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A SYSTEMATIC REVIEW TO INVESTIGATE THE ROOT CAUSES FOR VARIATIONS IN INFRASTRUCTURE DEVELOPMENTS

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ABSTRACT

Infrastructure development projects play a critical role in economic and societal advancement. However, they are frequently affected by variations that influence project cost, time, and performance. Given the limited knowledge about the root causes and impacts specific to infrastructure developments, a systematic literature review conducted using a mixed method approach. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. Relevant publications from Scopus, Web of Science, and ScienceDirect databases between 2019 and 2023 were identified using a structured search strategy based on the PICO framework. Following screening and eligibility assessment, fourteen peer-reviewed studies were selected for detailed analysis. The findings reveal that variations arise from interconnected financial, technical, administrative, environmental, institutional, and human-related factors. Key root causes include insufficient budget allocation, regulatory and policy changes, design deficiencies, unforeseen site conditions, material supply disruptions, and coordination failures among stakeholders. These factors contribute to project delays, cost overruns, contractual disputes, and scope modifications, ultimately affecting infrastructure project performance. The review further highlights the complex interactions among stakeholders and emphasizes the need for proactive risk management, improved financial planning, regulatory streamlining, and enhanced communication mechanisms to mitigate variation impacts. By synthesizing recent literature, this study provides a consolidated understanding of the drivers of variations in infrastructure developments and offers insights to support policy makers and practitioners in improving project resilience and delivery outcomes.

Keywords: *Development Projects; Impacts; Infrastructure; Root Causes; Systematic Literature Review; Variations.*

1. INTRODUCTION

Variations in the construction context pertain to the discrepancies between the planned and actual outcomes of events (Kerzner, 2017). Professionals acting in the current construction industry of the twenty-first century have placed a special emphasis on identifying the root causes of variations to reduce the resulting consequences (Alnuaimi et al., 2010). Amendments to the scheduled start time of an activity would unavoidably cause disruptions to other tasks, which could impact the project's quality and/or cost (Ibbs & Chih, 2011). As per the findings of Ali (2008), variations can also result from adding,

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removing or changing the project's objectives, the scope of work, contract drawings, specifications and/or bills of quantities (Cabalag & Silva, 2019). A variation order is issued after the contract starts to approve changes, additions or completions to the original agreement. It updates the original contract and becomes an extra part of the agreement. Because of the complicated activities during construction, it is impossible to finish a construction project without any variations in plans or the construction process (Ssegawa et al., 2002).Variation orders caused by the stakeholders, including owners, consultants, contractors and external factors, impact the project's success (Alkhattabi et al., 2023) The authors further stated that the presence of variation clauses in contracts indicates that no project can be completed without variations. Variation is thus a recurrent problem in the construction sector. Therefore, it is important to assess the root causes for variations in construction industry (Memon et al., 2014).

There is no exception for the occurrence of variations in infrastructure projects as well. Variations in infrastructure projects are high due to several factors including unexpected site conditions, changes in design requirements and unforeseen regulatory issues. Additionally, the complex nature of these projects often leads to difficulties in precise cost and time estimates. Variations are especially high in infrastructure projects due to their large scale, extended timelines and involvement of multiple stakeholders (Karim et al., 2020). Uncertainties such as unforeseen ground conditions, evolving design requirements and coordination challenges across disciplines and contractors can be commonly observed in these projects (Alnuaimi et al., 2010). Additionally, infrastructure developments tend to be more susceptible to regulatory changes, political influences and public consultations, all of which can contribute to frequent scope adjustments and contract modifications. According to Wambeke et al. (2011), infrastructure development project expenses fluctuate because of variations. By examining these variations, it becomes easier to identify and control unforeseen costs and make sure the project stays within budget. Additionally, Infrastructure projects may change in scope as they progress (Althiyabi & Qureshi, 2021). By analysing variations, one can prevent scope creep and preserve alignment with project objectives by ensuring that modifications are justified, regulated and documented (Ahmed & Jawad, 2022).

While variation orders in construction have been extensively studied (Sun et al., 2016; Wambeke et al., 2011; Memon et al., 2014), this review is positioned to address a more specific and underexplored niche. Existing research on variations in infrastructure projects tends to focus on conventional sectors such as road and building construction (Herrera et al., 2020; Alsuliman, 2019), with limited structured synthesis of root causes across diverse infrastructure project types. Moreover, several extant review studies have drawn primarily on older datasets, reducing their relevance to contemporary industry conditions characterized by evolving procurement environments, digitalization, and post-pandemic supply-chain disruptions. Unlike prior reviews that treat variation causes as isolated lists, this study employs a structured PICO-based search strategy and PRISMA-compliant methodology to synthesize causal mechanisms and map their interdependencies, providing a categorized and analytically grounded contribution to the field. Accordingly, this study investigates the root causes of variations in infrastructure developments and examines how interconnectivity develops among the parties responsible for variation initiation in Sri Lanka.

2. RESEARCH METHODOLOGY

Literature reviews have gained great importance among scholars since it is believed that "most research can only be understood in context - and a key part of that context consists of the results of other studies" (Petticrew & Roberts, 2006). The systematic reviewing methodology has gained popularity among many sorts of reviews due to its unique qualities that cannot be found in other traditional reviewing approaches (Pahlevan-Sharif et al., 2019). As a result, a systematic literature review (SLR) has been chosen for this study since it gives unbiased results from the literature with a high level of quality and efficiency (Liberati et al., 2009). SLR was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Liberati et al., 2009).

2.1 SYSTEMATIC LITERATURE REVIEW

Among the variety of SLR search tools, this study found the PICO framework to be the most suitable. PICO stands for Population (P), Intervention (I), Comparison (C), and Outcome (O), and its structured elements fit well into the context of investigating variations in infrastructure projects. The research question was formulated as, "What are the root causes and impacts related to variations in infrastructure development projects?".

The research question was developed based on an initial manual keyword search. The study identified articles to extract findings about the root causes, impacts, and future directions related to variations in infrastructure projects, aligning these findings with the PICO elements. The elements were defined as follows: Population (P): Construction projects; Intervention (I): Variations, Variation orders; Comparison (C): Road projects, Bridge projects, Infrastructure types; Outcome (O): causes, factors, issues, reasons, impacts, effects, consequences, outcomes. Subsequently, a logic grid was developed to finalize a comprehensive search string incorporating all possible keywords. The keywords used under each PICO element is presented in Table 1.

Table 1: Systematic literature review logic grid

Population (P)	Intervention (I)	Comparison (C)	Outcome (O)
Construction projects	Variations	Infrastructure projects	Causes
	Variation orders	Road projects	Impacts
	Change Orders	Bridge projects	Outcomes
		Civil Projects	Factors
			Issues
	Variation*	Infrastructure*	
			Reason*
			Effect*
			Consequence*
			Outcome*

Database selection is vital to ensure the success of an SLR. This study utilized three databases: Scopus, Web of Science and Science Direct, which are highly regarded for academic research and relevant to the study's context. A "title-abstract-keyword" search was employed to obtain precise and comprehensive results. However, for the intervention of this study, variations in construction projects, a “title only” search was conducted due to the abundance of articles that mention “variations” in abstracts without relevance to the specific context. Additionally, variations of the word "variation" were used in the search to cover all relevant phrases comprehensively.

Boolean operators (AND, OR) were utilized to enhance the versatility of the search results. The search criteria were limited to the last five years (from 2019) to ensure the results were current and accurate, given the fast-evolving nature of research on root causes, impacts, and future directions of variations in construction projects. Only publications in English were considered. The following search string was used to identify relevant records:

(“construction projects”) AND (“variations” OR “variation orders” OR “Change Orders” OR “variation*”) AND (“infrastructure projects” OR “road projects” OR “bridge projects” OR “Civil Projects” OR “infrastructure*”) AND (“causes” OR “impacts” OR “outcomes” OR “factors” OR “issues” OR “reason*” OR “effect*” OR “consequence*” OR “outcome*”).

2.2 SYSTEMATIC LITERATURE REVIEW RECORD RESULTS

As stated in the PRISMA (2020) guidelines for systematic reviews, the flow diagram for “systematic reviews which included searches of databases and registers only” was applied in this study. Figure 1 illustrates the summary of the process followed in this study through the three main stages of the SLR, which included the identification, screening, and inclusion of relevant articles on variations in infrastructure development projects.

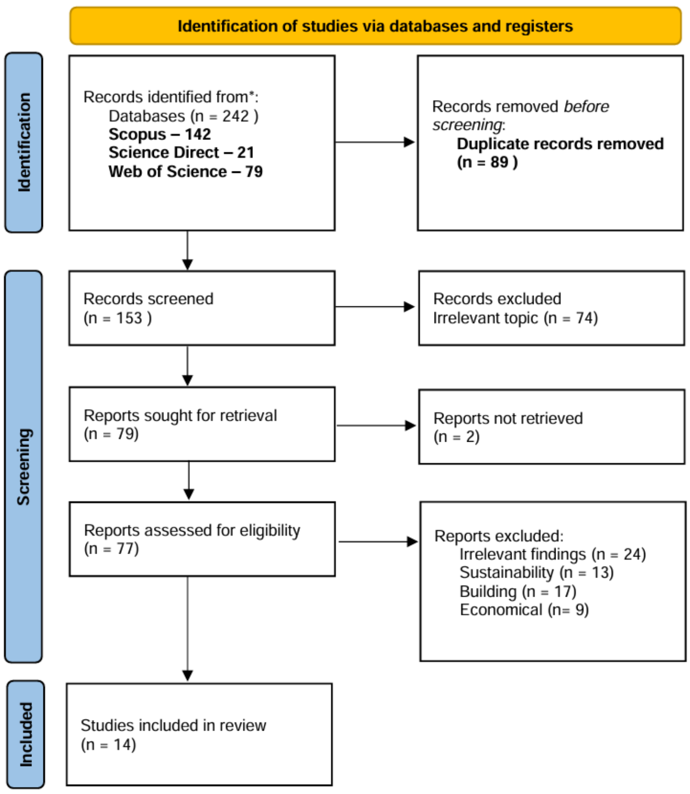

Figure 1: Identification of studies in the systematic literature review

Ultimately, 14 studies were included in the final review, comprising both journal articles and conference proceedings published between 2019 and 2023. Most studies were published in 2019 and 2020, with four journal articles and one conference proceeding in 2019, followed by three journal articles and two conference proceedings in 2020. The number of relevant publications gradually declined thereafter, with only journal articles selected from 2021 onward: two in 2021, and one each in 2022 and 2023. No conference proceedings were identified beyond 2020. A summary of the finalised articles, including their main themes and findings, is presented in Table 2.

Table 2: A summary of the finalised articles

No	Citation	Context / Project Type	Main Themes / Findings	Key Root Causes Identified
1	Herrera et al. (2020)	Road infrastructure, Latin America	Frequency and importance analysis of cost overrun causes in road projects	Design errors, poor planning, regulatory delays
2	Tran et al. (2020)	Construction projects, Vietnam	Variation order management challenges in developing-country context	Client changes, regulatory issues, unclear scope
3	Matu et al. (2020)	Urban road transport, Kenya	Stakeholder participation as prerequisite for effective project completion	Poor engagement, coordination failures
4	Mushato et al. (2020)	Road infrastructure, South Africa	Effects of poor performance on road infrastructure	Unforeseen site conditions, resource constraints
5	Johnson and Babu (2020)	Construction projects, UAE	Time and cost overruns and their critical causes	Supply chain, labour, financial constraints
6	Cabalag and Silva (2019)	Port infrastructure, Philippines	Principal component analysis for variation factor extraction	Planning-implementation gap, design deficiencies
7	Alsuliman (2019)	Public construction, Saudi Arabia	Causes of delay with policy and regulatory dimensions	Political interference, regulatory changes
8	Marzouk and Enaba (2019)	Construction contracts, Egypt	Text analytics applied to monitor contract correspondence	Administrative, coordination, design issues
9	Love et al. (2019)	Transportation infrastructure, international	Cost performance and planning fallacy in transport projects	Optimism bias, scope changes, financial disruptions
10	Belay et al. (2021)	Road construction, Ethiopia	Causes and effects of variation orders on road projects	Design deficiencies, client changes, site conditions
11	Melaku Belay et al. (2021)	Infrastructure, Ethiopia	Cost overrun and schedule delays in low-income economies	Financial constraints, capacity gaps, institutional failures

No	Citation	Context / Project Type	Main Themes / Findings	Key Root Causes Identified
12	Molinari et al. (2023)	Transport infrastructure, Belgium	Cost overrun variations across land transport modes	Scope changes, regulatory shifts, political factors
13	Ahmed and Jawad (2022)	Construction projects, systematic review	Causes and impacts of variation orders (systematic review)	Design flaws, owner changes, external environment
14	Mohammad et al. (2021)	Building & infrastructure, Iraq	Cost and time impact of variation orders	Budget constraints, design changes, coordination issues

3. RESULTS AND DISCUSSION

The next step involved conducting a detailed analysis of the 14 articles selected from the SLR. This analysis aimed to identify the root causes and impacts associated with variations in infrastructure development projects. The following section presents the findings of this analysis.

3.1 ROOT CAUSES AND IMPACTS ASSOCIATED WITH VARIATIONS IN CONSTRUCTION AND INFRASTRUCTURE PROJECTS

This section synthesizes findings from the SLR to examine the causal mechanisms through which underlying project conditions generate variations in construction and infrastructure developments. Variations are conceptualized here as deviations from the baseline project scope, cost, schedule, or technical requirements arising from misalignment between planning assumptions and execution realities (Love et al., 2019; Mohammad et al., 2021; Sun et al., 2016). Although such deviations occur across construction sectors, infrastructure projects exhibit heightened susceptibility due to their scale, institutional exposure, regulatory intensity, and stakeholder interdependencies (Flyvbjerg, 2014; Cantarelli et al., 2012; Molinari et al., 2023). These contextual features amplify uncertainty propagation and increase the likelihood of contractual modifications and rework.

Financial constraints constitute a primary driver of variation formation (Abd El-Razek et al., 2008). Insufficient budget allocation or irregular funding flows undermine planned resource mobilization and disrupt activity sequencing, forcing contractors to adjust execution strategies and prompting scope or schedule revisions (Belay et al., 2021; Molinari et al., 2023; Mohammad et al., 2021; Memon et al., 2014). In infrastructure delivery, which relies on sustained capital investment and structured financing, delayed disbursement may halt operations and necessitate renegotiation of contractual terms or implementation sequences (Love et al., 2019; Doloi et al., 2012). Such financial discontinuities therefore translate directly into variations by invalidating baseline planning assumptions and forcing reactive decision-making (Ali et al., 2020).

Regulatory processes generate variations through compliance and temporal misalignment. Infrastructure developments typically require layered approvals from environmental, planning, and safety authorities, and changes or delays in these processes necessitate design revisions or schedule adjustments (Herrera et al., 2020; Tran et al., 2020). Adaptive compliance requirements often introduce additional technical specifications, or mitigation works that alter project deliverables and contractual obligations (Mohammad et al., 2021; Sun et al., 2016). Consequently, governance-induced uncertainty acts as an institutional mechanism through which external regulatory dynamics materialize as project variations.

Political and policy shifts further intensify variation risk, particularly in long-duration infrastructure initiatives (Alkhattabi, 2023). Changes in governmental priorities or leadership may reshape funding allocations, sustainability targets, or social obligations, thereby altering project scope or timelines after implementation has commenced (Alsuliman, 2019; Love et al., 2019; Flyvbjerg, 2014). These macro-level interventions disrupt planning continuity and necessitate realignment of technical and contractual frameworks, illustrating how political volatility functions as a systemic catalyst for variations.

Design deficiencies and late-stage modifications represent another critical causal pathway. Incomplete preliminary investigations, including inadequate geotechnical surveys or environmental assessments, embed informational uncertainty within design documentation that becomes evident during execution (When discrepancies between assumed and actual conditions emerge, redesign and rework become necessary, resulting in cost and time deviations (Doloi et al., 2012; Love et al., 2019). Furthermore, evolving demand projections or land-use adjustments frequently trigger design alterations that propagate downstream procurement and construction changes (Mohammad et al., 2021; Sun et al., 2016).

Unforeseen site conditions similarly induce variations by invalidating baseline technical assumptions. Encounters with unknown utilities, contaminated soils, or complex subsurface conditions necessitate alternative construction methods or additional mitigation measures, expanding scope and increasing expenditure (Herrera et al., 2020; Mushato et al., 2020; Cantarelli et al., 2012). Such environmental uncertainty is particularly pronounced in infrastructure works due to extensive spatial exposure and limited subsurface predictability, reinforcing its role as a recurring source of variation claims.

Supply-chain disruptions and logistical constraints also contribute to variation formation. Large-scale infrastructure delivery depends on synchronized procurement and material flows, shortages, transportation bottlenecks, or market volatility interrupt planned workflows and compel substitution or resequencing strategies (Johnson & Babu, 2020; Love et al., 2019; Doloi et al., 2012). These adaptive responses alter execution parameters and generate contractual amendments, demonstrating how operational instability translates into measurable project deviations (Assaad et al., 2022).

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Macroeconomic fluctuations and technological transitions represent additional external catalysts. Inflation, exchange-rate volatility, and economic downturns destabilize cost baselines and procurement forecasts, forcing budget revisions and specification adjustments (Mohammad et al., 2021; Doloi et al., 2012). Meanwhile, technological evolution may require mid-project adoption of new tools or systems, altering workflows and skill requirements (Mushato et al., 2020; Belay et al., 2021). Both phenomena demonstrate how systemic environmental change propagates through project structures to produce variations.

Finally, inadequate stakeholder engagement can generate late-stage scope modifications when community or user concerns emerge after project initiation. Insufficient early consultation results in redesign, mitigation measures, or operational adjustments that disrupt schedules and contractual stability (Tran et al., 2020; Sun et al., 2016). This highlights the socio-institutional dimension of variation formation, wherein participatory deficiencies translate into technical and economic consequences (Ghimire et al., 2023).

Collectively, these mechanisms illustrate that variations are not isolated anomalies but emergent outcomes of structural misalignment between planned assumptions and dynamic execution environments. Infrastructure projects, due to their complexity and exposure to external influences, are particularly vulnerable, underscoring the importance of anticipatory governance, integrative coordination, and adaptive risk management strategies (Love et al., 2019; Molinari et al., 2023).

Following the SLR, identified root causes and impacts associated with variations in infrastructure development projects were linked to the identified issues and is presented in Figure 2.

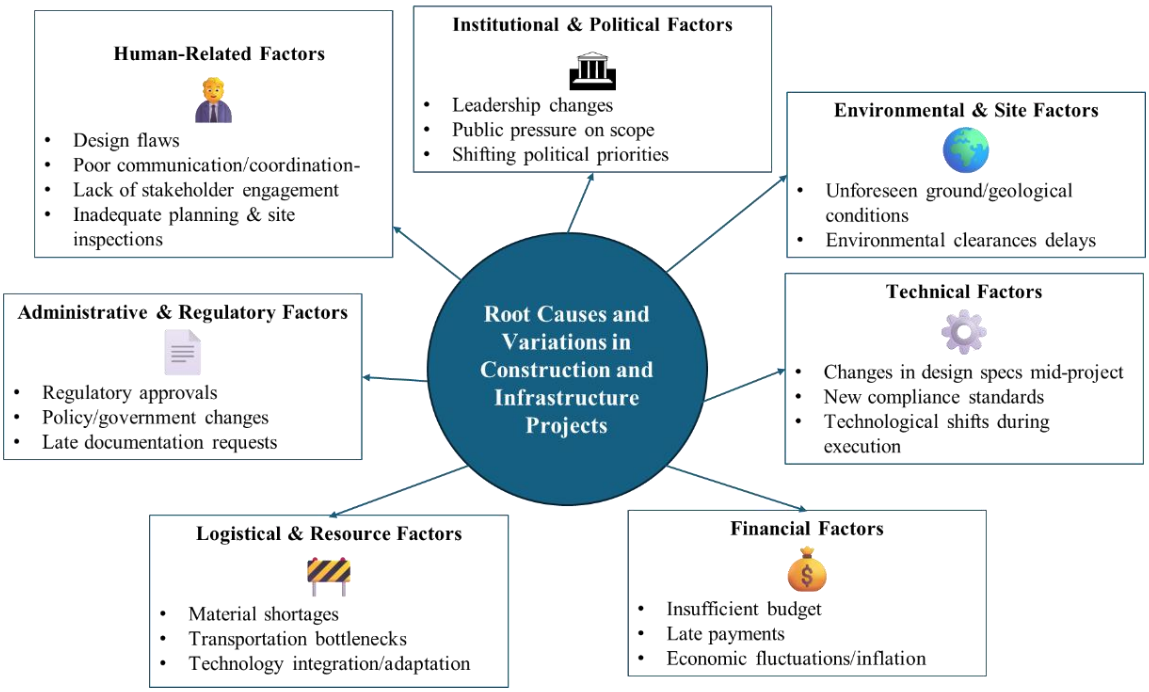

Figure 2: Root causes and impacts associated with variations in infrastructure development projects

Figure 2 presents a clear and comprehensive visual summary of the root causes contributing to variations in construction and infrastructure projects. The diagram effectively categorizes the causes into seven thematic groups: human-related, institutional and political, environmental and site, administrative and regulatory, logistical and resource, financial, and technical factors. Key factors contributing to these root causes are further detailed in this figure demonstrating how interrelated challenges, ranging from design flaws and regulatory delays to budget constraints and unforeseen site conditions, can collectively disrupt project scope, time and cost. The centralized hub-and-spoke layout reinforces the concept that all these factors ultimately feed into the central problem of project variations.

4. CONCLUSIONS

The study concludes that variations in infrastructure development projects are a recurring issue that significantly impacts project success, timelines, and costs. The systematic literature review conducted in the study revealed various root causes and impacts associated with these variations.

The research emphasizes the importance of addressing these root causes and mitigating their impacts to ensure the successful completion of infrastructure development projects. It highlights the need for proactive measures such as adequate financial planning, stakeholder engagement, risk management, regulatory streamlining, and resilience building. Additionally, it suggests the implementation of transparent procurement processes, robust anti-corruption measures, and effective project management strategies to minimize variations and enhance project outcomes.

The systematic literature review offers insights into variations in infrastructure projects but has limitations. It focused on recent English articles, possibly excluding relevant older studies and non-English sources. The exclusion of non-peer-reviewed sources might limit its comprehensiveness. Future studies could widen the scope to include a broader range of sources and languages. While the review identified various root causes and impacts, the depth of analysis for each factor may be limited. Future research could delve deeper into specific root causes and impacts to better understand their complexities. Additionally, the review focused on identifying issues rather than exploring solutions. Future studies could investigate effective strategies for mitigating variations and improving project resilience, including the role of emerging technologies. These efforts could enhance the success rate of infrastructure projects.

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