality, coordination, and the SEM analysis comprised the converted cost efficiency data.

Table 5. Kolmogorov-Smirnov test for one sample

	Function of SC	HRM	Coordination	Quality	Sustainability	Cost efficiency
Mean	1.3023	0.6353	0.5254	0.6343	0.6429	369569.55
Std deviation	0.20271	0.09551	0.18078	0.13542	0.16497	848371.25
Kolmogorov-Smirnov Z	0.734	0.680	1.270	0.730	0.898	2.478
Asymp. Sig (2-tailed)	0.661	0.751	0.086	0.698	0.417	0.000

5.5. Two Framework Models are Compared

By using the SEM approach, the internal validity of framework models A and B will be evaluated and compared. The values of (χ^2/df) equal 1.232 and 1.514 for models A and B, respectively. These values are considered acceptable because they fall between 1 and 2 ($1 < \chi^2/df < 2$). Model A and Model B's AIC and ECVI are displayed in **Table 6**. Compared to model B, model A's AIC, BCC,

BIC and CAIC are smaller. Additionally, model A has lower ECVI and MECVI values than model B. As a result, model A fits the data better than model B [36], and it has been established that sustainability and coordination have little effect on cost efficiency. This outcome supports the assertions of two experts that there were no appreciable direct effects of sustainability and coordination on project cost. As a result, model A is utilized for more research.

Table 6: AIC, BCC, BIC, CAIC, AND ECVI for MODEL A and MODEL B

Model	AIC	BCC	BIC	CAIC	ECVI	LO 90	HI 90	MECVI
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Model A	365.85	38.64	62.28	76.28	0.66	0.64	0.865	0.742
Model B	39.38	44.46	69.46	85.46	0.72	0.67	0.944	0.89

5.6. Framework Model A's Goodness-of-Fit Indices

It is often advised to evaluate a model using a variety of indicators. The constructs in model A were evaluated for validity and reliability, and a closer look at the goodness-of-fit indices for model A in **Table 7** reveals that the model fits the data rather well [37]. According to the fit indices analysis shown in **Table 7**, model A is deemed acceptable if the χ^2 has a p-value greater than 0.05, so model A fits with the data. [38]. In this case, model A appears to be acceptable based on the χ^2 value of 9.865 ($p = 0.375$). In addition, the values of CFI, GFI, IFI, NFI, RMR, and RMSEA demonstrate that the impact framework is appropriate and that the model fits well.

Table 7: The measurement model's goodness of fit indices

Fit index	Indices for data	Acceptable fit
Chi-square	9.865	
Df.	16	
P	0.375	>0.05
χ^2/df	1.621	≤ 2 to 5
CFI	0.976	≥ 0.90
GFI	0.965	≥ 0.90
IFI	0.995	≥ 0.90
NFI (TLI)	0.944 (0.98)	≥ 0.90
RMR	0.032	<0.06
RMSEA	0.075	≤ 0.05 to 0.08

5.7. Hypothesis Testing of Model A and Evaluation

Amos software was used to test Model A with all of the relationships depicted in **Fig. 3**. **Table 8** displays the regression weights that correspond to the path coefficients. Some relationships are confirmed based on the estimations. For instance, at the 0.001 level, the regression weight for HRM in the Function of SC

Table 8: The outcomes of the hypothesis tests

	Estimate	S.E.	C.R.	P	Conclusion
HRM ----> Function of SC	0.452	0.258	3.76	***	Certain

prediction is significantly different from zero, indicating that HRM significantly affects the Function of SC. The results of the SEM to evaluate the seven hypotheses are shown in **Table 8**. Five of the seven hypotheses were validated based on the outcomes of hypothesis testing. It was confirmed that HRM has a statistical influence on the functions of the supply chain (SC), where the C.R. value is higher than the cutoff of 1.96. The Functions of SC were discovered to influence quality, coordination, and sustainability, and quality, in turn, influences cost efficiency.

Nevertheless, it was shown that the effects of coordination and sustainability on quality were not statistically significant. **Fig.4** shows the map for the analysis outcomes summarized in **Table 8**, where the relationships with statistical confirmation are shown by solid arrows, and the numbers represent the standardized correlation coefficient values, while statistically unconfirmed associations are shown by dot-pointed arrows.

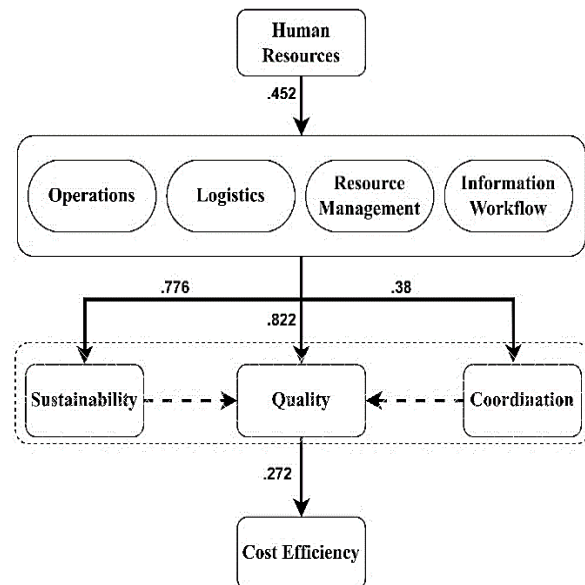


Fig. 4. The Influence Framework for the Significant Paths.

Function of SC ----> Design Efficiency	0.38	0.111	3.043	**	Certain
Function of SC -----> Sustainability	0.776	0.07	9.125	***	Certain
Function of SC -----> Quality	0.822	0.091	5.579	***	Certain
Sustainability ----> Quality	-0.132	0.108	-0.923	0.356	Not certain
Coordination -----> Quality	0.05	0.067	0.516	0.606	Not certain
Quality -----> Cost Efficiency	-0.272	4.729	-2.095	*	Certain

6. Discussion

6.1. Results and findings

Consistent with earlier studies, there was a statistically significant negative correlation between project cost and SCA. According to the SEM findings, the χ^2 value was 9.865 ($p = 0.275 > 0.05$), indicating that the proposed framework is acceptable. These results suggest that improving the performance level of SCA can significantly enhance the likelihood of reducing project costs. Five of the seven hypotheses were statistically confirmed in Model A of the influence framework. Fig. 4 illustrates the influence framework along with the standardized correlation coefficient values for the statistically validated relationships. The correlation values and directional arrows indicate both the magnitude and direction of influence among variables, where higher values represent stronger effects. The following sections discuss quality, HRM, and cost-effectiveness.

1. Impact on project cost effectiveness.

- A. There are three identified paths through which HRM influences cost effectiveness. The first path is HRM–Function of SC–Quality–Cost efficiency. The second path is HRM–Function of SC–SC–Sustainability–Quality–Cost efficiency. The third path is HRM–Function of SC–SC–Coordination–Quality–Cost efficiency. Among these, the HRM–Function of SC–Quality–Cost efficiency path was statistically validated, with a path coefficient of -0.102 , indicating that 10.2% of the variance in project cost efficiency can be indirectly explained by improvements in HRM.
- B. The path coefficient of SC–Quality–Cost efficiency was -0.223 , statistically confirming that SC can indirectly contribute to cost

efficiency improvement, explaining 22.3% of the variation in cost efficiency.

- C. The direct path coefficient affecting quality and cost efficiency was -0.272 , indicating that quality enhancement accounts for 27.2% of the variation in cost efficiency.
 - D. Three SCAs demonstrated both direct and indirect effects on project costs. Quality was the most influential factor, followed by the function of SC and HRM.
- #### 2. The effect of the function of SC on transformation variables
- A. The function of SC had the strongest impact on quality, followed by its impact on sustainability and then coordination.
 - B. Improvements in the function of SC significantly enhanced sustainability and quality levels. Coordination also improved; however, this improvement was not statistically significant.
- #### 3. The Quality factor
- A. Quality represents the foundation of the influence structure, linking SC functions and project costs. However, quality exhibited a negative and statistically insignificant direct effect on cost efficiency.

Conclusions

This study investigates the relationship between supply chain attributes (SCA) and construction project costs and represents one of the first statistical analyses to quantify the pathways and magnitude of this impact. The research was conducted in three stages: a literature review to establish the relationship between SCA and project costs and to formulate seven hypotheses, empirical testing of the proposed impact framework using Structural Equation Modeling (SEM), and an in-depth analysis of the validated framework.

The results confirm a statistically significant negative relationship between project cost and SCA, with five out of the seven hypotheses empirically supported. The findings indicate that quality, the function of the supply chain, and human resource management (HRM) play a critical role in enhancing cost efficiency. Among these factors, quality was identified as the most influential attribute, accounting for 27.2% of the variation in cost efficiency. In addition, HRM was shown to indirectly improve cost efficiency through its positive influence on supply chain functions and quality performance.

The study also demonstrates that investments in quality improvement, supply chain functions, and HRM can be offset by overall cost reductions, emphasizing that these attributes do not drive project costs beyond critical limits. From a practical perspective, the findings provide valuable guidance for contractors and project managers by emphasizing the importance of strengthening HRM, supply chain functions, and construction quality to achieve cost-driven project objectives.

Finally, this research offers a validated impact framework that can serve as a foundation for future studies. Further research is recommended to examine the relationships among sustainability, coordination, and quality and to extend the applicability of the model across different construction sectors and project types.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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