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Assessing The Impact of Lean Management on The Efficiency of Urban Road Construction Projects

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1. Abstract

The Egyptian urban road construction sector faces persistent challenges related to schedule delays, cost overruns, quality deficiencies, and inefficient resource utilization. Lean Management provides a structured approach to waste reduction and workflow improvement; however, empirical evidence of its implementation in developing-country contexts remains limited. This study examines the relationship between Lean Construction implementation and four dimensions of urban road project performance in Egypt: time, cost, quality, and resource utilization. It also investigates the moderating roles of organizational culture, management support, regulatory environment, and training and awareness. A quantitative design was employed using a structured questionnaire administered to project managers, consultants, site engineers, and client representatives involved in urban road projects in New Cairo, Egypt. A total of 120 valid responses were obtained from a target population of 150 professionals, representing an 80% response rate. Data were analyzed using reliability assessment, descriptive statistics, correlation analysis, and 24 multiple linear regression models. Composite Lean implementation was positively and significantly associated with time performance ($b = 0.810$, $p < 0.001$, adjusted $R^2 = 0.579$), cost performance ($b = 0.800$, $p < 0.001$, adjusted $R^2 = 0.394$), quality performance ($b = 0.770$, $p < 0.001$, adjusted $R^2 = 0.429$), and resource utilization ($b = 0.882$, $p < 0.001$, adjusted $R^2 = 0.533$). Individual-tool analyses showed significant positive relationships between the Last Planner System and time performance, Value Stream Mapping and cost performance, and 5S and quality performance. Combined Just-In-Time and 5S practices were significantly associated with resource utilization. Of the 16 interaction terms examined, eight were statistically significant, primarily involving organizational culture, management support, and the regulatory environment. Training and awareness showed no statistically significant moderating effects. These findings highlight the relevance of Lean Construction practices to multidimensional performance in New Cairo's urban road projects and provide practical insights for construction management, while indicating the need for further research to assess the generalizability of the findings to other Egyptian locations.

Keywords: Lean Management, Urban Road Construction Projects, Project Performance, Last Planner System, Value Stream Mapping, Just-In-Time, 5S, Visual Management, Egypt.

2. Introduction

Urban road construction is a critical component of Egypt's infrastructure agenda, directly driving economic productivity and mobility. However, despite substantial public investment, projects frequently face schedule delays, cost overruns, and quality issues that reduce stakeholder satisfaction. Rapid urbanization demands more efficient and sustainable construction practices (Berta & Tesfaye, 2025). Consequently, professionals are turning to lean management utilizing tools like the Last Planner System (LPS), Value Stream Mapping (VSM), Just-In-Time (JIT), workplace organization, and Visual Management (VM) to eliminate waste, optimize resource utilization, and improve process reliability beyond traditional methods. Globally, these tools have been proven to enhance project performance and value delivery (Hyarat et al., 2024). Given that Egypt's road sector absorbs billions of Egyptian pounds annually, construction inefficiencies directly impair national economic growth and trigger substantial social losses.

Despite global evidence, the adoption of lean management in Egypt’s urban road sector remains limited, characterized by low awareness, inadequate training, conflicting stakeholder interests, and the lack of a national framework. While isolated successes exist, lean practices are not yet systematic or institutionalized (Elmalky et al., 2024). To address this gap, this study investigates how lean management tools impact the efficiency of Egyptian urban road projects (in terms of time, cost, quality, and resource utilization) and the key organizational, cultural, and regulatory factors that enable or hinder their successful implementation.

3. Problem Definition

Urban road construction projects in Egypt face persistent performance challenges, including severe schedule delays and cost overruns stemming from planning weaknesses, poor coordination, and inadequate waste management (Ismail, 2023). While international evidence confirms that Lean management tools such as LPS, VSM, JIT, 5S, and VM improve time, cost, quality, and resource utilization (Ramirez et al., 2024), empirical research evaluating their quantitative impact within Egypt's urban road sector remains sparse.

Furthermore, there is a critical knowledge gap regarding how contextual factors namely organizational culture, management support, training, and the regulatory environment moderate the relationship between Lean adoption and project outcomes. Accordingly, this research addresses the following central problem: How does Lean management implementation relate to the perceived performance (time, cost, quality, and resource utilization) of urban road projects in New Cairo, Egypt, and to what extent do contextual organizational, cultural, and regulatory factors moderate this relationship?

4. Research Importance

This study contributes to the construction management literature and industry at academic, practical, and sectoral levels.

Academic Significance: It provides empirical evidence on the relationship between individual and combined Lean tools and project performance within New Cairo's urban road sector, while clarifying the moderating role of organizational and contextual factors.

Practical Significance: It offers project managers, contractors, and consultants' evidence-based guidelines to systematically adopt Lean tools, reduce operational waste, optimize resource utilization, and foster continuous improvement in road construction.

Sectoral Significance: Given that Egypt's National Roads Project allocates over EGP 150 billion annually to transport infrastructure (Ministry of Planning, 2023), and conventional practices incur 15% to 30% in material waste and delays (Babalola et al., 2019), this study provides a validated framework to minimize public expenditure losses and optimize national resource allocation.

5. Research Objectives

The primary objective of this research is to examine the relationship between Lean management implementation and the performance of urban road construction projects in New Cairo, Egypt, while evaluating the moderating role of organizational and contextual factors.

Specifically, the study aims to:

1- Assess the individual and combined impacts of Lean management tools (LPS, VSM, JIT, 5S, and VM) on project performance across four key dimensions: time, cost, quality, and resource utilization.

2- Evaluate how organizational culture, management support, training and awareness, and the regulatory environment moderate the relationship between Lean implementation and project performance.

3- Formulate empirical, evidence-based recommendations to enhance Lean adoption and optimize performance in Egyptian urban road construction.

6. Research Hypotheses

Based on the research objectives and relevant literature, the following hypotheses are formulated:

H1: Individual Lean tools have statistically significant positive effects on project performance dimensions:

H1a: LPS positively affects time performance.

H1b: VSM and JIT positively affect cost performance.

H1c: 5S and VM positively affect quality performance.

H1d: VSM, JIT, 5S, and VM positively affect resource utilization.

H2: Overall Lean management implementation has a statistically significant positive impact on project performance dimensions (**H2a**: time, **H2b**: cost, **H2c**: quality, and **H2d**: resource utilization).
H3: Contextual factors significantly moderate the relationship between Lean implementation and project performance (**H3a**: organizational culture, **H3b**: management support, **H3c**: regulatory environment, and **H3d**: training and awareness).

7. Research Theoretical Model

As shown in Figure 7-1, the proposed theoretical framework posits that Lean construction practices (LPS, VSM, 5S, and VM) directly enhance project performance across four dimensions: time, cost, quality, and resource utilization. Furthermore, the framework evaluates the moderating role of contextual factors, including organizational culture, management commitment, regulatory environment, and Lean training, while controlling project size, complexity, and organization type. This integrated structure guides the empirical analysis and forms the foundation for actionable strategies to improve urban road project delivery in Egypt.

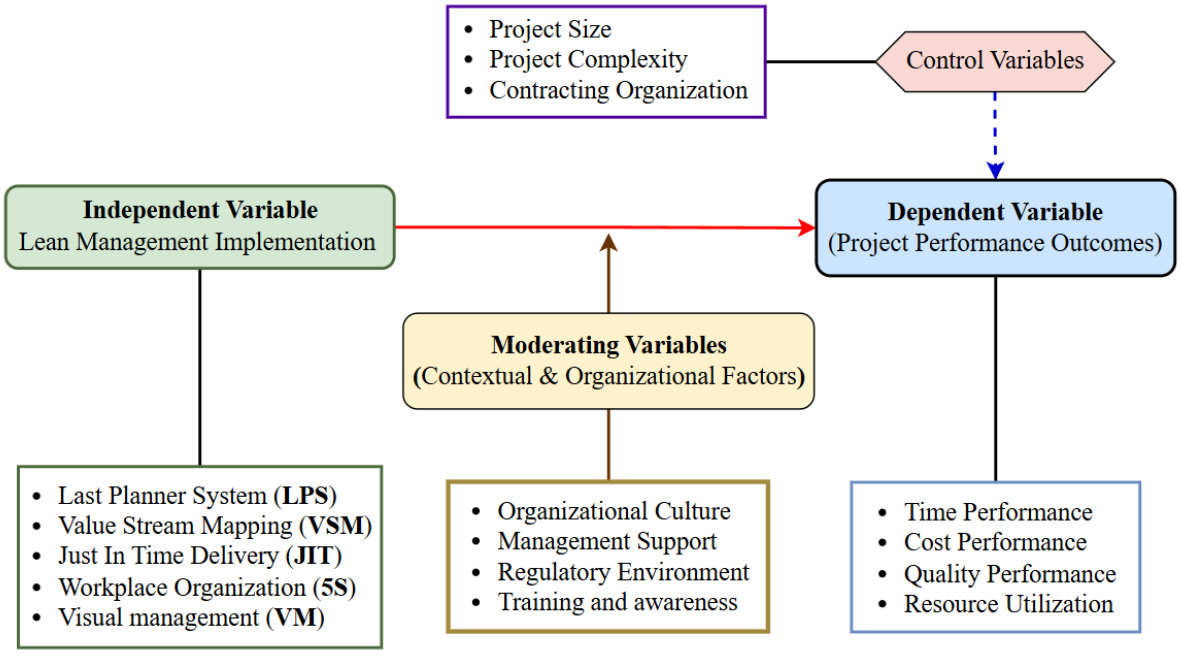


Figure 7-1: Theoretical Model of lean management in urban road projects
Source: Compiled by the researcher

8. Literature Review

The urban road construction sector has gained increasing attention for implementing Lean management to mitigate delays, cost overruns, and resource inefficiencies (Abdullahi & Tembo, 2023). While tools such as LPS, VSM, JIT, 5S, and VM have consistently improved schedule adherence, cost efficiency, and workflow reliability globally (Tezel et al., 2018), empirical research within Egypt and similar developing contexts remains limited (Ismail, 2023).

8.1 International Literature Review

(Ramirez et al., 2024) evaluated Lean adoption in an urban pavement project in Peru. Utilizing look-ahead planning, VSM, and LPS, the project improved plan reliability (PPC > 70%) and Schedule Performance Index (SPI), successfully mitigating initial progress deficits (29.38% vs. 86.21% planned). However, as a single case study, it did not address scaling Lean across differing regulatory and cultural contexts like Egypt.

(Githae & Mungai, 2024) examined Lean practices across 29 road projects in Kenya using a cross-sectional survey (N = 181). Statistical analysis revealed strong positive correlations between project performance and both VSM ($r = 0.546$, $p < 0.001$) and waste identification ($r = 0.814$, $p < 0.001$). While underscoring capacity-building needs, the study lacked insights on contextual moderation variables such as organizational culture.

(Aguome et al., 2024) evaluated Lean adoption in Bushenyi, Uganda, finding significant positive Spearman correlations with schedule adherence, cost control, and quality. However, execution was constrained by low awareness, resistance to change, and weak management support, highlighting the need for context-sensitive implementation frameworks.

(Limenih et al., 2022) investigated LPS application in Addis Ababa road projects using a mixed-methods approach and multi-criteria decision modeling. The study identified traditional push-planning reliance and key adoption barriers (labor, stakeholder, and environmental constraints) while conceptualizing LPS benefits. However, it lacked quantitative testing across broader Lean tools and performance dimensions.

(Xing et al., 2021) analyzed integrated Lean tools (LPS, JIT, 5S, VM) in Suzhou, China. Findings demonstrated significant reductions in material waste and waiting time, enhanced site safety, and improved labor productivity. Nevertheless, success relied heavily on top-management commitment and aligned contracts, limiting direct generalizability to developing countries with different organizational structures.

(Wu et al., 2019) quantitatively assessed 120 highway construction professionals, revealing that project transparency and detailing significantly enhanced work speed and efficiency ($R^2 \approx 0.669, p < 0.0001$), supporting the utility of LPS, JIT, and VM in large-scale road infrastructure.

(Elkherbawy et al., 2018) conducted a mixed-methods study across UK road projects, demonstrating that LPS, 5S, VSM, and JIT improved quality control and schedule reliability. Notably, systematic PPC and RNC tracking in a £365M project yielded ~£78,000 in direct savings. The authors emphasized the need for standardized frameworks and digital integration to sustain continuous improvement.

8.2 Arabic Literature Review

(Elmalky et al., 2024) surveyed 133 Egyptian construction professionals on fast-track projects. While 88% had heard of Lean construction, only 44.4% possessed a solid understanding of its core principles. Increased Lean awareness correlated significantly with application, yielding reduced waste, lower lifecycle costs, and improved quality. However, the study evaluated fast-track projects generally, omitting a targeted empirical analysis of urban road construction and its moderating contextual factors.

(Ismail, 2023) investigated Lean techniques in Egypt using a mixed-methods approach. Systematic applications of VSM, LPS, and 5S significantly enhance workflow reliability, schedule adherence, and cost control. Major barriers identified included limited formal training, resistance to change, and weak digital integration, underscoring the need for context-specific frameworks.

(Saleh, 2022) examined Lean implementation across Saudi Arabia's road and building projects. Despite growing awareness of LPS, VSM, 5S, and JIT, implementation remained fragmented. Projects with systematic adoption achieved measurable gains in time, cost, and resource efficiency. The study highlighted cultural similarities with Egypt, reinforcing the critical role of management commitment and structured training.

(Shaqour, 2022) surveyed Egyptian engineers and managers, identifying 31 distinct economic and operational benefits from Lean adoption, including reduced waste and higher productivity. Nevertheless, widespread implementation was constrained by university curricula gaps, organizational inertia, and limited collaborative delivery models.

(Aziz & Hafez, 2013) analyzed Lean thinking in Egyptian construction, focusing on the Last Planner System (LPS). They demonstrated that master schedules integrated with look-ahead planning and Percent Plan Complete (PPC) tracking stabilized workflows and maximized resource utilization, provided top-management commitment and cultural alignment were present.

(Issa, 2013) applied LPS as a time-risk mitigation tool on an Egyptian industrial project. Across 13 execution cycles, Lean implementation reduced total project duration by 15.57%, increased PPC, and eliminated 67% of initial time-overrun risks (PET), confirming LPS as a proactive schedule risk management tool in uncertain environments.

8.3 Synthesis of Literature

Global and regional studies consistently confirm that lean tools, specifically LPS, VSM, JIT, 5S, and VM, enhance project performance through improved schedule adherence, waste reduction, and optimized resource utilization.

However, a critical empirical gap remains existing Egyptian and regional literature lacks a comprehensive, quantitative assessment evaluating Lean management specifically within urban

road infrastructure. Furthermore, prior research rarely models statistical associations between Lean tools and multidimensional project performance (time, cost, quality, and resource utilization) while testing for moderating contextual variables (organizational culture, management support, regulatory environment, and training). To bridge this gap, this study develops and empirically tests an integrated framework directly examining these relationships within Egypt's urban road construction sector.

9. Theoretical Foundations of Lean Construction

9.1 Concept and Core Principles of Lean Construction

Lean Management originated from the Toyota Production System (TPS) (Ohno, 1988). Structured upon two foundational pillars Jidoka (autonomation/built-in quality) and Just-In-Time (JIT) the system balances five objectives: safety, quality, cost, delivery, and people development. This framework is theoretically conceptualized as the House of Lean Figure 9-1.



Figure 9-1: The House of Lean (Liker, 2004)

(Womack & Jones, 1996) codified Lean thinking into five core principles: Define Value from the customer's perspective; Identify the Value Stream to isolate value-adding from non-value-adding activities; Make Value Flow continuously without bottlenecks; Implement Pull-based Production aligned with actual demand and Strive for Perfection through continuous improvement (Kaizen) These key principles are shown in Figure 2-2

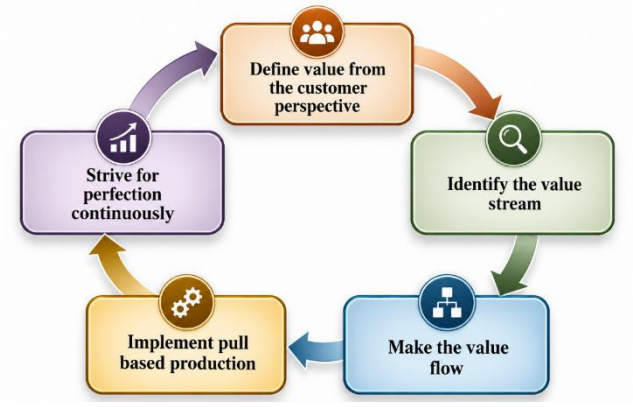


Figure 9-2: Key Principles of Lean Thinking (Womack & Jones, 1996)

Adapting Lean from manufacturing to construction, (Koskela, 2000) introduced the Transformation-Flow-Value (TFV) theory, emphasizing that traditional management over-focused on transformation (conversion) while neglecting material/information flow and value creation. Unlike manufacturing, construction is characterized by unique project conditions, fragmented supply chains, dynamic site environments, and high process variability (Howell & Ballard, 1998). Consequently, Lean Construction shifts focus on systematic waste minimization, value maximization, and collaborative planning.

9.2 Key Lean Construction Tools

Last Planner System (LPS) Developed by (Ballard & Howell, 2003), the LPS replaces traditional top-down push scheduling with collaborative pull planning driven by frontline executors (last planners). LPS operates across five hierarchical planning levels shown in Figure 9-3.

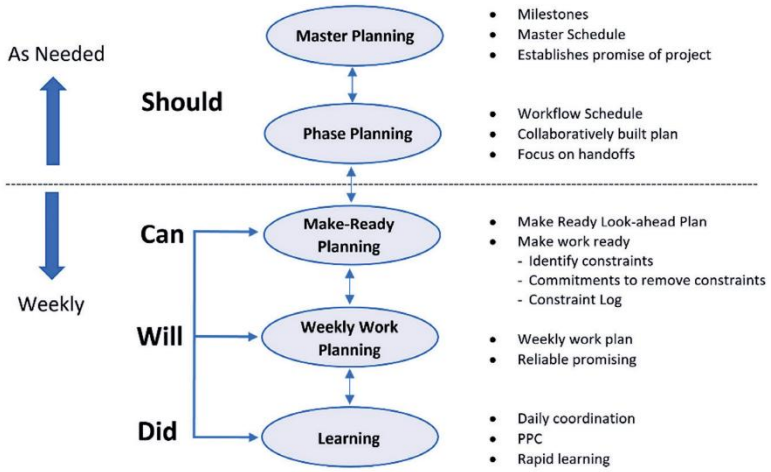


Figure 9-3: Last planner system adapted from (Ballard & Tommelein, 2016)

Value Stream Mapping (VSM) visually maps the entire flow of materials, information, and tasks required to deliver a project (Yu et al., 2009). As shown in Figure 9-4, VSM follows a systematic four-step process: defining the product family, mapping the current state to identify waste, mapping the future state to establish continuous flow, and executing an implementation plan.

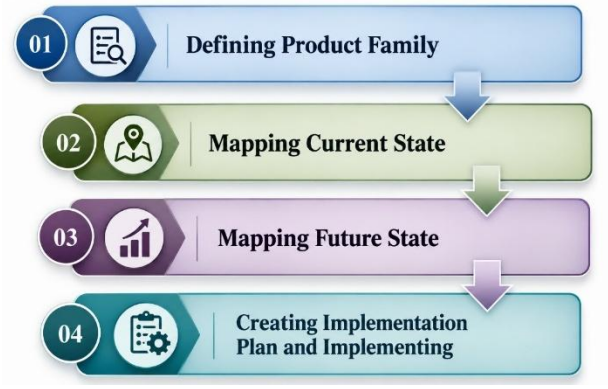


Figure 9-4: VSM processes (Demirkesen, 2021)

Just-In-Time (JIT) is a pull production strategy where materials and resources are delivered precisely when needed and in exact quantities, minimizing site storage, material degradation, and overproduction (Tommelein & Weissenberger, 1999). The core JIT principles in construction encompass pull-based ordering, supplier integration, small batch deliveries, and quality at source.

The Workplace Organization (5S) methodology structures the physical workspace to enhance safety, efficiency, and standardization (Veres et al., 2018). It follows five sequential stages shown in Figure 9-5.



Figure 9-5: 5S Stages (Demirkesen, 2021)

Visual Management (VM) converts hidden operational data (schedules, quality standards, safety risks) into accessible visual signals (Singh & Kumar, 2021). It performs five core functions and delivers significant operational benefits, including process efficiency, waste reduction, safer workflows, maintained inventory levels, team engagement, and standardization.

9.3 Project Performance Dimensions

Project performance in construction has traditionally been defined by the Iron Triangle (Time, Cost, and Quality) (Atkinson, 1999), as shown in Figure 9-6. However, to align with Lean philosophy and waste-elimination goals, this research expands the framework into a four-dimensional dependent construct incorporating Resource Utilization (Formoso et al., 2002).

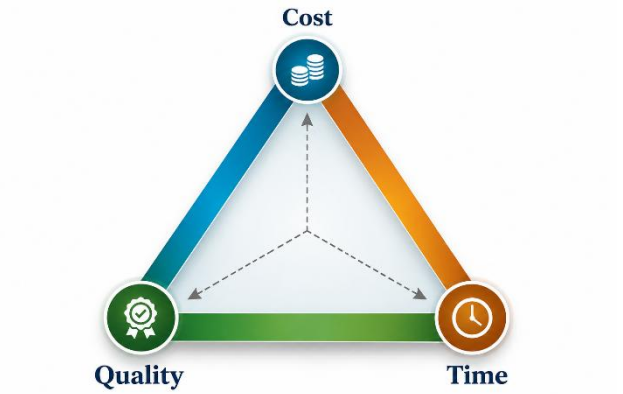


Figure 9-6: The Iron Triangle of Projects Management (Atkinson, 1999)

Time performance evaluates schedule adherence, delay frequency, and time overruns (Issa, 2013). Lean tools specifically the Last Planner System (LPS) enhance time performance by removing execution constraints during look-ahead planning, stabilizing workflow reliability, and driving PPC levels above 70–80% (Ramirez et al., 2024).

Cost performance reflects budget adherence, cost overrun rates, and cost control efficiency (Elbehairy & Nagy, 2023). Lean implementation optimizes financial outcomes by identifying non-value-adding activities via VSM and reducing material inventory carrying costs and waste through JIT procurement (Githae & Mungai, 2024).

Quality performance comprises two distinct dimensions: Conformance Quality (compliance with technical specifications and defect prevention) and Perceived Quality (stakeholder and end-user satisfaction). Lean practices elevating quality by embedding defect prevention at source (Jidoka), standardizing workplaces (5S), and rendering quality standards transparent through Visual Controls (Tezel et al., 2018).

Resource utilization measures the efficiency of consuming materials, labor, and equipment while minimizing physical and process waste (Paranavithana et al., 2024). By combining VSM, JIT, 5S, and Visual Management, Lean Construction systematically eliminates the eight categories of waste, improving labor productivity and material yield (Formoso et al., 2002).

9.4 Contextual and Organizational Factors

The theoretical framework positions contextual and organizational variables as moderators that condition the strength and direction of the relationship between Lean tool implementation and project performance outcomes (Aguome et al., 2024):

Organizational Culture shared values emphasizing teamwork, innovation, and adaptability serve as key enablers of Lean adoption, whereas traditional hierarchical structures and cultural resistance to change act as primary barriers in Egyptian construction (Ismail, 2023).

Management Support active leadership commitment, resource allocation, and strategic alignment are essential for embedding Lean tools into organizational routines and sustaining performance gains over time (Aguome et al., 2024).

Regulatory Environment public procurement laws, rigid specifications, and bureaucratic approval processes (e.g., Building Law No. 119 of 2008) can constrain Lean flexibility (such as JIT lead times and LPS collaborative contracts), making regulatory adaptability a critical moderator (Shaqour, 2022).

Training and Awareness structured Lean education bridges the documented awareness-implementation gap (where 88% of Egyptian construction professionals recognize Lean

concepts, but only 44.4% understand their practical tool application), mitigating resistance and building technical execution capacity (Sbeih, 2024).

9.5 Control Variables

Control variables are factors that are defined as constant or statistically controlled in the research design to determine the net impact of lean management on project performance. The following control variables are included in this study:

Project Size and Complexity controlled based on contract value, planned duration, technical difficulty, and stakeholder count to ensure performance variations are attributable to Lean execution rather than inherent project scale (Hyarat et al., 2024).

Contracting Organization Type controls structural differences in management practices, institutional capacity, and resource availability across public entities, private contractors, joint ventures, and international firms (Wu et al., 2019).

10. Statistical Analysis and Results

The empirical results were evaluated based on valid questionnaire responses collected from urban road construction projects in New Cairo, Egypt. The analysis proceeds through data preparation, profiling demographic characteristics, assessing the reliability of the measurement scale (Cronbach's alpha), descriptive statistics, and correlation analysis. To test the study hypotheses, twenty-four regression models were estimated across three structured stages:

Stage One: The effects of individual Lean tools (LPS, VSM, JIT, 5S, and VM) on the different dimensions of project performance were examined.

Stage Two: The analysis assessed the effect of overall Lean implementation, represented by a composite Lean Implementation (LI) index, on project performance dimensions.

Stage Three: the moderating effects of organizational and contextual factors on the relationship between Lean implementation and project performance were tested.

10.1 Target Population and Sampling Frame

New Cairo was selected as the study location, focusing on active urban road construction projects during the 2025–2026 academic year. The organizational scope encompassed six major contracting enterprises: Al-Mokawloon Al-Arab, Orascom Construction, Hassan Allam Construction, Nile Road, National Construction, and Maxim, alongside public client and supervisory bodies, including the New Urban Communities Authority (NUCA).

Based on official project personnel registries and organizational charts, a total population frame of 150 eligible stakeholders was identified across four stakeholder categories: project managers, consultants, site and planning engineers, and government and client representatives. A census

approach was adopted, and questionnaires were distributed electronically via Google Forms. A total of 120 valid questionnaires were returned, yielding an 80% response rate.

10.2 Data Preparation and Measurement Approach

Responses from the bilingual Google Forms questionnaire were converted into numerical values and standardized on a common (0–1) scale. Higher values represented better Lean implementation, more supportive organizational conditions, and better project performance. Composite scores were then calculated for Lean tools, performance outcomes, and organizational factors.

10.3 Demographic and Project Profile of the Sample

As shown in Figure 10-1, the sample profile demonstrates robust managerial representation and substantial operational scale across New Cairo's urban road construction sector. Project managers constituted the largest professional group (43.3%), followed by consultants (34.2%), site engineers (11.7%), and government officials (10.8%), ensuring highly credible technical and decision-making insights. Regarding project characteristics, the vast majority were medium-to-extra-large in size (85.8%) and characterized by high or very high complexity (75.0%), reflecting the significant technical and stakeholder demands of the sampled infrastructure works. Finally, private contracting firms represented the largest organizational share (51.7%), followed by government agencies (26.7%) and joint ventures (21.7%).

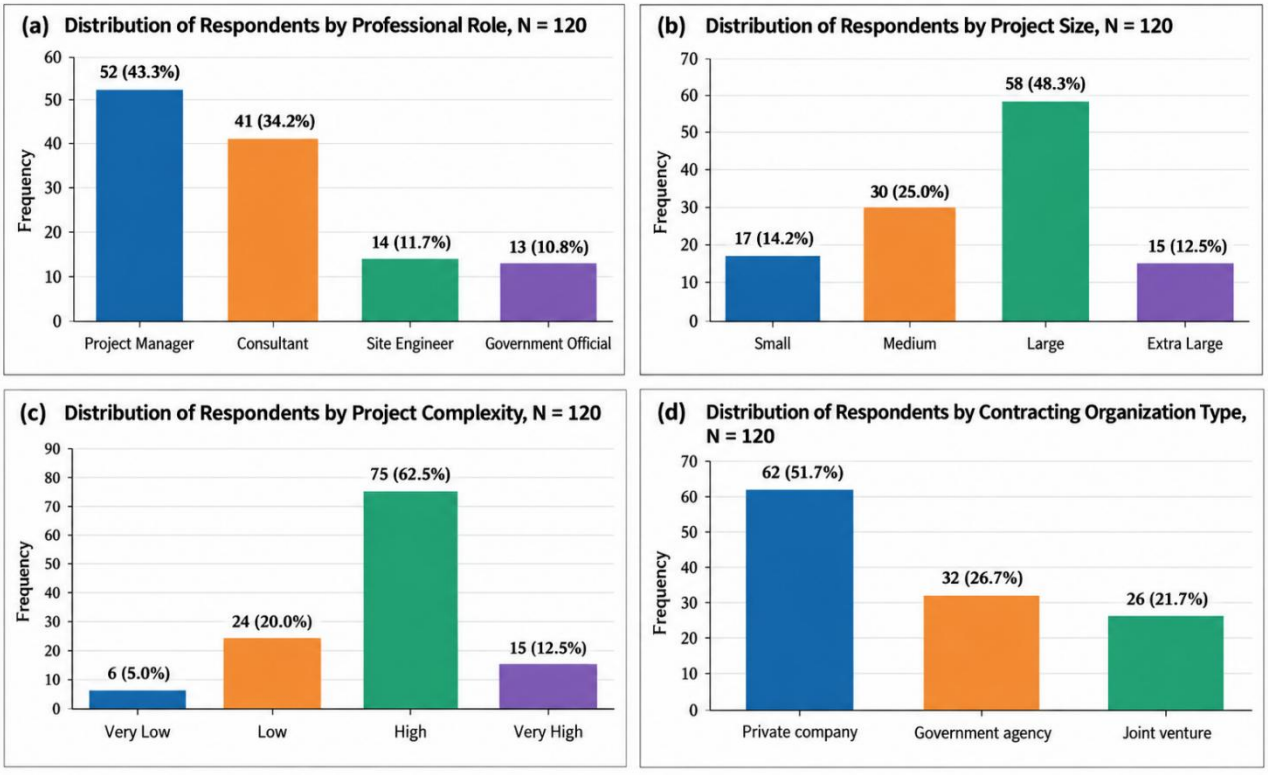


Figure 10-1: Distribution of Respondents and Project Characteristics

Source: Compiled by the researcher

10.4 Reliability Analysis of Measurement Scales

To ensure internal consistency before hypothesis testing, Cronbach's alpha coefficients were evaluated for all study constructs against the standard benchmark $\alpha \geq 0.70$. As detailed in Table 10-1 and Figure 10-2, the overall composite Lean Implementation scale demonstrated excellent internal reliability $\alpha = 0.940$, with all individual Lean tools exceeding the acceptable threshold: Visual Management $\alpha = 0.854$, Last Planner System $\alpha = 0.871$, JIT & 5S $\alpha = 0.848$), and Value Stream Mapping $\alpha = 0.757$. Similarly, high internal consistency was established across moderating and performance constructs, including Management Support $\alpha = 0.946$, Time Performance $\alpha = 0.863$, Resource Utilization $\alpha = 0.846$, Regulatory Environment $\alpha = 0.728$, Quality Performance $\alpha = 0.725$, and Organizational Culture $\alpha = 0.695$. Conversely, lower coefficients were observed for Training & Awareness $\alpha = 0.310$ and Cost Performance $\alpha = 0.526$, primarily attributable to scale brevity and mixed item formats; both constructs were retained to preserve the conceptual framework's integrity, with their measurement limitations acknowledged during hypothesis testing. Overall, the measurement instrument displayed sufficient reliability to proceed with inferential statistical procedures.

Table 10-1: Reliability (Cronbach's Alpha) of the Study Constructs

Construct	No. of Items	N	Cronbach's Alpha
Last Planner System (LPS)	4	120	0.871
Value Stream Mapping (VSM)	4	120	0.757
JIT & 5S (Waste Minimization)	4	120	0.848
Visual Management (VM)	4	120	0.854
Organizational Culture	3	120	0.695
Management Support	3	120	0.946
Regulatory Environment	2	120	0.728
Training & Awareness	2	120	0.310
Time Performance	4	120	0.863
Cost Performance	4	120	0.526
Quality Performance	4	120	0.725
Resource Utilization	4	120	0.846
Lean Implementation (composite, 16 items)	16	120	0.940

Source: Compiled by the researcher

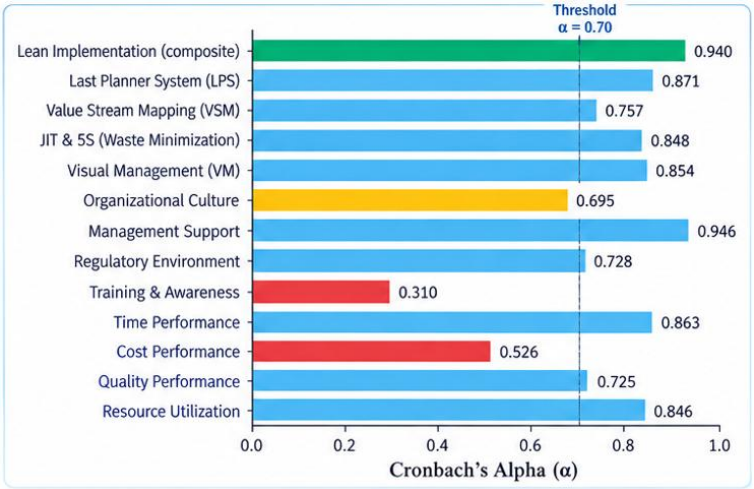


Figure 10-2: Internal Consistency Reliability of Study Constructs

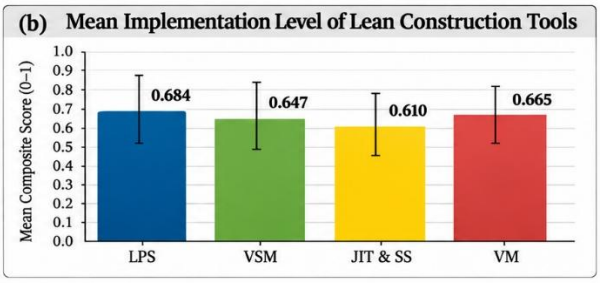
10.5 Descriptive Statistics of the Study Constructs

Figure 10-3 presents descriptive statistics (mean, standard deviation, minimum, and maximum) for the normalized 0-to-1 composite scores of Lean tools, overall Lean implementation, moderating variables, and project performance dimensions. On average, respondents reported moderate-to-high Lean tool implementation, with overall Lean implementation averaging 0.651 (SD = 0.187). The Last Planner System (LPS) recorded the highest implementation level (0.684), whereas JIT & 5S recorded the lowest (0.610), indicating that collaborative planning tools are more systematically embedded than physical flow and waste-minimization routines in Egyptian urban road projects. Quality Performance scored highest (0.826), while Resource Utilization was lowest (0.699). Among moderating variables, organizational culture exhibited the highest baseline (0.756), whereas training and awareness scored lowest (0.487, SD = 0.315), corroborating the awareness-implementation gap documented in Egyptian Lean literature (Elmalky et al., 2024).

(a) Descriptive Statistics of Study Constructs

Construct	Mean	Std. Dev.	Min	Max
Lean Management Implementation				
Last Planner System (LPS)	**0.684**	0.198	0.00	1.00
Value Stream Mapping (VSM)	**0.647**	0.225	0.00	1.00
JIT & 5S (Waste Minimization)	**0.610**	0.214	0.00	1.00
Visual Management (VM)	**0.665**	0.200	0.00	1.00
Lean Implementation (composite)	**0.651**	0.187	0.00	1.00
Organizational and Contextual Factors				
Organizational Culture	**0.756**	0.186	0.00	1.00
Management Support	**0.585**	0.264	0.00	1.00
Regulatory Environment	**0.547**	0.267	0.00	1.00
Training & Awareness	**0.487**	0.315	0.00	1.00
Project Performance Outcomes				
Time Performance	**0.724**	0.201	0.00	1.00
Cost Performance	**0.721**	0.247	0.00	1.00
Quality Performance	**0.826**	0.228	0.00	1.00
Resource Utilization	**0.699**	0.228	0.00	1.00

Note: N = 120. All constructs are measured on a 0–1 scale.



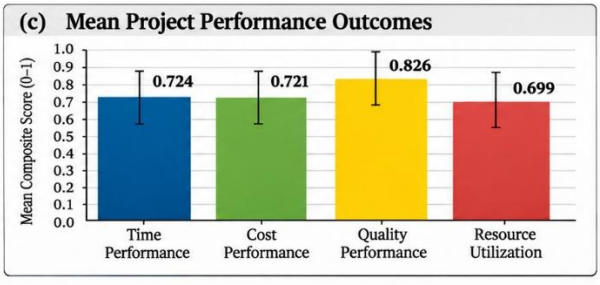


Figure 10-3: Descriptive Statistics of Study Constructs

10.6 Correlation Analysis and Collinearity Diagnostics

Prior to regression estimation, Pearson correlation coefficients were computed across all composite constructs to assess bivariate associations and provide an initial screen for potential multicollinearity. As illustrated in the heat map Figure 10-4 , overall Lean Implementation (LI) is strongly and positively correlated with all four project performance dimensions: Time Performance (r = 0.76), Resource Utilization (r = 0.73), Quality Performance (r = 0.64), and Cost Performance (r = 0.62), providing preliminary bivariate support for Hypothesis H1. Intercorrelations among individual Lean tools were moderate-to-strong (e.g., LPS and VSM, r = 0.61), reflecting their complementary nature as an integrated management approach. Furthermore, contextual moderating variables demonstrated positive associations with both Lean adoption and project performance, led by Management Support and Organizational Culture. To ensure statistical validity, formal collinearity diagnostics Table 10-2 confirmed that Tolerance values ranged between 0.258 and 0.414, with Variance Inflation Factor (VIF) values between 2.417 and 3.873 well below the severe multicollinearity threshold of 5.0 confirming shared variance without problematic collinearity.

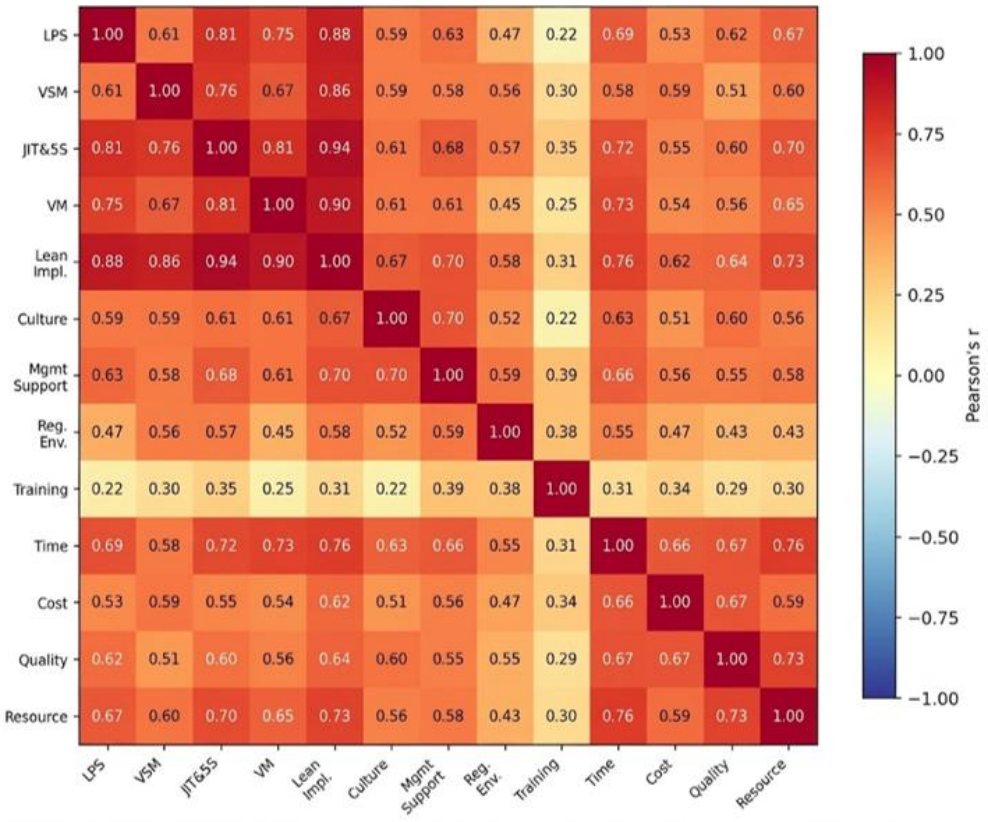


Figure 10-4: Correlation Matrix of Study Constructs

Source: Compiled by the researcher

Table 10-2: Collinearity Diagnostics

Model	Predictors Tested	Predictor	Tolerance	VIF
Model 2	VSM + JIT + Controls → Cost Performance	VSM	N/A[a]	N/A[a]
		JIT	N/A[a]	N/A[a]
Model 3	5S + VM + Controls → Quality Performance	5S	N/A[a]	N/A[a]
		VM	N/A[a]	N/A[a]
Model 4	VSM + JIT&5S + VM + Controls → Resource Utilization	VSM	0.414	2.417[b]
		JIT & 5S	0.258	3.873[b]
		VM	0.337	2.968[b]
Model 5	Lean Implementation → Time Performance	LI	N/A[a]	N/A[a]
Model 6	Lean Implementation → Cost Performance	LI	N/A[a]	N/A[a]
Model 7	Lean Implementation → Quality Performance	LI	N/A[a]	N/A[a]
Model 8	Lean Implementation → Resource Utilization	LI	N/A[a]	N/A[a]

Source: Compiled by the researcher

10.7 Regression Analysis Framework

To comprehensively evaluate the study hypotheses grounded in the Transformation-Flow-Value (TFV) theory, a structured three-stage regression modeling framework comprising twenty-four distinct models was estimated. Stage 1 investigates the individual effects of specific Lean management tools, namely LPS, VSM, JIT, 5S, and VM, on each corresponding project performance dimension (time, cost, quality, and resource utilization) while controlling project size, complexity, and contracting organization type. Stage 2 evaluates the holistic impact of the composite Lean Implementation score to assess Lean as an integrated management approach across all four performance outcomes. Finally, Stage 3 examines the conditional moderating effects of four contextual factors, like organizational culture, management support, regulatory environment, and training and awareness to determine how they influence the strength and direction of the Lean-performance relationship.

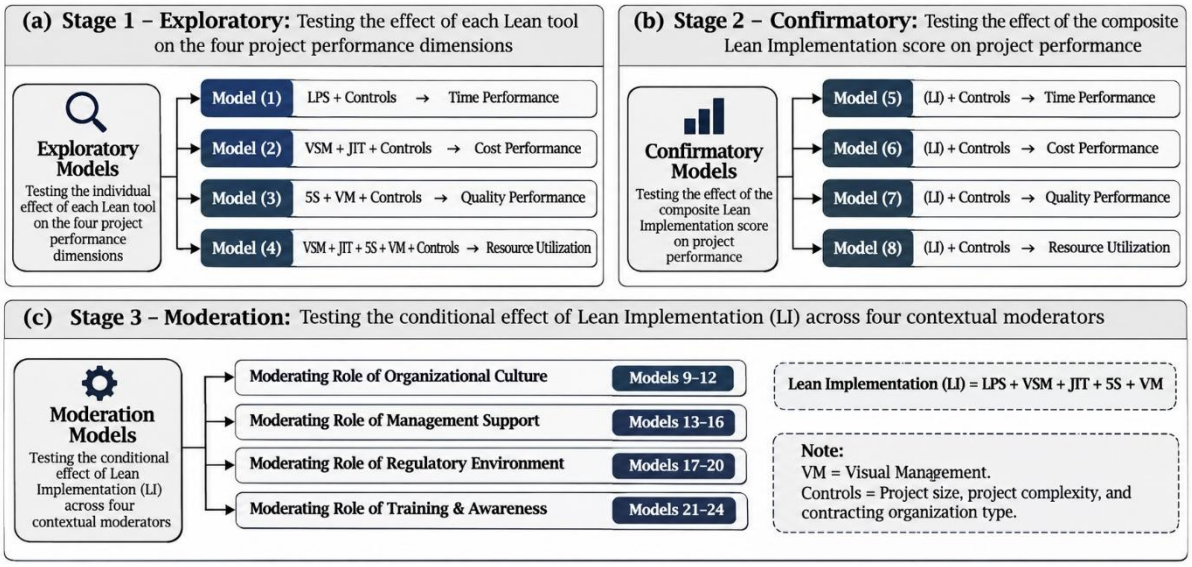


Figure 10-5: Regression Analysis Framework

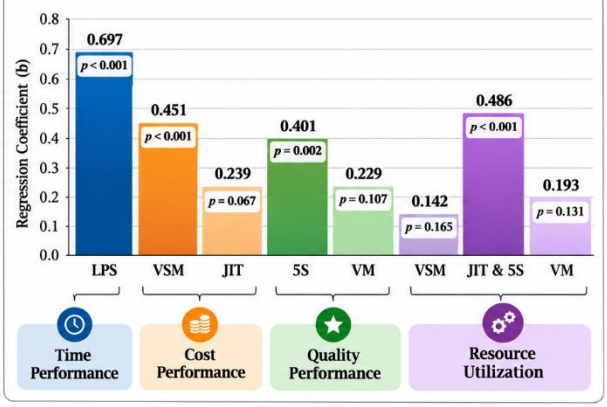
10.7.1 Stage One: Effects of Individual Lean Tools on Project Performance

Stage One evaluated the exploratory regression models (Models 1–4) to examine the individual effects of specific Lean management tools on project performance dimensions, controlling for project size, complexity, and contracting organization type Figure 10-6. In Model 1 (H1a), the Last Planner System (LPS) emerged as a highly significant positive predictor of Time Performance ($b = 0.697$, $p < 0.001$), confirming that collaborative planning routines directly enhance schedule adherence. In Model 2 (H1b), Value Stream Mapping (VSM) significantly improved Cost Performance ($b = 0.451$, $p < 0.001$), whereas Just-In-Time (JIT) delivery exhibited a non-significant positive trend ($b = 0.239$, $p = 0.067$). In Model 3 (H1c), 5S workplace organization demonstrated a statistically significant positive impact on Quality Performance ($b = 0.401$, $p = 0.002$), while Visual Management (VM) was non-significant ($b = 0.229$, $p = 0.107$). Finally, in Model 4 (H1d), the combined JIT & 5S routine served as the primary driver of Resource Utilization ($b = 0.486$, $p < 0.001$), whereas VSM ($b = 0.142$, $p = 0.165$) and VM ($b = 0.193$, $p = 0.131$) showed non-significant individual contributions due to shared inter-tool variance. Overall, these Stage One results provide partial empirical support for Hypothesis H1, demonstrating that while specific tools like LPS, VSM, 5S, and JIT & 5S drive individual performance outcomes, shared variance among tools obscures their isolated multivariate contributions.

(a) Regression Results for Individual Lean Tools

Model	Sub-hypothesis	Lean Tool Tested	Performance	b	P	Conclusion
1	H1a	LPS	Time Performance	0.697	< 0.001	Significant positive
2	H1b	VSM	Cost Performance	0.451	< 0.001	Significant positive
		JIT		0.239	= 0.067	Not significant
3	H1c	5S	Quality Performance	0.401	= 0.002	Significant positive
		VM		0.229	= 0.107	Not significant
4	H1d	VSM	Resource Utilization	0.142	= 0.165	Not significant
		JIT & 5S		0.486	< 0.001	Significant positive
		VM		0.193	= 0.131	Not significant

(b) Unstandardized Regression Coefficients



Note: Project size, complexity, and contracting organization type were included as control variables in all models. Both statistically significant and non-significant Lean-tool effects are presented. Significance level: $p < 0.05$.

Figure 10-6: Summary of Stage One Exploratory Regression Models

Source: Compiled by the researcher

10.7.2 Stage Two: Effects of Composite Lean Implementation on Project Performance

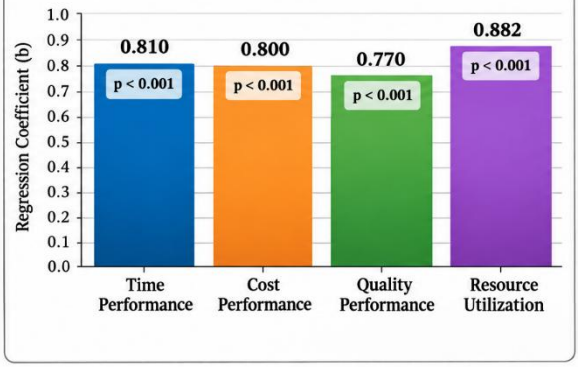
Stage Two evaluated the confirmatory regression models (Models 5–8) to examine the holistic impact of the composite Lean Implementation score (LI) on project performance outcomes, controlling for project size, project complexity, and contracting organization type (Figure 4-

16). Across all four models, composite Lean Implementation demonstrated statistically significant, strong positive associations with performance outcomes ($p < 0.001$). Specifically, composite LI exhibited the strongest positive impact on Resource Utilization in Model 8 ($b = 0.882$, $p < 0.001$), followed by Time Performance in Model 5 ($b = 0.810$, $p < 0.001$), Cost Performance in Model 6 ($b = 0.800$, $p < 0.001$), and Quality Performance in Model 7 ($b = 0.770$, $p < 0.001$). These results provide full empirical support for Hypothesis H2 and its corresponding sub-hypotheses (H2a, H2b, H2c, H2d). By aggregating individual tools into an integrated construct, Stage Two resolves the shared variance limitations observed in Stage One, confirming that Lean construction operates most effectively as a unified, systemic management methodology in Egypt's urban road infrastructure sector.

(a) Regression Results for Composite Lean Implementation

Model	Sub-hypothesis	Lean Tool Tested	Performance	b	P	Conclusion
5	H2a	Composite (LI)	Time Performance	0.810	< 0.001	Significant positive
6	H2b	Composite (LI)	Cost Performance	0.800	< 0.001	Significant positive
7	H2c	Composite (LI)	Quality Performance	0.770	< 0.001	Significant positive
8	H2d	Composite (LI)	Resource Utilization	0.882	< 0.001	Significant positive

(b) Unstandardized Regression Coefficients (Composite Lean Implementation)



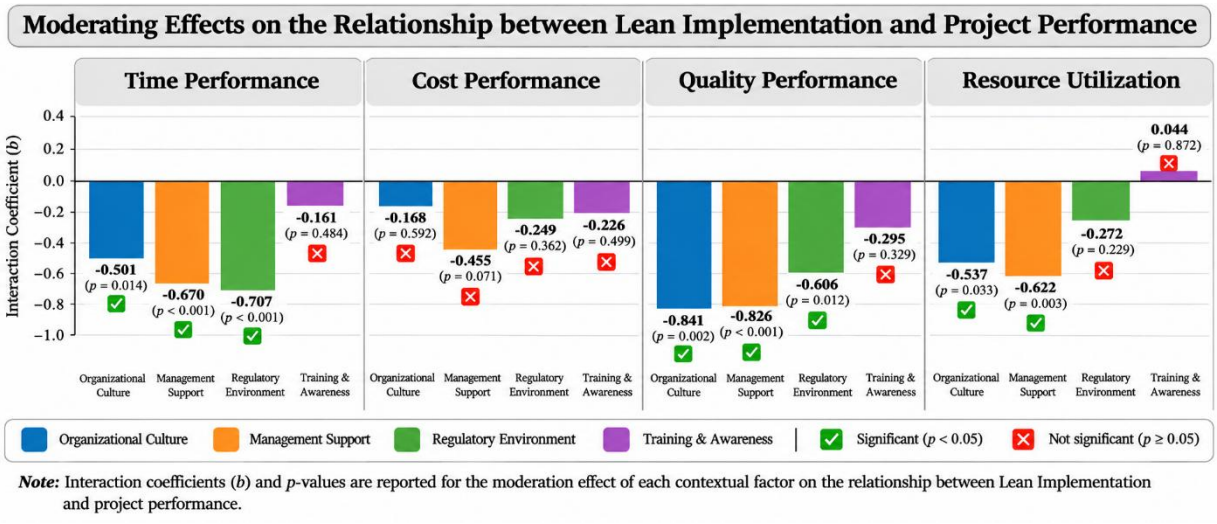
Note: Project size, complexity, and contracting organization type were included as control variables in all models. LI (LPS, VSM, JIT, 5S, VM). Significance level: $p < 0.001$.

Figure 10-7: Summary of Stage two Confirmatory Regression Models
Source: Compiled by the researcher

10.7.3 Stage Three: Contextual and Organization Factors Moderation Analysis

Stage Three evaluated sixteen moderated regression models (Models 9–24) to test Hypothesis H3 regarding the conditional effects of organizational culture, management support, regulatory environment, and training and awareness on the Lean-performance relationship (Figure 4-20). All interaction terms (*LI* × Moderator) were mean centered prior to estimation to reduce non-essential multicollinearity. Overall, eight of the sixteen interaction terms achieved statistical significance ($p < 0.05$), exhibiting a consistent buffering pattern where interaction coefficients (b) were negative while main effects remained strongly positive. Specifically, Organizational Culture significantly moderates the impact of LI on Time Performance ($b = -0.501$, $p = 0.014$), Quality Performance ($b = -0.841$, $p = 0.002$), and Resource Utilization ($b = -0.537$, $p = 0.033$). Similarly, Management Support significantly moderated Time Performance ($b = -0.670$, $p < 0.001$), Quality Performance ($b = -0.826$, $p < 0.001$), and Resource Utilization ($b = -0.622$, $p =$

0.003). The Regulatory Environment significantly moderates Time Performance (b = -0.707, p < 0.001) and Quality Performance (b = -0.606, p = 0.012). Conversely, no significant moderation effects were observed for Cost Performance across any moderator, nor for Training & Awareness across any performance outcome, providing partial support for H3a, H3b, and H3c, while leaving H3d unsupported.



Note: Interaction coefficients (*b*) and *p*-values are reported for the moderation effect of each contextual factor on the relationship between Lean Implementation and project performance.

Figure 10-8: Summary of Stage Three moderating effects Regression Models

Source: Compiled by the researcher

11. Discussion of Findings

The empirical results strongly validate the primary proposition that Lean construction tools significantly enhance project performance in Egypt's urban road sector. At the individual tool level (**Stage 1**), the Last Planner System (LPS) emerged as the dominant predictor of Time Performance (b = 0.697, p < 0.001, R^2 = 0.495). This robust effect occurs because LPS directly targets workflow variability through look-ahead constraint analysis, pull scheduling, and daily commitment tracking (PPC), replacing reactive site management with predictive workflow control a finding aligning with international evidence (Ramirez et al., 2024) and (Ismail, 2023). Similarly, Value Stream Mapping (VSM) served as the primary driver of Cost Performance (b = 0.451, p < 0.001), while 5S workplace organization (b = 0.401, p = 0.002) and combined JIT & 5S (b = 0.486, p < 0.001) significantly improved Quality and Resource Utilization, respectively. When evaluated as an integrated composite construct (LI, **Stage 2**), Lean implementation demonstrated systemic positive impacts across all performance dimensions (p < 0.001), confirming that Lean tools operate together rather than as isolated interventions.

A notable outcome is the structural variance in explanatory power (R^2) across performance dimensions, where composite Lean implementation explained the highest variance in Time Performance (Adj R^2 = 0.579) and Resource Utilization (Adj R^2 = 0.533), but relatively lower variance in Cost Performance (Adj R^2 = 0.394). Theoretically, time and resource workflows are

directly controllable through site-level operational discipline, constraint removal, and waste reduction routines. Conversely, cost performance in Egyptian infrastructure megaprojects is heavily moderated by external macroeconomic disruptions such as currency devaluations, material price volatility, and government payment delays, which lie outside the immediate sphere of Lean operational control (Daoud et al., 2023). Nevertheless, the substantial R^2 across all models confirms that Lean adoption remains a first-order determinant of overall project delivery efficiency.

Contrary to traditional literature assuming that organizational factors only serve as direct enablers, **Stage 3** revealed a statistically significant negative interaction pattern ($b < 0$) across eight moderation models involving Organizational Culture, Management Support, and Regulatory Environment ($p < 0.05$). Rather than invalidating Lean efficacy, this finding uncovers a critical compensatory (substitution) mechanism grounded in Transformation-Flow-Value (TFV) theory:

- In Low-Support / High-Constraint Environments: Lean tools yield their highest marginal performance gains (b coefficients are largest) because formal procedures (e.g., LPS constraint logs, VSM flow mapping) actively substitute for absent managerial guidance and unstructured culture.
- In High-Support / Favorable Environments: Where informal collaboration and active leadership are already established, coordination bottlenecks are pre-emptively resolved through interpersonal communication, resulting in diminishing marginal returns for formal Lean practices.

Management Support demonstrated the strongest buffering coefficient among statistically significant interaction models ($b = -0.670$ to -0.826), followed by Regulatory Environment ($b = -0.606$ to -0.707) and Organizational Culture ($b = -0.501$ to -0.841). Training & Awareness showed non-significant moderation ($p > 0.32$), a result primarily attributed to scale measurement noise ($\alpha = 0.310$) and the documented awareness-implementation gap in Egypt (Elmalky et al., 2024).

12. Summary and Recommendations

The findings of this study have practical and policy implications for improving the performance of urban road construction projects in New Cairo, Egypt. At the project level, priority should be given to the Last Planner System (LPS) as a practical approach to improving schedule performance, while Value Stream Mapping (VSM), Just-In-Time production (JIT), and the 5S methodology should be applied as complementary tools to support cost control, quality improvement, and resource utilization. At the institutional level, public agencies should review procurement and payment procedures to reduce administrative delays, while regulatory

authorities should streamline permitting procedures for projects that adopt documented lean construction practices. In addition, training programs should focus on the practical, on-site application of lean construction tools, particularly JIT and 5S, rather than relying solely on general awareness initiatives.

Despite these contributions, the study has several limitations. The findings are based on cross-sectional perceptual data collected from 120 construction professionals involved in urban road projects in New Cairo and therefore should not be generalized to other infrastructure sectors or regions in Egypt without further empirical validation. The use of self-reported measures and the relatively low internal consistency of some measurement scales, particularly the training and awareness scale, may also affect the reliability of the findings. Therefore, future studies should follow projects over a longer period, use actual project records, investigate why JIT and 5S are difficult to implement, and examine how the effects of these methods vary with working conditions by studying a larger number of construction projects across Egypt and different regions.

Overall, the findings indicate that lean construction practices are significantly associated with improvements in schedule performance, cost performance, quality, and resource utilization. The findings also indicate that lean construction practices may yield greater benefits for project performance under certain organizational and regulatory constraints, highlighting their potential role in supporting project performance even when institutional conditions are not entirely favorable. These findings contribute to a better understanding of the application of lean construction in urban road construction projects in Egypt and provide a solid basis for further research and practical implementation.

13. List of Abbreviations

Abbreviation	Definition
5S	Sort, Set in order, Shine, Standardize, Sustain
BIM	Building Information Modeling
CPM	Critical Path Method
EFCBC	Egyptian Federation for Construction and Building Contractors
EGP	Egyptian Pound
GDP	Gross Domestic Product
JIT	Just-In-Time delivery
KPIs	Key Performance Indicators
LI	Lean Implementation
LPS	Last Planner System
MENA	Middle East and North Africa
MS	Management Support
NUCA	New Urban Communities Authority
OC	Organizational Culture
PET	Percent Expected Time-Overrun
PLS	Partial Least Squares
PPC	Percentage of Plans Completed
RE	Regulatory Environment
RNC	Reasons for Non-Completion
SD	Standard Deviation
SE	Standard Error
SPI	Schedule Performance Index
TA	Training and Awareness
TFV	Transformation-Flow-Value
TPS	Toyota Production System
VIF	Variance Inflation Factor
VM	Visual Management
VSM	Value Stream Mapping
WM	Waste Management

Source: Compiled by the researcher

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