Hettiarachchi, K., Kulatunga, U. and Uduwage, D.N.L.S., 2026. Typological synthesis of cost overrun determinants in road construction using "K-means": A narrative synthesis. In: Waidyasekara, K.G.A.S., Jayasena, H.S., Chandanie, H. and Tennakoon, G.A. (eds). *Proceedings of the 14th World Construction Symposium*, 10-11 July 2026, Sri Lanka. pp. 1774-1787. DOI: https://doi.org/10.31705/WCS.2026.129. Available from: https://ciobwcs.com/papers/

TYPOLOGICAL SYNTHESIS OF COST OVERRUN DETERMINANTS IN ROAD CONSTRUCTION USING "K-MEANS": A NARRATIVE SYNTHESIS

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ABSTRACT

Road projects are indispensable for a country's economic and social development. Despite the importance, road construction projects are vulnerable to cost overruns. Thus, the identification of causative factors is prudent to mitigate the risk of cost overruns. While previous studies have identified cost overrun factors in isolation even lack systematic clustering of factors. Furthermore, few studies have employed unsupervised clustering techniques to objectively classify cost overrun factors, whereas most have relied on subjective categorisation methods. This study conducted a data-driven typology of cost overruns in global road construction projects through a narrative synthesis. The data were extracted from peer-reviewed literature in the Scopus, Taylor & Francis and ProQuest databases, which provide comprehensive coverage of construction management and engineering literature from 2020 to 2025, to capture contemporary road cost overrun factors. Subsequently, hierarchical clustering was applied to determine the number of clusters, followed by K-means clustering to optimise the classification of cost overrun factors. Results identified 253 cost overrun factors, which were first organised into nine thematic categories and subsequently grouped into the three identified clusters. The most frequently cited factors across the literature were 'political instability, supply chain disruptions, contractor's incompetence, inaccurate cost estimation, project scope changes, claims due to uncertainty incidents, financial mismanagement by contractor, delays in obtaining permits, delays in contractor's payments and inappropriate procurement systems. The unsupervised clustering offers a systematic classification of cost overrun factors that can be applied to different domains in future.

Keywords: *Hierarchical Clustering; K-Means; Road Cost Overruns; Typology.*

1. INTRODUCTION

A well-developed road network is essential for economic growth, reducing transportation costs, boosting trade and fostering regional integration in a country. Even though roads are important, recurring cost overruns are a global issue that affects the expansion of roads (Asiedu & Adaku, 2019). Nonetheless, cost overruns in road projects result in project

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prolongation, project termination and construction disputes suffered by stakeholders (Babalola et al., 2022). In one of the earliest studies in construction, Love et al. (2015) found that nearly 90% of the transportation projects experienced cost overruns based on the analysed project samples. Aljohani (2017) reported cost overruns within a range of 15% to 28%. One of the most cited studies is that of Flyvbjerg et al. (2018), who determined the probability of cost overrun is 86% based on analysed project datasets. Further, recent studies have also emphasised the growing prevalence of cost overruns in road construction projects as well. According to Zhao et al. (2024), the actual cost spent on the development of the England highway system from 2020 to 2025 was estimated to exceed the original estimate by approximately 31%. Empirical evidence has established that cost overruns have experienced unprecedented growth over the past ten years, emphasising the necessity of a formal classification to facilitate the prioritisation of management efforts. Numerous studies have been conducted to study a multitude of cost overrun factors in construction projects e.g. road projects (Wibowo & Santoso, 2024), mega construction projects (Elshamy et al., 2025), building projects (Alshihri et al., 2022), and categorised by the attributes of the factors. One of the most common classifications was technical, economic, contractual, psychological and political factors (Plebankiewicz, 2018). However, environmental factors were not included in Plebankiewicz (2018) classification. In contrast to Plebankiewicz (2018) classification, Isfahani et al. (2024) divided 85 factors into six groups according to the conceptual basis as external, material, labour, equipment, subcontractor and finance. Zhao et al. (2024) identified seven most critical cost overrun factors into two categories, as per the scope of application, named expertise-related factors and personal factors. Additionally, prior studies relied on expert reviews and deductive taxonomies, failing to fully address the multidimensional, data-driven nature of road cost overrun factors (Isfahani et al., 2024; Zhao et al., 2024). Furthermore, past studies have failed to consider certain unexpected costs emerging after tendering (Love et al., 2025). Certain traditional typologies incompletely represented cost overrun factors by omitting emerging factors such as climate change impacts and digital transformation challenges (Plebankiewicz, 2018). In summary, existing classifications are subjective and fragmented; a reproducible data-driven typology is needed (Gómez-Cabrera et al., 2024). To address the methodological and empirical gap, this study utilises statistically validated unsupervised clustering techniques to develop a comprehensive, data-driven road cost overrun typology based on global literature synthesis.

2. METHODS

This study was conducted as a structured narrative synthesis combined with data-driven clustering to synthesise cost overrun factors in road construction projects. A structured narrative synthesis provides a synthesis of cost overrun factors across the rapidly evolving construction sector, where heterogeneous study designs preclude traditional systematic meta-analysis (Green et al., 2006). Literature searches were performed in Scopus, Taylor & Francis, ProQuest and Google Scholar using search terms 'roads', 'road network', 'rural roads', 'road project', 'highway', 'road construction', 'factors causing cost overrun', 'cost overrun', 'cost exceed' and 'cost contingency'. The references included English-language journal articles and conference papers for further screening. The findings were informed by recent empirical evidence published between 2020 and 2025 to ensure that the evidence reflects current economic, technological, and institutional conditions affecting road construction projects. The post-2020 period represented a transformation in construction costs, driven by supply-chain disruptions, inflation volatility, pandemic-induced project delays, fuel and material price escalation, and the rapid digitalisation of project management practices. However, pre-2020 findings were less focused on contemporary factors driving road cost overruns. Additionally, recent studies emphasised that contemporary road projects experience greater cost overruns than in the past (Eliasson, 2024). Therefore, restricting the review to the 2020-2025 period is not a limitation rather a methodological necessity. Literature was analysed using thematic analysis to identify recurring cost overrun factors. The frequency of occurrence for each factor was recorded through the studies to recognise patterns. Factors were then compared conceptually to identify similarities and group related factors using the inductive coding method. Moreover, agglomerative hierarchical clustering was first applied to determine the optimal number of clusters using dendrogram analysis. Subsequently, K-means was utilised in this study to refine cluster assignments compared to a single method (Ling & Weiling, 2025) (refer Figure 1).

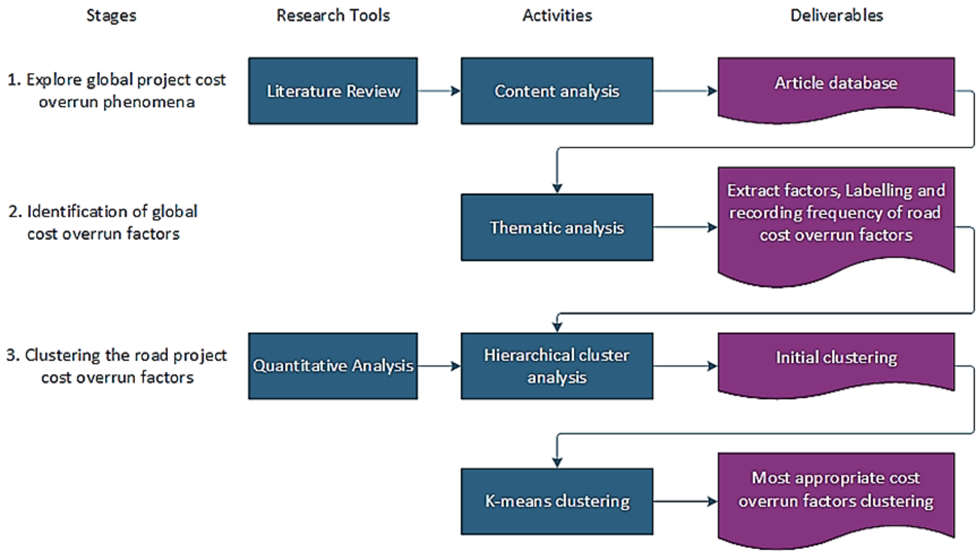

Figure 1: Research method

Agglomerative clustering merges clusters until all observations form a single cluster (Sieranoja & Fränti, 2025). The Ward's method was applied to minimise within-cluster variance. Nevertheless, the hierarchical technique has a slow computational speed and limited operational scalability for large datasets. Therefore, K-means was employed to partition heterogeneous data points into a predetermined number of clusters (K) without overlapping groups. The refined iteration process of K-means optimises clustering by minimising variance within clusters (Khan et al., 2024) and has less influence by outliers than hierarchical clustering, thereby producing more balanced clusters (Izuzquiza et al., 2026). The optimal number of clusters (K) was first determined by analysing the agglomerative clustering dendrogram. The optimal K value was then used as input for K-means clustering (Govender & Sivakumar, 2020). Eventually, the resulting clusters were labelled based on the dominant factor characteristics, which resulted in distinct, well-separated clusters.

3. RESULTS

This study examines the prominence of causative factors of road project cost overrun. Since the frequency of the factors was captured using content analysis and examined by thematic analysis. Subsequently, hierarchical clustering and K-means clustering were applied for systematic grouping of the factors into typologies. The methodology enhances the reliability and robustness of data-driven typology through a combination of frequency patterns with thematic similarity to categorise cost overrun factors systematically.

3.1 COST OVERRUN DEFINITION

The definition of cost overrun has evolved. Cost overrun has been consistently defined as the difference between actual and estimated costs (Enrica et al., 2021; Flyvbjerg et al., 2003, 2018), though the specific baseline for comparison varies across studies. Conversely, Shehu et al. (2014) defined cost overrun as an increase in project costs that stakeholders did not anticipate. Love et al. (2015) drew on the work of Shehu et al. (2014), suggesting that the difference between a 'cost overrun' and a 'cost escalation' is that cost overruns are typically not anticipated in the pre-tendering stage, while cost escalation is pre-determined. While a variety of definitions of the term cost overrun have been suggested, this study adopts Love et al. (2015) definition of cost overrun as 'the deviation where actual expenditures surpass the budgetary baseline agreed upon by stakeholders prior to the tendering process' to recognise the global road cost overrun factors. This selected cost overrun definition identifies cost overrun factors that represent genuine project control failures rather than foreseeable external conditions at the time of contracting.

3.2 FACTOR IDENTIFICATION

Identifying the causative cost overrun factors is a stepping stone towards improving the cost performance of a road project. Therefore, this study identified major factors causing road cost overrun through content analysis of recent literature from developed and developing countries, including the United Kingdom, United States, Canada, Australia, Ethiopia, Kenya, Benin, Bangladesh, and Pakistan etc. (refer Figure 2).

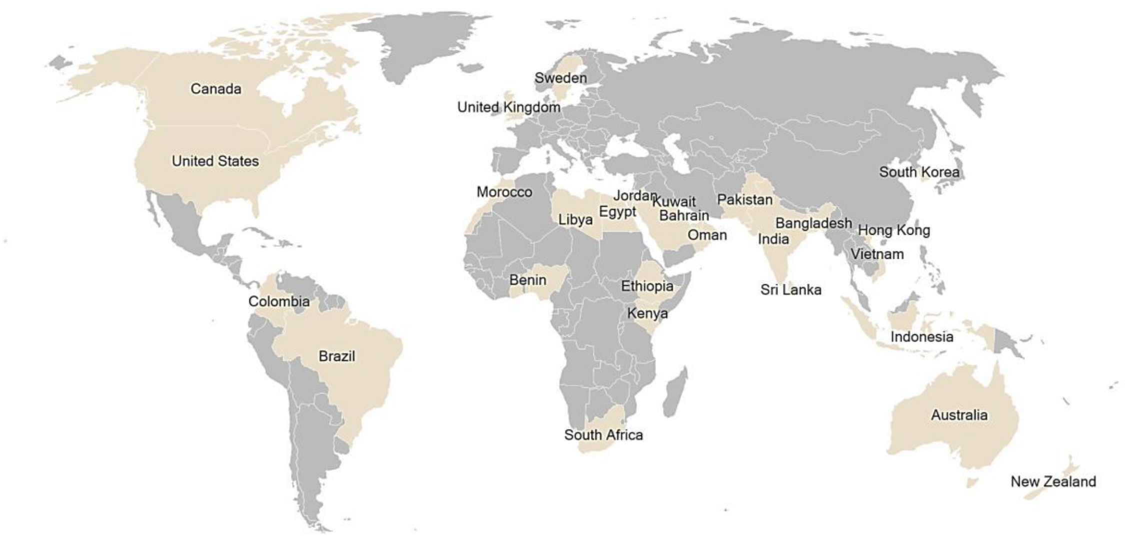

Figure 2: Road cost overrun reported in different countries

The factors were selected based on the definition of cost overrun, whereas this study did not encompass controversial factors like 'inflation in construction commodities' and 'volatility in fuel prices' (refer Figure 3).

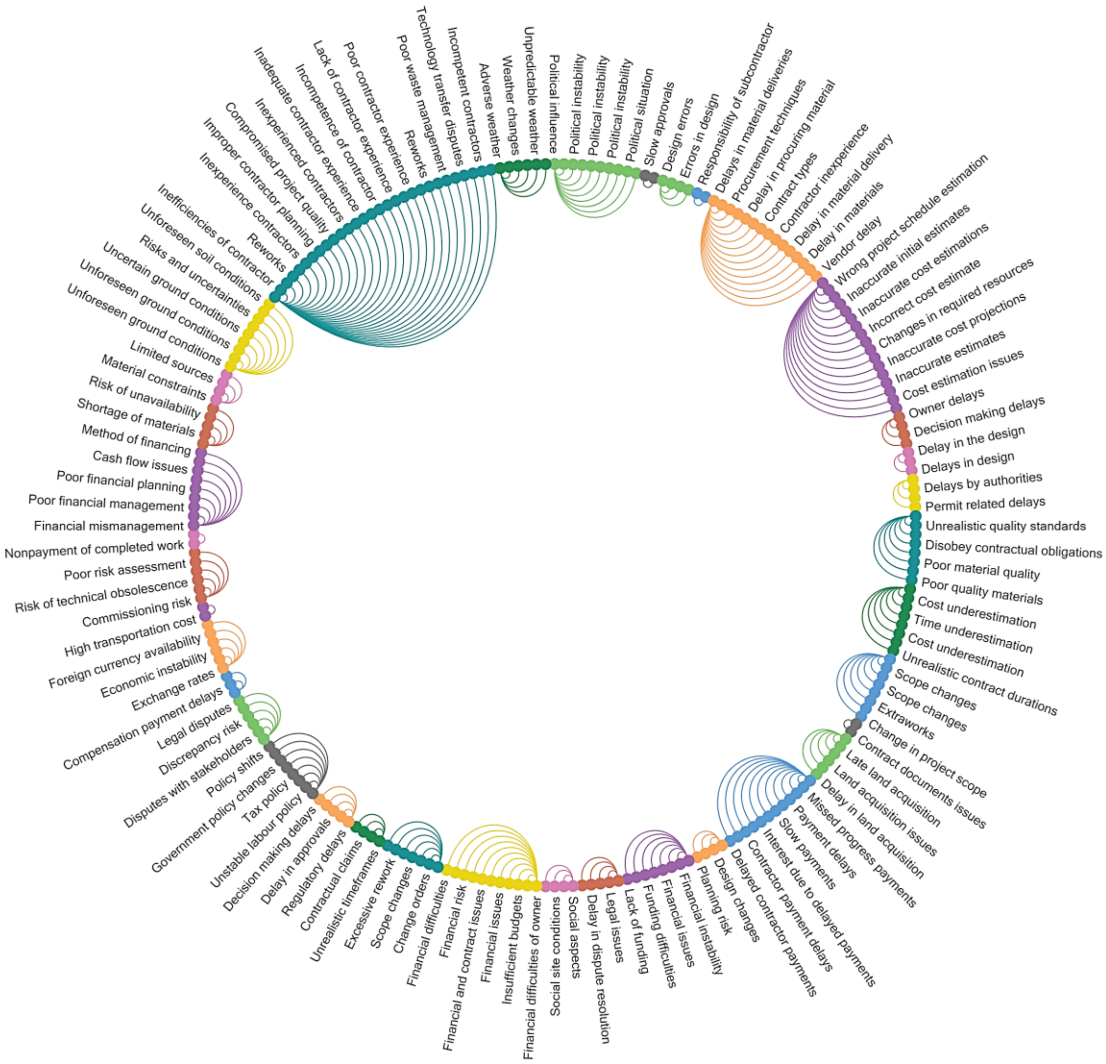

Figure 3: Road cost overrun factors reported in last five years

Unlike traditional deductive classifications, this study adopted an inductive coding modelled on a grounded theory approach that allowed categories to emerge from the extracted cost overrun dataset. The coding process comprised three systematic phases. First, open coding was applied to identify initial concepts and patterns. Second, axial coding recognised trends across each category by examining thematic topics of concern, manifest content and latent content. Third, selective coding yielded brief summaries of patterns within the coded categories (Hagen et al., 2022) (refer Table 1). Hence, the inductive categorisation approach enhanced the reliability and accuracy of the primary factor classification compared to predetermined frameworks (Sanders & Cuneo, 2010).

Table 1: Literature review of factors of cost deviations in road projects

No.	Selective Coding	Label	Frequency
1	Political & Regulatory Risks	Approval issues	27
2	Scope Variation Risks	Claims & variations	31
3	Contractual & Legal Risks	Construction disputes	11

No.	Selective Coding	Label	Frequency
4	Design Risks	Design issues	11
5	Cost Estimation Risks	Estimation issues	26
6	Financial Risks	Financial issues	42
7	Contractor Performance Risks	Performance issues	37
8	Resource Procurement Risks	Procurement issues	33
9	External Environmental Risks	Unforeseen events	35

The nine thematic categories were further analysed using agglomerative hierarchical clustering and K-means clustering methods to systematically cluster the categories based on thematic similarities.

3.3 Static Clustering

The clustering process consists of data normalisation, hierarchical clustering and K-means clustering. The thematic data (refer Table 1) underwent Z-score normalisation to standardise the significance of each attribute in the distance matrix to ensure that each attribute contributed equally to the clustering analysis. Afterwards, the Z-score data were clustered using hierarchical clustering with Ward's linkage and the Squared Euclidean distance metric. Ward's linkage encourages creating homogeneous clusters in hierarchical clustering (Jolliffe & Philipp, 2010; Tufféry, 2011). The hierarchical clustering algorithm results are presented as follows (refer Figure 4).

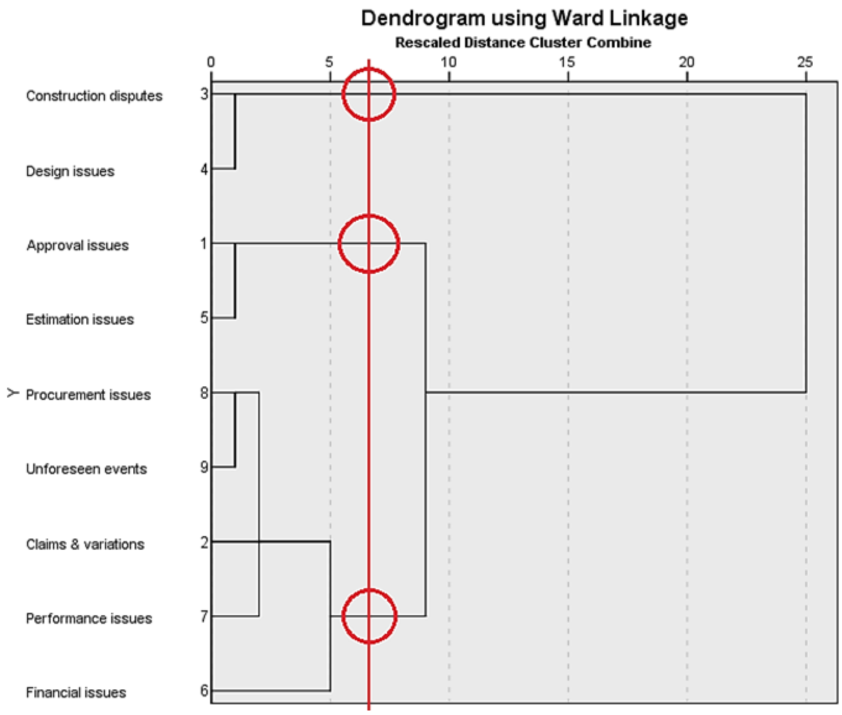

Figure 4: Dendrogram of the hierarchical clustering

The dendrogram (refer Figure 4) shows the hierarchical relationships among the nine thematic categories. Construction disputes (3) and Design issues (4) show closer proximity than the distance between Claims and variations (2) and Estimation issues (5). Meanwhile, data on Procurement issues (8) and Performance issues (7) are grouped together due to the proximity of the data points. Conversely, Financial issues (6) are isolated from Construction disputes (3) due to the significant distance gap. However, segmenting the dendrogram at a desired level yields a set of clusters (Kassomenos et al., 2010). After evaluating the results and manually inspecting the dendrogram, the best configuration consisted of three clusters. The analysis was further refined by K-means clustering. Unlike hierarchical techniques, K-means produces a flat clustering structure. The optimal number of clusters was predetermined by the hierarchical clustering. Accordingly, the K-means cluster analysis was run with three preconceived clusters after two iterations. The ANOVA table reveals that the clusters are statistically significant (refer Figure 5).

ANOVA

	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
Zscore(Frequency)	3.751	2	.083	6	45.148	.000

Figure 5: ANOVA table

Cluster Membership

Case Number	Factor	Cluster	Distance
1	Approval issues	1	.207
2	Claims & variations	1	.161
3	Construction disputes	3	.000
4	Design issues	3	.000
5	Estimation issues	1	.299
6	Financial issues	2	.368
7	Performance issues	2	.092
8	Procurement issues	1	.345
9	Unforeseen events	2	.276

Number of Cases in each Cluster

Cluster	1	4.000
	2	3.000
	3	2.000
Valid		9.000
Missing		.000

Figure 6: Cluster breakdown

The final solution allocated four thematic labels to Cluster 1, another three to Cluster 2, and the remaining two to Cluster 3, without missing data (refer Figure 6). This categorical distribution emphasises a unique thematic stratification within the factors, reflecting the heterogeneity of road project cost overruns. The integration of descriptive thematic labels improves the clustering analysis and provides a more comprehensive understanding of the data. Clusters were labelled according to the dominant thematic characteristics of factors within each cluster. The results from the cluster breakdown were denoted as Cluster 1: Pre-construction and Contractual Uncertainties, Cluster 2: Integrated Project Risk and Performance Constraints, and Cluster 3: Contractual and Design Coordination Failures (refer Figure 7). Further analysis showed that the factors in Cluster 2 have been reported more frequently. Cluster 2 suggested that systemic risks and performance barriers are frequently cited as major threats to budgetary integrity in road projects globally. The single most striking observation to emerge from the data comparison was the highest occurrence frequency of ‘Political instability’ in Cluster 2. Political influence, political connections, project termination due to economic policy change, persistent political instability, unstable labour policy, political force majeure (war, riot, terrorism, strike, etc.), and availability of foreign currency were all categorised under the 'Political instability' factor. Road projects are highly susceptible to broader socio-political conditions and are often beyond the immediate control of project stakeholders. Moreover, several factors showed moderate reporting frequencies, including supply chain disruptions, contractor incompetence, financial mismanagement by the contractor, and delays in the contractor's payments. In contrast, other factors were reported less frequently, including inappropriate procurement systems, insufficient budgets, administrative bottlenecks, slow payment process, adverse weather conditions, poor construction quality, contract types, lack of technical expertise, nonpayment of completed work, project planning issues, pandemics, and quantity changes. The factors in Cluster 2 were the most frequently cited, and the factors in Cluster 1 were less frequently cited. Frequency patterns suggested that macro-level systemic risks (Cluster 2) may be more common and salient in the literature than site-specific contractual issues (Cluster 1). Cluster 1 included inaccurate cost estimation, project scope changes, other claims due to uncertainty incidents, delays in permit acquisition, delays in land acquisition, delays in decision-making by stakeholders, project underestimation, unrealistic time schedules, and contractor claims, highlighting the vulnerabilities inherent in the early lifecycle stages of road construction. Cluster 3 contained the barely cited road cost overrun factors, yet the cluster remained theoretically significant for understanding technical failures. 'Design errors' was the most frequently cited factor in Cluster 3. Errors and omissions in the design, inadequate designer capabilities, and a lack of proper basic engineering led to an increase in the severity of design errors. While 'design errors' were reported less frequently, the factor's presence remains a persistent driver of secondary cost overruns in road projects. Together, the results provided important insights into a proper cost overrun typology. Nonetheless, the below typology assists project stakeholders to prioritise road cost overrun mitigation strategies (refer Figure 7).

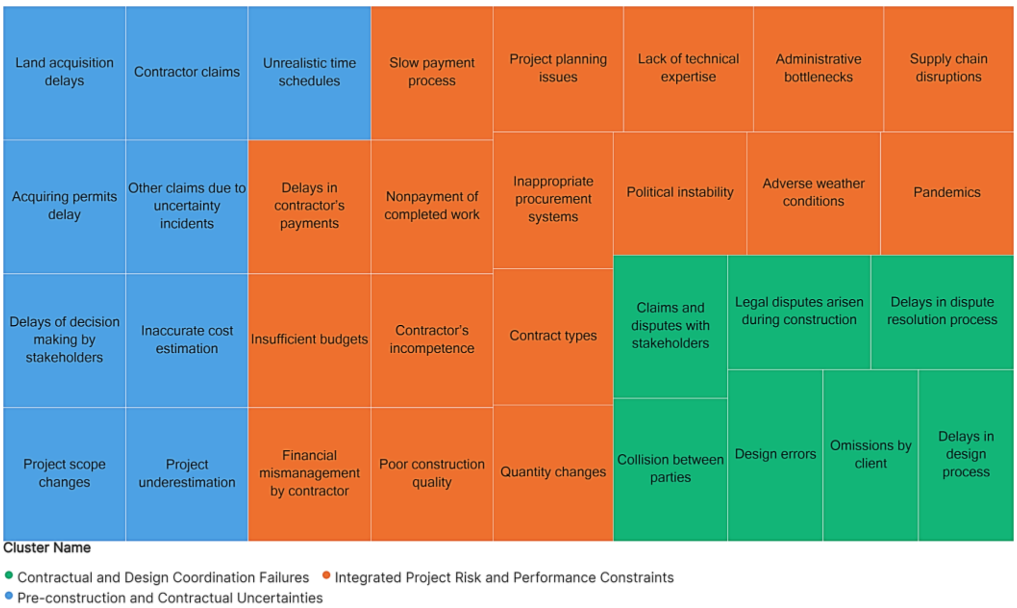

Figure 7: Cost overrun typology

A considerable amount of recent research has been done to study the characteristics of factors affecting cost overruns. Earlier typologies focused on a few cost overrun factors related to the road construction sector and prioritised high-impact factors only. In contrast, contemporary studies have expanded the scope by adopting a multidimensional aspect (refer Table 2).

Table 2: Past road cost overrun typologies

No.	Classification	Source
1	Contractor related, Project management and contract administration related, Design and documentation related, Financial management related, Information and communication technology related, Labour management related, Material management related, Environment related, Psychological related, Political related	Atapattu et al. (2023)
2	Client related, Design related, Contractor related, External related and Other stakeholders related	Al Adawi & Yahia (2021)
3	External factors and Internal factors (Project and Activities)	Ammar et al. (2022)
4	Project owner perspective and Contractor perspective	Anwari (2022)
5	Technical, Financial, Political, Legal, Environmental and Social factors	Verma et al. (2020)
6	Design, Consultant, Owner, Contractor, Material, Equipment, Contract, Labour risk, External (corona virus effects), External (others) and operational factors	Gamal et al. (2023)
7	Consultant, Contract, Contractor, Contractual relationships, Design, Equipment, External, Financial, Laws and regulations, Materials, Owner, Personal, Programming and control, Project and Site factors	Herrera et al. (2020)

Building on the work of Rahman et al. (2013), Atapattu et al. (2023) advanced the cost overrun classification framework with three additional and significant areas. Accordingly, most articles identified ‘poor project management’ as a significant cause of road cost overrun. In addition, ‘frequent design changes’, ‘unpredictable weather conditions’, ‘lack of experience in similar projects’ and ‘shortage of technical personnel’ were also identified as significant factors among the fifty-three factors examined. Similarly, Al Adawi & Yahia (2021) ranked the top five most critical cost overrun factors amongst fifty-two factors in Oman road projects as ‘contractors are not paid on time’, ‘incomplete design at the time of tender’, ‘design errors’, ‘cost underestimation’ and ‘funding difficulties’. Ammar’s cross-country analysis (2022) identified fifty-six road cost overrun factors, including the two most critical, namely ‘political interference’ and ‘inflation’. The remaining six factors were related to internal factors, namely ‘inaccurate cost estimates’, ‘design modifications’, ‘quantity changes’, ‘variation orders’, ‘specification changes’ and ‘scope of work’. Furthermore, the results revealed that ‘design modifications’ and ‘low estimates for budgets and quantities’ were the main factors affecting road cost overruns. Another important finding of the study was no relationship between project size or duration and cost overrun percentage. Anwari (2022) identified the top eight causes among twenty-five factors in Afghan road projects: weather and climate conditions, improper planning, financial issues, land acquisition and community challenges, fluctuations in material prices, shortages of resources/ materials/ equipment, and delays in payments. Deferment in land acquisition, cash flow the throughout construction process, mishandling by the contractor (finance, supplier, support, sub-contract), inappropriate planning and variation in the scope of the project or extra work were the top five risk factors among thirty five factors that had the greatest impact on cost overrun of Public Private Partnership constructed roads and highway projects in India (Verma et al., 2020). Gamal et al. (2023) reported similar effects of road cost overrun when prioritising eleven high-risk categories from one hundred sixty-two variables: operation risk, external risk (Coronavirus effects), external risk (Others), contract risk, equipment, material, contractor, design risk, owner, labour risk and consultant risk. The results also indicated that the two biggest influences on cost overruns in road projects were operational and external risks. A recent systematic literature review by Herrera et al. (2020) identified the ten most important and frequent cost overrun factors from thirty-eight determinants: failures in design, price variation of materials, inadequate project planning, project scope changes, design changes, unrealistic contract duration, inadequate bidding method, legal issues, late decision-making by the owner, and political situation. The factors identified in this study corroborate earlier findings. On the other hand, the frequency of key factors in this investigation is more influential compared to the seminal studies (refer Figure 8).

Most Infulential Cost Overrun Factors Based On This Study

- Political instability
- Supply chain disruptions
- Contractor's incompetence
- Inaccurate cost estimation
- Project scope changes
- Claims due to uncertainty incidents
- Financial mismanagement by contractor
- Acquiring permits delays
- Delays in contractor's payments
- Inappropriate procurement systems

Cost Overrun Factors Based on The Previous Studies

- Planning and design failures
- Inaccurate cost estimates
- Payment issues
- Price fluctuations
- Variations and claims
- Late decisions-making
- Shortage of technical personnel
- Shortage of material and equipment
- Unpredictable weather
- Political interference

Figure 8: Comparison of the cost overrun typology and ordinary cost overrun factors

The conceptual framework presented below (refer Figure 9) illustrates the comprehensive interconnections between cost overrun of rural road projects as dependent variables and the multifaceted factors which are causing the problem as independent variables. Referring to the cost overrun typology (refer Figure 7), 33 most influential cost overrun factors were systematically identified and classified under nine different core themes, providing a structured approach to understanding this complex phenomenon. The themes encompass various dimensions, including approval issues, claims and variations, estimation issues, performance issues, procurement issues, unforeseen events, construction disputes, design issues and financial issues that contribute to project cost overrun. Clients often suffer significant financial and operational consequences due to road project cost overrun, as demonstrated in strategic consequences, which may include delayed project completion, reduced return on investment, project suspension, project abandonment, stakeholder dissatisfaction, and compromised project quality. Furthermore, the framework below incorporates evidence-based mitigation strategies to minimise cost overrun in road projects, offering practical interventions that stakeholders can implement throughout the project lifecycle to enhance cost control and improve overall project performance (refer Figure 9).

Figure 9: Conceptual framework for mitigate cost overrun in road construction projects

The results revealed a typology of road cost overruns rather than individual factors. Traditional typologies are mostly deductive and expert-based classifications that do not fully capture the complex, multidimensional nature of road cost overruns revealed by data-driven approaches. In contrast, this study discovered three clusters using an unsupervised hybrid clustering method rather than relying on predetermined expert labels. The clusters derived from statistically validated similarity patterns better reflect the rigorous factors that affect road cost overruns. This comprehensive study conducted a systematic analysis of road cost overrun factors that were categorised according to the stipulated definition. Thus, this study provides theoretical insight and practical guidance by synthesising the latest factors influencing road cost overruns. The relative infrequency of some factors does not necessarily diminish the criticality of the road cost overrun factors.

4. CONCLUSIONS

Road cost overruns are an endemic problem. Cost overruns are a significant concern and financial risk for project owners. In the worst cases, cost overruns lead to interruption of construction activities and even the abandonment of projects. Despite the consequences, systematic typologies that provide a comprehensive overview of the phenomenon and global solutions are lacking. This investigation aimed to develop a comprehensive, data-driven typology of global road cost overruns. Accordingly, 253 project cost overrun factors derived empirically from literature patterns were grouped into 'approval issues, claims and variations, construction disputes, design issues, estimation issues, financial issues, performance issues, procurement issues and unforeseen events' labels and categorised into three clusters using 'Hierarchical clustering' and 'K-means'. This study advanced the field from expert groupings toward the discovery of empirical structure. The findings clearly indicated that the most frequently reported factor in the analysed literature is 'political instability', which belonged to Cluster 2. Strategically, multi-dimensional political and economic volatility may be mitigated through strong Political Risk Insurance (PRI). The necessary stabilisation clauses must be contained in host-government contracts to protect projects from arbitrary fiscal or policy shifts. Furthermore, companies must adopt adaptive financial engineering strategies in particular multi-currency financing and local sourcing and a holistic risk management framework such as Enterprise Risk Management (ERM) to help maintain operational continuity amid foreign exchange fluctuations and force majeure events. Additionally, contractors must exercise due diligence and duty of care to mitigate 'supply chain disruptions, incompetencies, inaccurate cost estimation and financial mismanagement'. Remarkably, continuous changes in scope are a crucial cause of cost overruns, which may be minimised by modifying design development methodologies and implementing advanced technologies (e.g., BIM). Additionally, this data-driven typology may support stakeholders in accurate estimation, take pre-emptive actions to mitigate future cost overrun risk and prioritise investments. The study was limited in several ways. First, the study used four academic databases to capture the road cost overrun factors from 2020 to 2025, which may not capture all relevant factors or regional variations. Second, the analysis was based on citation frequency rather than project-level empirical data, which may not reflect the relative importance of cost overrun factors. Third, the interpretation of cluster names is subject to judgments that may affect reproducibility. The study should be repeated to strengthen the results of this data-driven typology across different project datasets and geographic regions. Moreover, examine the relative impact magnitude of road cost overrun factors within each cluster.

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