Analyzing Causes of Delays in Financial Institution-Funded Road Projects

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ABSTRACT

Delays in road infrastructure projects funded by multilateral development banks like the Asian Development Bank (ADB) and the World Bank are still a serious issue. They harm economic returns, public service delivery, and investment efficiency. This study examines the factors, trends, and statistical correlations that contribute to delays in road infrastructure projects financed by development banks in developing regions. Utilizing an extensive dataset of 702 projects financed by the World Bank and Asian Development Bank, the study employs descriptive, inferential, and predictive statistical methodologies to analyze the impact of project attributes—such as type, duration, complexity, and accessibility—on schedule performance. The study utilizes Project Completion Reports and Implementation Completion Reports to quantify the magnitudes of delays and cost overruns, while also identifying significant causal factors such as environmental conditions, logistics of materials and equipment, contractor inefficiencies, and financial constraints. Descriptive and frequency analyses demonstrate considerable variability in project duration, cost, and scale, highlighting the diversity of road development initiatives. Association tests and non-parametric methods (Kruskal–Wallis, Chi-square) show that the type and complexity of a project.

Descriptive and frequency analyses show that the duration, cost, and scale of road development projects vary a lot, which shows how different these efforts are. Association tests and non-parametric methods (Kruskal–Wallis, Chi-square) indicate that project type and complexity significantly affect delay severity, while length and accessibility do not exhibit statistically significant effects. Logistic regression analysis corroborates these findings, emphasizing the predictive efficacy of structural complexity and institutional-financial variables in classifying delays.

The study provides a data-driven framework for comprehending delay dynamics in large-scale infrastructure delivery by integrating empirical evidence with insights from construction and transportation management theory. The results provide actionable guidance for policymakers, financiers, and project managers, emphasizing the importance of complexity-sensitive planning, enhanced financial governance, and targeted risk mitigation strategies to improve the timeliness and efficiency of road infrastructure development.

Keywords: Road Infrastructure, Development Banks, Project Delays, Statistical Analysis, Logistic Regression, Kruskal–Wallis, Cost Overrun

ÖZ

Çok taraflı kalkınma bankaları, özellikle Asya Kalkınma Bankası (ADB) ve Dünya Bankası tarafından finanse edilen karayolu altyapı projelerinde yaşanan gecikmeler hâlâ ciddi bir sorun teşkil etmektedir. Bu gecikmeler ekonomik getirileri, kamu hizmeti sunumunu ve yatırım verimliliğini olumsuz etkilemektedir. Bu çalışma, kalkınma bankaları tarafından finanse edilen karayolu altyapı projelerinde gecikmelere neden olan faktörleri, eğilimleri ve istatistiksel ilişkileri incelemektedir.

Dünya Bankası ve Asya Kalkınma Bankası tarafından finanse edilen 702 projeden oluşan kapsamlı bir veri seti kullanılarak, proje türü, süresi, karmaşıklığı ve erişilebilirliği gibi proje özelliklerinin zamanlama performansı üzerindeki etkisini analiz etmek için tanımlayıcı, çıkarımsal ve öngörücü istatistiksel yöntemler uygulanmıştır. Çalışmada, Proje Tamamlama Raporları ve Uygulama Tamamlama Raporları kullanılarak gecikme ve maliyet aşımı büyüklükleri nicel olarak belirlenmiş, çevresel koşullar, malzeme ve ekipman lojistiği, yüklenici verimsizlikleri ve finansal kısıtlar gibi önemli nedensel faktörler tespit edilmiştir.

Tanımlayıcı ve frekans analizleri, proje süresi, maliyeti ve ölçeğinde önemli değişkenlikler olduğunu göstermekte; bu durum karayolu geliştirme girişimlerinin çeşitliliğini ortaya koymaktadır. İlişki testleri ve parametrik olmayan yöntemler (Kruskal–Wallis, Ki-kare) proje türü ve karmaşıklığının gecikme şiddetini önemli ölçüde etkilediğini; sürenin ve erişilebilirliğin ise istatistiksel olarak anlamlı bir etkisinin bulunmadığını göstermektedir. Lojistik regresyon analizi de bu bulguları desteklemekte, yapısal karmaşıklık ve kurumsal-finansal değişkenlerin gecikmeleri sınıflandırmada öngörü gücünü vurgulamaktadır.

Bu çalışma, ampirik kanıtları inşaat ve ulaştırma yönetimi teorilerinden elde edilen içgörülerle birleştirerek, büyük ölçekli altyapı teslimatında gecikme dinamiklerini anlamaya yönelik veri odaklı bir çerçeve sunmaktadır. Elde edilen sonuçlar, politika yapıcılara, finansörlere ve proje yöneticilerine eyleme dönüştürülebilir rehberlik sağlamaktadır. Bulgular, zamanında ve verimli karayolu altyapıgeliştirme süreçleri için karmaşıklığa duyarlı planlama, güçlü finansal yönetişim ve hedefe yönelik risk azaltma stratejilerinin önemini vurgulamaktadır.

Anahtar Kelimeler: Karayolu Altyapısı, Kalkınma Bankaları, Proje Gecikmeleri, İstatistiksel Analiz, Lojistik Regresyon, Kruskal–Wallis, Maliyet Aşımı

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INTRODUCTION TO STUDY

1.1 Problem Statement

Despite the critical role of road infrastructure in promoting economic growth, regional integration, and social inclusion, many developments bank–financed road projects continue to face significant time overruns, cost escalations, and implementation inefficiencies. Persistent delays undermine not only project performance but also the developmental objectives of improved connectivity, trade facilitation, and accessibility that such investments are intended to achieve.

Existing research has identified numerous delay factors—ranging from technical and managerial inefficiencies to financial bottlenecks, environmental constraints, and administrative hurdles—but these studies often focus on localized contexts or small sample sizes, limiting their generalizability. Furthermore, there is insufficient empirical evidence on how project characteristics such as type, complexity, length, and accessibility influence the severity and likelihood of delays, particularly within the framework of multilateral development bank (MDB) financing.

This gap creates a challenge for policymakers, financiers, and practitioners who require evidence-based insights to design more resilient, efficient, and accountable project delivery systems. Without a comprehensive, data-driven understanding of delay dynamics across diverse geographic and institutional settings, mitigation strategies remain reactive rather than predictive.

Therefore, this study seeks to address this problem by conducting a large-scale quantitative analysis of 702 World Bank and Asian Development Bank–funded road infrastructure projects, identifying key determinants of delay, and statistically evaluating their relationships using descriptive, inferential, and predictive methods. The findings aim to support improved project planning, monitoring, and governance frameworks to enhance on-time delivery and performance outcomes.

1.2 Aim and Objective

The aim of this study is to investigate the causes and determinants of delays in development bank–financed road infrastructure projects and to develop a data-driven framework for improving project delivery performance.

Objectives:

- To analyse the performance of 702 World Bank and Asian Development Bank–funded road projects in terms of cost, duration, and delay patterns.
- To identify and classify the major factors contributing to delays and cost overruns, based on both literature review and empirical evidence.
- To examine the statistical relationships between project characteristics (type, length, complexity, and accessibility) and delay severity using inferential and predictive models.

1.3 Research Questions

- What are the most common and important reasons why development bank-financed road infrastructure projects are delayed?
- Do the type, length, complexity, and accessibility of the projects are associated with different delay class of projects?
- Are the complexity and delay cause factors can predict the delay classes of the project?

1.4 Contribution, Novelty and Limitations of Study

Suggests a single framework for classifying and coding delays that is specific to road projects funded by multilateral development banks. This makes it easier to compare projects across countries and situations.

It brings together descriptive, inferential, and predictive statistical analyses into one methodological framework. This includes techniques like Chi-square tests, Kruskal–Wallis tests, logistic regression and survival analysis.

Provides one of the initial comparative analyses of delay causes between development bank-funded and non-development bank-funded road projects, correlating delay profiles with financing structures, institutional capacity, and governance conditions.

Presents a region-sensitive risk assessment model that takes into account geopolitical, environmental, and institutional factors, and offers specific ways to reduce risk.

Creates a standardised delay coding system that can be used in future infrastructure studies and added to institutional monitoring systems.

It looks at a big dataset of 702 road projects from many countries, which makes the results more reliable and lets us see patterns across regions.

The analysis is confined to projects with accessible and comprehensive data from ADB and World Bank completion reports; incomplete or inconsistent reporting may result in bias. The delay coding framework is meant to be useful in many situations, but it might not fully capture some local and context-specific factors. Predictive modelling outcomes depend on the quality and completeness of historical data; rare or extreme delay events may be underrepresented in the dataset.

Chapter 2

LITERATURE REVIEW

2.1 Road Infrastructure Projects

The existence of roads is a critical economic development force, regional integration, and inclusion. These projects help in business activities, reduce travel time, as well as providing access to essential facilities especially in developing and transitional economies. Planning and implementation of road infrastructure projects on the other hand are beset with complexities that include mostly financial issues as well as socio-political challenges. The recent literature therefore highlights the importance of strategic models that would emphasise on construction by also assessing their long-term performance, sustainability and socio-economic payoffs. This is due to the fact that the creation of tough assessment models allows stakeholders to know whether a project has been successfully concluded in relation to the original objectives, and this extends to the scale of accountability and transparency[1]. The infrastructure projects also need to elevate their chances of success by applying rigorous assessment methods. There is general agreement that the basic cost-benefit models are essential, but it is often them that tend to undervalue the cost-benefit analysis in terms of economic and social, wider implications of road developments. Some researchers therefore promote adaptive methods of evaluation which focus on mixing qualitative data as well as plannings based on scenarios to maximise expenditures in infrastructure. This is because they reveal that there is need to create clearer definitions of indicators and a higher level of stakeholder involvement in the evaluation aspect[2]. A future analysis of the critical success factors in 2025 proves that good technical implementation alone cannot lead to a successful project. There is also a need for political goodwill, experience of the contractor, involvement of interested parties and strict monitoring. Based on project management and participatory development theories, the following research paper outlines a predictive framework in which these variables are brought to the fore. It emphasizes that incorporation of these aspects into the project lifecycle makes a significant difference in delivery performance level and stakeholder satisfaction[3].

One of the challenges to the building of road infrastructure, especially in remote areas or in unstable situations, is risk. A new approach has thus been proposed to detect and categorize possible risks to time and money efficiency and thus allow preventor work to be performed with the aim of concentrating on them. A similar analysis conducted in Aceh, Indonesia reported that fuel price fluctuation was the major risk to both schedules and budgets. These findings increase the importance of active contractors on the ground and robust time-early risk management in preventing undesired consequences[4], [5]. Environmental sustainability is becoming prominent in discussions on road development. A study indicates that green road infrastructure ought to be evaluated through multimodal sustainability criteria—economic, environmental, and social. It evaluates global rating systems such as green roads and aims to establish performance standards for sustainable road construction. Essential sustainability attributes encompass lifecycle design, material innovation, and social equality. These criteria increase environmental compliance, long-term usage, and public approval of road developments[6].

Finally, finance models and execution tactics are advancing alongside the emergence of digital economies and global investment. A recent study emphasises that diverse financing sources—spanning national budgets to public-private partnerships—can improve project feasibility and adaptability. It contends that digital tools provide enhanced targeting and assessment of project impacts, hence fostering more responsive and inclusive infrastructure design[7].

2.2 Road Projects Financed by Development Banks

Road infrastructure development is the centre point of national building, as it enhances the movement between regions, facilitates trade, and promotes growth in the economy. In most developing states, development banks fund such endeavours because it would require significant capital outlays and long terms of repayment. Those multilateral development banks (MDBs) such as the World Bank and the Asian Infrastructure Investment Bank (AIIB) along with national ones such as BNDES of Brazil, fill in a central position in this sphere of the industry. These institutions provide concessional loans, guarantees, and advice which enhance the financial feasibility and appeal to infrastructure projects to investors in the private[8], [9], [10]. Among the key merits of development bank funding, it can be noted its ability to facilitate the mobilization of capital in projects that the private investment companies will not be willing to partake due to possible political or market risks.

The MDBs overcome this weakness by offering a long-term, low-interest debt finance, which would not be possible to acquire otherwise. Practical investigation demonstrates that the development banks have been regularly providing what is termed as the additionality of the money, which refers to the idea that their involvement significantly increases the aggregate investment levels as compared to initiatives that are not supported by development banks[8]. These banks have instruments (financial tools) in their portfolio that they use to mitigate the financial risks that come with road developments like sovereign backed loans, project, and blended finance. Such modalities are specifically useful when dealing with infrastructure, which is used in the long term, and is not associated with quick returns. MDBs assist in projects in many contexts, particularly in Southeast Asia and Sub-Saharan Africa, in accordance with the national development strategies by supporting financing of infrastructure development[11]. Despite such advantages, development bank-funded road projects are confronted with some challenges. The volatility of difference in interest rates may drive up borrowing rates and compromise the financial feasibility of such endeavours. Interest-rate risk has a relevant material impact on the allocation of resources and on the prices of materials involved in building roads in areas of the temporarily unstable monetary conditions[12]. Institutional obstacles also contribute to the deceleration of project execution. Inadequate procurement procedures, deficient project management, and insufficient technical supervision can result in budget excesses and postponements. Research on World Bank-funded Road projects in Africa indicates that insufficient governance structures considerably affect project timeframes and efficacy[13]. Furthermore, the strategic aims of development banks may vary, affecting the categories of road projects they endorse. Some institutions emphasise regional connectivity and economic corridors, while others concentrate on local access roads or sustainability-oriented infrastructure. This variety illustrates divergent development ideologies and geopolitical goals, especially in regions such as Central and South Asia[10].

2.3 Definition of Delays in Construction Project

The delays in construction projects are usually described as incidents occurring beyond the time agreed upon or time devoted to the project. Such variations would represent failure in performing the stipulated and meeting the proposed complete in the stated duration hence occasioning operational and financial distress[14]. In the project environment, delays are most of the time categorized to either critical or non-critical. Critical delays have implications on the project delay date and non-critical delays have implication on certain operational details but it does not extend the delivery. Specific categorisation is essential in successful mitigation and adhering to the stipulated terms of a contract[15]. Some of the usual ways of identifying delays include juxtaposition of the proposed schedule with the one being made. The methods that make use of Gantt charts, critical path analysis, and earned values are only some of the methods utilized to measure time overruns[16]. Delays may be caused by a variety of internal and external issues, such as poor planning, shortages of materials, poor financing, labour union, and poor weather conditions. The factors tend to be interdependent and can speed up rapidly, stressing the need to detect and obtain intervention early to minimize the harm[14].

2.3.1 Delay vs. Disruption

In the field of construction and project management, the phenomena of delay, schedule, and disruption represent independent but conjoined issues. Delay is the failure of a project to be completed within the set completion timeline, a fact that is usually blamed on inefficiency in the entity or the occurrence of unfavourable outside distractions. The schedule, on the other hand, assigns the initially conceptualized order and timing of project activities. Lastly, disruption is an unanticipated event that affects task performances or alters the planned performance, despite the direct time-related consequences. It is important to differentiate these concepts since delays are often a result of disruptions, thus, increasing the project risks[17]. Modern research indicates a growing use of advanced methodologies i.e. Building Information Modelling (BIM) so as to have a more accurate view of causal relationship between interruption and schedule disruption. The time-integrated three-dimensional simulation capability of BIM namely the 4D simulations, allows forensic analysts to model the events scheduled beforehand, and to spot precisely when workflow or productivity changes as a result[18]. In a real-time project management, perturbations, like a lack of resources or disbanded coordination, may reduce labor efficiency, and change the schedule but not cause an acute delay. To overcome this variation, resilience-based scheduling methods reallocate work during shocks and ensure surveillance of indicators, such as non-worked scheduled hours (NWAS)[19].

2.3.2 Delay Significance and Impacts in the Road Sector and Large-scale Infrastructure

The delays in large-scale infrastructure and road construction projects are a long-standing and disruptive case phenomena and undermine the pursuit of development goals, associated with cost overruns and undermined citizen services. There is a host of interconnected and concurrent technical, financial, administrative and environmental proficiencies that are usually attached to these kinds of delays. Infrastructure projects are often faced with such impediments as difficulties in acquiring land, lapses in schedules and lack of cooperation among stakeholders as well as planning. An investigation of toll road projects in Indonesia cited unresolved land issues and scarcities in resources as dominant influencers of time slack, more so when exacerbated by poor arrangements and contract administration. In the Philippines road projects on which the government monitored concerned largely involved road right-of-way issues, unexpected changes in project scope, and severe weather patterns[20].

An extensive investigation employing the Analytic Hierarchy Process (AHP) in Brazil classified delay factors in public road projects as contractor inefficiencies, environmental problems, and material shortages. The research highlighted that meteorological conditions and procurement delay substantially influenced the schedule of government-funded road projects, with contractors and external variables identified as the primary sources of delay risk[21]. In various developing nations, insufficient planning and the lack of experience among project managers were recognised as primary factors contributing to infrastructure delays. A quasi-meta-analysis found that delays stemming from stakeholder cooperation and land disputes usually exert a more significant influence than commonly addressed matters such as design alterations[22].

In Libya, delay analysis utilising structural equation modelling indicated that contractor-related variables were the predominant cause of time overruns, succeeded by financial and management inefficiencies. The findings demonstrated a significant correlation between contractor delays and cost consequences[23].

The Woliso–Ambo Road project in Ethiopia experienced substantial delays, with a time overrun exceeding 97% and a cost excess of 85%. Analysis indicated that material price inflation and subcontractor delays were pivotal to the issue, compounded by insufficient consultant oversight and inadequate site management[24].

The road sector in Thailand exhibited same trends, with delay drivers included insufficient design documentation, suboptimal equipment utilisation, and the inexperience of site engineers. Surveys administered to project teams indicated that technical planning and pre-construction evaluation were frequently insufficient, resulting in expensive and extended delays[25]. A comprehensive global assessment classified delay issues in road building into seven primary categories, highlighting ineffective contractor management and insufficient technical personnel as significant impediments. The investigation indicated that enhancing planning quality and utilising qualified personnel were among the most commonly suggested mitigation options[26].

In Malaysia, an AHP-based analysis of a state highway project highlighted land acquisition, weather instability, and delays in design approvals as the primary reasons of delay. The findings underscored the necessity for early risk identification, inter-agency collaboration, and enhanced project governance methods[27].

2.3.3 Excusable vs. Non-Excusable and Compensable Delays

Delay classification in construction project management is crucial for dispute settlement, cost recovery, and schedule management. Delays are typically classified as excusable or non-excusable, with excusable delays further subdivided into compensable and non-compensable categories. Excusable delays are those outside the contractor's control—such as extreme weather, force majeure, strikes, or government-imposed restrictions—and often entitle the contractor solely to a time extension, without financial recompense[28], [29], [30]. Nevertheless, delays that are caused by owner-related factors, such as late approvals, scope changes, site inaccessibility, or design revisions, are both compensable and excusable, thereby bestowing entitlement to both time and cost recovery[29]. Non-excusable delays arise from contractor deficiencies such as inadequate planning, insufficient manpower, coordination problems, or supply chain disruptions; these lead to penalties such as liquidated damages, without any extension of time or recovery of costs[31]. To objectively identify responsibility—particularly in intricate or concurrent delay situations—project managers utilise delay analysis methodologies, including Time Impact Analysis and as-planned versus as-built comparisons, which offer systematic frameworks to evaluate the compensability of delays and the existence of concurrency[29].

2.3.4 Different Categorization of Delay Causes

Delays in construction projects constitute a widespread global issue, frequently leading to financial losses, contractual disputes, and reduced stakeholder satisfaction. Delays are an unavoidable aspect of large-scale building projects due to their complexity; nonetheless, comprehending and classifying their causes enables the implementation of more focused mitigation solutions. Researchers have suggested multiple frameworks and classifications based on stakeholder responsibilities, control over causative factors, and the characteristics of delay events. A prevalent method for classifying reasons of delays is based on stakeholder accountability. This includes delays caused by contractors, consultants, clients (owners), and external sources. Contractor-related delays generally encompass problems such as inadequate site management, insufficient planning, a shortage of trained labour, and equipment malfunctions[32]. However, client-related delays frequently arise from tardy payments, alterations in project scope, and procrastinated decision-making[33]. Consultant-related factors, however rarely mentioned, encompass delays in design approvals, inaccuracies in construction drawings, and inadequate monitoring[32].

External variables generally encompass detrimental climate circumstances, supplier complications, and governmental meddling[34].

A further effective categorisation method is predicated on the project lifecycle, which classifies reasons of delay according to the phase in which they arise: 1) pre-construction, construction, or 2) post-construction. This approach associates the reasons of delays with particular workflows and roles throughout a project timetable. Pre-construction delays typically stem from factors such as inadequate project feasibility studies, delays in obtaining regulatory permits, extended design development, and complications in land acquisition. These are frequently caused by insufficient planning or misalignment among stakeholders during the initial phases[35]. An illustrative instance involves delays in acquiring environmental or municipal permits, which can substantially impede project mobilisation. Delays during the construction phase are the most extensively analysed and frequently documented. This encompasses several factors including as labour shortages, equipment malfunctions, supply chain interruptions, design flaws identified during execution, and contractor inefficiencies. They frequently lead to the most substantial direct financial losses owing to the active allocation of resources and logistics at this phase[36]. Post-construction delays, while infrequent, can nonetheless be substantial. These pertain to project commissioning, testing, securing final approvals, or challenges with operational preparedness. Occasionally, problems discovered upon handover necessitate further remedial work. In intricate infrastructure or institutional edifices, post-completion delays may arise from contractual finalisation, dispute resolution, or postponed certifications.

A more recent study of Public Works Authority projects employed Pareto Analysis to determine the primary reasons of delays, indicating that roughly 80% of delay issues originated from 20% of the causes. This approach facilitated a systematic classification and coding of delay factors, aiding in the formulation of remedial and preventive measures alongside a responsibility matrix[37]. Several authors propose a functional classification that organises delays into categories based on technical, managerial, financial, and external reasons. Managerial delays may result from inadequate project planning or insufficient cooperation among stakeholders. Financial delays are often ascribed to tardy payments, liquidity issues, or funding deficiencies[36]. Technical expertise causes comprise design flaws or delays in material acquisition, whereas external causes involve regulatory changes, environmental disturbances, or socio-political turmoil. Qualitative investigations have created additional complexities. In a series of interviews with experts involved in the London 2012 Olympics project, researchers uncovered underexplored yet significant factors, including deficient risk management, insufficient logistics planning, and a lack of professional expertise. These findings underscore the significance of context-specific and qualitative investigations in delay classification[38].

2.4 Root Causes of Delays in Road Construction

Delay cause looks at the main reasons why road construction projects go over schedule. To understand delay patterns and come up with ways to speed up project delivery, you need to know what these underlying factors are.

2.4.1 Engineering/Design-related Delays

Delays connected to engineering and design are a common impediment in road construction projects, especially in developing areas. These delays frequently arise from insufficient design development, tardy submission of workshop drawings, and recurrent alterations by project stakeholders. Delays in engineering may stem from insufficient or erroneous technical designs, misunderstanding among consultants and contractors, and mistakes in the drawing approval process. Research conducted in Egypt identified three primary categories of these delays: (1) design evolution, (2) workshop drawing authorisation, and (3) modifications solicited by stakeholders[39]. Employing Quality Function Deployment (QFD), a further analysis identified design modifications and postponed workshop documents as significant engineering-related delay drivers, underscoring the necessity for explicit communication and contractually established protocols[40]. In Egypt's road sector, misunderstandings among site engineers, consultants, and contractors exacerbated delays. Research examining 293 causes of delay revealed that inadequate cooperation about design issues was a persistent problem[41]. These results emphasise the need of early stakeholder involvement and the implementation of integrated information systems to enhance collaboration and minimise delays in road construction projects[42].

2.4.2 Procurement and Contractor Performance Issues

Delays in road construction tasks are typically related to procurement inefficiencies and contractor performance deficiencies. Inefficient procurement procedures, characterised by impractical schedules, insufficient planning, and a deficiency in transparency, frequently result in project delays and budget overruns. In Tanzania, procurement challenges such as corruption, financial limitations, and non-compliance with contractual obligations have substantially impacted the timely and quality execution of road construction projects[43]. Additionally, delays associated with contractors are a significant issue. In Indian road projects, contractor inefficiencies stemming from design modifications, permission delays, and inadequate risk distribution were significant contributors to delays, particularly across several contract modalities[44]. Studies from Kenya supports this, indicating that project effectiveness is closely associated with contractor capability and the clarity of procurement procedures[45].

Financial capability also impacts contractor performance. Contractors employing low-bid techniques may jeopardise quality and induce delays, as evidenced by a study utilising artificial neural networks to evaluate prequalification and forecast delay concerns[46]. Furthermore, Indian road projects indicate that delays attributable to contractors arise from variables such as design modifications, inadequate coordination, and suboptimal risk distribution among stakeholders, all of which are affected by the employed contract model[44].

2.4.3 Environmental and Weather-related Causes

Delays in road construction projects caused by environmental and meteorological factors are a considerable issue due to their unpredictability and extensive effects. Inclement weather—characterized by substantial precipitation, severe temperatures, strong gusts, and inundation—can disrupt operations, damage goods, and make locations inaccessible. Research indicates that weather accounts for delays in around fifty percent of building projects worldwide, with climate change anticipated to exacerbate these impacts[47]. Rainfall, especially in tropical and monsoonal areas, undermines ground conditions, hinders equipment mobility, and postpones essential tasks such as asphalt paving and concrete pouring[48]. In Ethiopia, road construction is significantly blocked during the three-month rainy season, underscoring the necessity for seasonal planning and adaptable strategies[49]. In areas such as Nigeria, weather-related damage, such asphalt rutting and floods, not only postpones building but also accelerates the deterioration of road infrastructure[50]. Additionally, probabilistic weather modelling frameworks have been suggested to enhance the integration of weather data into project planning, with the objective of minimising conflicts and unforeseen downtime[51].

2.4.4 Financial Delays (Disbursement, Late Payment)

Financial delays, especially in disbursements and tardy payments, are enduring obstacles in road building projects, frequently affecting project schedules and contractor activities. A recent study in Nepal identified funding insufficiency, procedural inefficiencies, and insufficient contract clarity as the primary causes of payment delays. These delays immediately resulted in project slowdowns and contractor liquidity problems[52]. In Malaysia, subcontractors are commonly impacted by delayed payments, typically rationalised by “pay-when-paid” provisions from primary contractors. This approach substantially affects the liquidity of small enterprises, occasionally resulting in bankruptcy. Researchers underscored the necessity for contractual provisions that mandate prompt payments and impose penalties for tardiness[53]. During the COVID-19 epidemic, problems in project funding intensified, as mobility restrictions delayed work and increased financial strain on contractors. The research indicated adequate planning, payment bonding, and more stringent budgeting as effective mitigation techniques[54]. In Kenya, while no clear statistical association was shown between payment delays and profitability, qualitative data suggested that persistent payment delays exacerbate financial strain, especially for small construction enterprises functioning on narrow margins[55].

2.4.5 Bureaucratic and Administrative Bottlenecks

Bureaucratic and administrative problems make it very hard to build roads well, especially in developing countries. These bottlenecks often show up as slow decision-making, ineffective approval processes, and strict adherence to outdated rules.

Bureaucratic systems that put hierarchy and control ahead of flexibility and response lead to inefficiencies. In nations such as Nigeria, extensive bureaucratic procedures, insufficient inter-agency collaboration, and inadequate institutional capability have markedly impeded infrastructure development and diminished the quality of results[56].

Bureaucratic problems are intensified by diminished public sector motivation and corruption, leading to resource mismanagement and subpar project performance. Administrative obstacles impede prompt policy execution, particularly when regulations and protocols are inflexible and unadaptable. This is seen in various abandoned or postponed road projects when procedural hindrances impede advancement despite the availability of financing[57]. Identical issues are examined in the extensive governance literature, which illustrates how bureaucratic obstacles can hinder developmental initiatives until modified by politically-endorsed, adaptable methodologies[58]. Furthermore, inadequate accountability systems inside bureaucracy facilitate the misappropriation of public funds and obscure project failures, as evidenced in numerous infrastructure initiatives where a deficiency in openness compromises efficiency[59].

2.4.6 Regional Risk Factors and Geopolitical Influences

Regional dangers and geopolitical effects have a big impact on how long it takes to build roads, especially in developing and unstable areas. Research has shown that outside factors like unstable governments, community opposition, and pandemics can slow down schedules. In Egypt, disruptions caused by COVID-19, consultant delays, and contractor inefficiencies were the primary drivers to delays, with external and operational risks having the greatest impact[60].

In Malaysia, delays in public infrastructure projects were caused by land acquisition concerns, environmental uncertainties such as flooding, and technical challenges including poor designs[61]. Additionally, research in Indonesia revealed inadequate quality control, material shortages, and stakeholder miscoordination as primary issues contributing to delays, exacerbated by insufficient community involvement and labour inefficiencies[62], [63].

The geopolitical aspects highlight in analyses of conflict-prone regions like Papua, Indonesia, where elements such as community opposition, inadequate public safety, and regional cultural challenges considerably hinder project progress[64]. Comprehensive evaluations of high-risk nations indicate that geopolitical instability directly influences construction timelines, particularly in contexts characterised by fragile institutions, political volatility, and external diplomatic conflicts[65].

2.5 Quantitative and Qualitative Analysis of Delays

This section offers both quantitative and qualitative analyses of delays, integrating statistical assessment with contextual insights to deliver a thorough comprehension of the factors affecting project performance.

2.5.1 Statistical Testing (Chi-square, ANOVA)

Chi-square test and Analysis of Variance (ANOVA) are methodologies that can be deemed as essential tools when analysing civil engineering project delays. The Chi-square test determines the statistic of significance in stated differences between a categorical variable, e.g., role or level of experience, and perceptions of delay held by stakeholders. ANOVA is used to determine whether or not there is a significant difference between the means of various groups (e.g. contractors, consultants, and clients) regarding their estimates of factors contributing to delays. Such methods are commonly used to support the results in construction delays research. Researchers in a study of a construction site in Nigeria used both ANOVA and Chi-square in the analysis of how stakeholders perceive delays as affected by fluctuations in labour productivity, material availability, and the environmental conditions[66]. Another research project on heavy industrial buildings also used Chi-square, ANOVA, and t - tests to achieve statistically significant results that show presence of delay during the design, procurement, and construction phases. The nine key predictors were formulated such as long cycles of approval and unclear scope to the long delay of purchases, which were confirmed as significant. ANOVA was applied to test the differences among the means of the delay severity among different project phases and Chi-square analysis was applied to verifying the relationships among certain project variables and delay categories[67]. In Iraq, scientists investigated road construction projects impacted by terrorism and economic volatility. Chi-square tests were employed to validate the variances in delay causes—such as financial issues during the design phase and terrorism during the implementation phase—across different project stages. The statistical significance indicated that various phases are influenced by distinct types of delays, hence facilitating more focused delay mitigation strategies[68]. In Zambia, Chi-square analysis demonstrated a significant statistical correlation between contractor educational attainment and the incidence of cost overruns. This research highlighted the correlation between cost overruns and time delays, underscoring the importance of human resource capabilities in project performance, as well as the necessity for training and quality control measures[69].

2.5.2 Regression Modelling and Survival Analysis

Regression modelling and survival analysis are robust statistical methodologies employed to investigate the determinants and timing of delays in road building projects. Delays in construction management research are affected by a complex interplay of technical, environmental, financial, and human factors. Regression modelling quantifies the association between explanatory variables and delay outcomes, whereas survival analysis examines the length until these delays transpire. These methodologies have been effectively implemented in transportation and engineering research to enhance delay forecasting and risk evaluation[70]. Regression modelling is establishing a statistical correlation between a response variable—such as project delay duration—and other explanatory variables, such material supply challenges, site accessibility, or personnel availability. This method enables researchers and engineers to evaluate the elements that substantially affect delays and their degree of impact. A study on queue-based delay prediction employed regression modelling alongside real-time operational data to forecast waiting times and service delays, a framework readily adaptable to construction workflows where numerous variables concurrently influence project advancement[71]. Survival analysis is employed when the timing of an event (e.g., a construction delay) is of paramount relevance, particularly when not all events have transpired within the observation period. It is intended to manage censored data, wherein the delay may be continuous or unrecorded during the analysis period. Survival analysis is particularly appropriate for real-world road construction studies, as certain projects may remain ongoing or experience incremental delays. Instead of only predicting the occurrence of a delay, survival analysis assesses the timing of its likelihood and the evolution of risk over time. This approach has been utilised in research concerning transportation hazards and public health, where delay-to-event data is prevalent[72]. These two methods can be combined to create both predictive and temporal information into delays. Survival modelling was utilised in a study on traffic risk to quantify the impact of external variables on the time before an accident, illustrating a framework applicable to delay modelling in road building[73]. A separate study suggested integrating queueing models with regression to enhance delay forecasting in dynamic settings[71].

2.5.3 Review of Effectiveness and Limitations of Each Approach

Chi-square and ANOVA are critical statistical instruments for examining group disparities. The chi-square test is particularly adept at examining connections inside contingency tables, with newer uses including acceptance of AI analysis and classification of content[78], [79]. ANOVA remains a fundamental technique for assessing numerical group differences and has been adapted for network intrusion detection and gene expression research[80], [81]. In spite of their ease of use, both tests indicate significant limitations. Chi-square tests exhibit sensitivity to sample size and may yield suboptimal results with tiny anticipated frequencies or high-dimensional tables[82]. The hypotheses of ANOVA, including normality and homogeneity of variance, are frequently contravened in empirical data. Recent methodologies employing modified statistics and multiple imputation techniques have been established to enhance robustness in the face of such violations[83]. The ANOFA structure improves interpretability by dissecting effects similarly to traditional ANOVA[81]. To figure out how strong the links are between variables, you need regression models like linear, logistic, and others. Cox proportional hazards models and other survival analysis methods are often used with time-to-event data, like clinical trials or failure analysis[84]. Newer semiparametric methods, such as SPARES, make predictions better when there is censoring[85].

Standard regression assumes that the data is linear, which makes it less effective with data that isn't linear. Cox and other survival models don't take into account how covariates change over time[86]. It is still hard to deal with censoring, multicollinearity, or high-dimensional covariates[87].

2.6 Literature Gaps and Study Contribution

Even though a large amount of research has been done on construction and infrastructure project delays, there are still a number of significant gaps in the literature that this study aims to fill.

First, the majority of earlier research on construction delays has been context-specific, concentrating on specific nations, individual case studies, or constrained regional analyses. These studies pinpoint important delay factors, like budgetary limitations, design modifications, inadequate planning, or weather-related delays, but their conclusions are not cross-nationally generalisable. Large-scale, multi-country studies that take into account the various institutional and economic contexts of development bank-financed projects are required.

Secondly, prior studies have mostly used qualitative or descriptive methods, which offer insightful information but frequently miss statistically significant connections between project attributes and delay intensity. Few studies have empirically validated the ways in which factors like project type, length, complexity, or accessibility affect delay outcomes using reliable inferential tests or predictive modelling (such as logistic regression). The ability to create evidence-based frameworks for project risk forecasting and mitigation is hampered by this gap.

Third, although a number of studies acknowledge the function of development banks in funding infrastructure, little is known about the long-term performance of projects financed by MDBs, specifically with regard to delays, cost overruns, and implementation difficulties. There is a gap in our knowledge of how institutional factors influence project performance because current delay models do not adequately account for the distinct governance, procurement, and financial structures of multilateral development bank (MDB) projects.

By performing a thorough quantitative analysis of 702 road projects funded by the World Bank and Asian Development Bank, systematically identifying important delay factors, evaluating their statistical relationships, and creating a predictive framework for comprehending delay severity across various project types and contexts, this study fills these gaps.

Chapter 3

METHODOLOGY

3.1 Methodology Framework

This study's dataset comes from carefully examining Project Completion Reports and Implementation Completion Reports from the Asian Development Bank and the World Bank. The study focused solely on road infrastructure projects these banks financed, compiling a total of 702 projects that met our criteria.

It carefully reviewed each report to extract key insights, such as project features, performance assessments, and reasons for any delays or additional costs. The variables that were gathered included information on the project's overall timeline, such as the completion year, the starting year, and the concluding year. It is also noted down the location, specifically the country where the project took place, along with its physical dimensions, such as the road's total length in kilometres. There were three types of project classification: Maintenance/Rehabilitation, Improvement, and New Construction. Accessibility was rated as high, medium, or low. It was said that engineering was complicated because of the presence of important structural elements like tunnels, bridges, and viaducts, overpasses and underpasses, drainage and culvert systems, and environmental protection structures like noise barriers, animal crossings, slope protection, and retaining walls.

Performance indicators for both the time and cost parameters were obtained. Time efficiency included the estimated duration, the actual duration, the delay in months, and the delay percentage. The financial performance was measured in terms of estimated cost, actual cost, cost overrun in USD million, and cost overrun percentage. To make sure that projects and countries could be compared, all monetary values were converted to millions of US dollars. The delay found in months by subtracting the estimated duration from the actual duration. The delay percentage was calculated by dividing the difference by the estimated duration and then multiplying by 100. The cost overrun was determined from the difference between the actual and estimated costs. The percentage overrun was obtained by dividing this difference by the estimated cost and multiplying by 100. The researchers restructured factors like known reasons for delays and cost overruns were carefully organized into established conceptual groups. This categorization allowed for a more precise quantitative analysis. The dataset was set up in rows and columns, with each row representing a different project and each column representing a different variable. Nominal and ordinal variables were defined as numbers to facilitate statistical analysis. Continuous variables such as road length, durations, and costs were retained in their original numerical form.

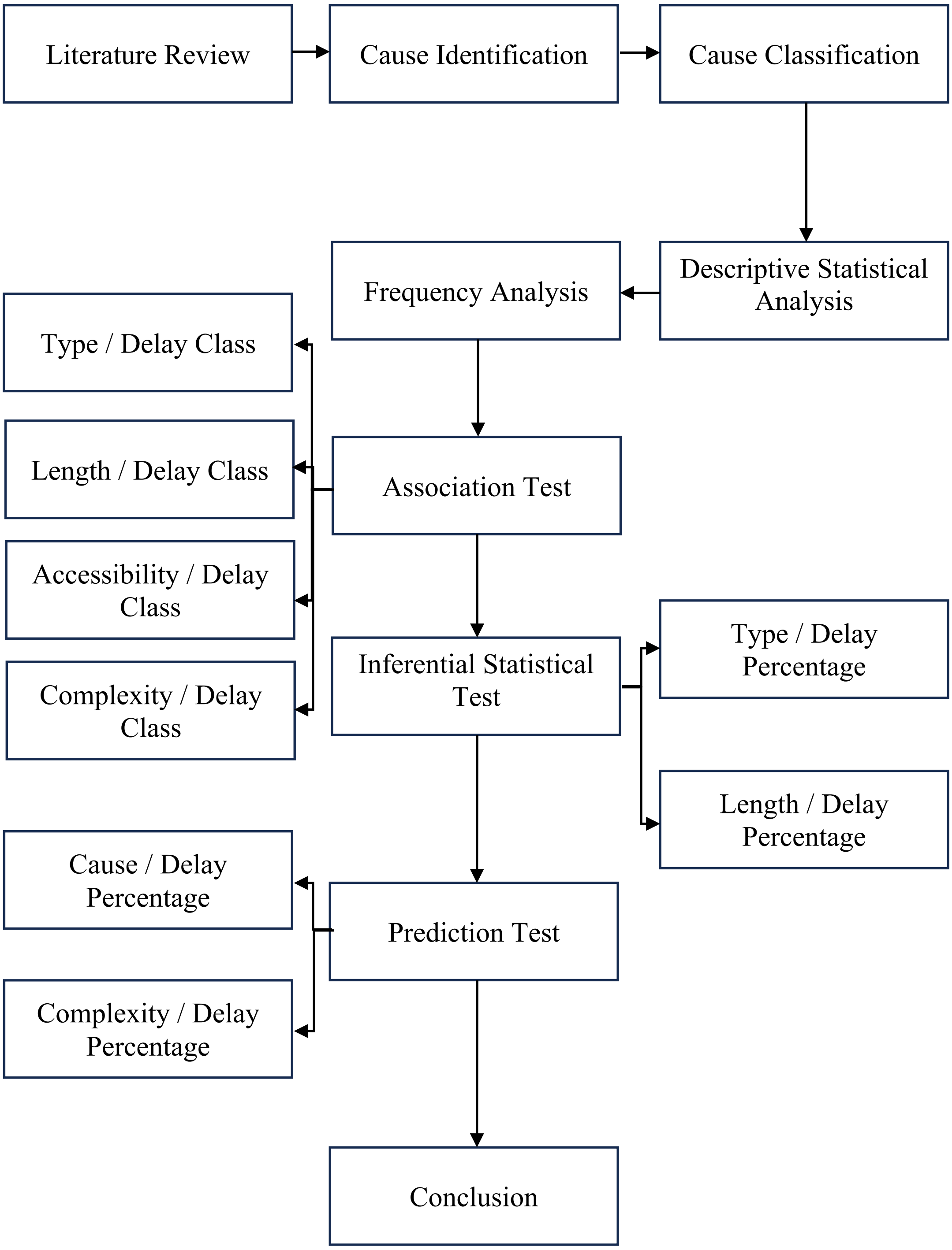

Figure 1: Methodology Framework

3.2 Descriptive Analysis

To comprehensively describe the parameters of project length, duration, and cost in the dataset, a descriptive analysis was conducted on various attributes, including actual cost, actual duration, cost overrun amount, cost overrun percentage, delay amount, and delay percentage. Results of descriptive analysis reveal the main features of a dataset in a way that is easy to understand and use. Some common outputs are measures of central tendency (mean, median, mode) that show the "average" value, measures of variability (range, variance, standard deviation) that show how spread out the data is, and frequency distributions or percentages that show how often certain values or categories happen[92]. This analysis gave an accurate depiction of the project's length, duration, and cost parameters, which helped us understand their features better.

3.3 Frequency Analysis

Frequency analysis was conducted to examine the distribution of projects across key categorical variables, specifically project type and project complexity. Project type was classified into three categories: Maintenance/Rehabilitation, Improvement, and New Construction. The complexity of a project was based on whether or not it had major structural parts like tunnels, bridges, viaducts, overpasses, and underpasses, as well as drainage and culvert systems and environmental protection structures like noise barriers, animal crossings, slope protection, and retaining walls. For each group, the analysis presented three important measures: frequency, relative frequency, and cumulative relative frequency. Frequency showed the exact number of projects in each category, making it easy to see how common each type of project and level of complexity was in the dataset. Relative frequency showed these counts as a percentage of the total number of projects. This made it possible to compare categories directly, even if the total sample size was different. Cumulative relative frequency showed the running total of relative frequencies, which showed how many projects were included as you moved through the ordered categories. Through this method, both a numerical and proportional view of the dataset's makeup was provided, which allowed a better understanding of how the variables were distributed before further statistical tests were conducted. The frequency analysis also showed patterns that could affect future analyses of delay causes and cost overruns by showing which categories were most common in terms of project type and complexity.

3.4 Statistical Test

Statistical tests are methods used to look at data and draw conclusions about a larger group from a smaller group. These tests help researchers and analysts figure out if differences or connections they see in the data are real differences or connections that exist in the larger population, or if they just happened to happen. Statistical tests make it easier to figure out how important these differences or connections are by giving a structured way to do so. This helps people make smart decisions in many areas[93]. In general, there are two types of statistical tests: parametric and non-parametric. Parametric statistics is a subdivision of statistics that makes assumptions about particular variables based on the idea that the data comes from a certain probability distribution, usually the normal distribution. When the underlying assumptions show that parametric tests are appropriate, these tests can give a more accurate estimate, which is why they are often thought of as strong methods[94]. On the other hand, nonparametric tests are also known as assumption-free or distribution-free tests. These tests can be used on nominal or ordinal data, as well as data measured on scales that don't follow the normal distribution, like interval or ratio scales[94]. It is important to note that parametric tests are stronger than non-parametric tests, but they also have some extra benefits. For example, they can work with different sample sizes, different types of data (including nominal and interval), and datasets that may have outliers or data that isn't measured correctly[95], [96].

Table 1 shows the most common type of parametric test and its non-parametric test that does the same thing. Before either of the tests below can be used, it is important to carefully check the data that has been collected to make sure the test's assumptions are correct. This is because breaking any of these rules could lead to the wrong choice of tests, which means that the test gives unreliable or inconsistent results when trying to interpret or generalise sample results to the whole population[93].

Table 1: Statistical Tests' Groups

Parametric Tests	**Non-parametric Tests**
One-Way ANOVA (comparing the means of more than two sample taken from)	Kruskal Wallis Test
Unpaired T-test (comparing the means of two sample taken from independent)	Mann-Whitney Test
Chi-square test	Chi-square test

3.4.1 Statistical Test Assumption

As mentioned before, the assumption must be evaluated in order to choose the right test. This process needs to be done in two steps. The first step is to choose the test group. Finding out what kind of data you have and how it is spread out is the most important thing to do when choosing a test from either the parametric or non-parametric group. When using parametric tests, you have to assume that the variables are either ratio or ordinal and follow a normal distribution. But after the test group is chosen, each test depends on its own assumptions. To test the consensus level among data from different length and project type groups with respect to the percentage of delay, the test should be designed for more than two groups. The most important assumption to examine for tests involving more than two groups is normality test[97].

IBM Statistics Version 24 was used to perform the statistical tests in this study. The Kolmogorov–Smirnov and Shapiro–Wilk tests were applied to examine whether all the projects were normally distributed in terms of type and length. The results show p-values less than 0.05 for all the causes, which means that the null hypothesis for the normality test (H0: The population is normally distributed) is not true. Thus, it can be stated that the assumption of normality has been violated. This means that if this assumption is broken, all the tests should come from the non-parametric test group. In conclusion, Kruskal Wallis test along with Dunn’s post hoc test will be perform to evaluate the level of consensus among different project type and different length group with respect to delay percentage.

3.4.2 Hypothesis Development

For testing the level of the consensus, following hypotheses are developed:

H_{01}: There is no difference between the length group of projects and the delay percentage.

H_{02}: There is no difference between the type of projects and the delay percentage.

If the P-value for the chosen test is greater than 0.05, the null hypothesis cannot be rejected. This means that there is a substantial consensus between respondents.

3.5 Association Test

This part talks about how to use association tests to look at the links between categorical variables. This helps find important links between project traits and delay outcomes.

3.5.1 Crosstabulation

Crosstabulation, which is also called a contingency table analysis, is a descriptive statistical method that looks at the connection between two categorical variables by putting the data into a matrix of frequencies[98]. The two things being looked at in this study are Project Complexity Category (like Bridge and Viaduct, Drainage and Culvert Systems) and Delay Class (like Extreme Delay, High Delay, Low Delay, and Moderate Delay). The crosstabulation shows how many cases fall into each category, making it easier to find possible patterns or links between the complexity of a project and the severity of the delay.

3.5.2 Chi-Square Test of Independence

The Pearson Chi-Square Test of Independence is used to see if there is a statistically significant link between the two categorical variables[99].

The null hypothesis (H_0) assumes that the variables are independent, whereas the alternative hypothesis (H_A) proposes that the variables are associated.

The Pearson Chi-Square statistic is calculated as:

$$\mathcal{X}^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(O_{ij} - E_{ij})}{E_{ij}} \tag{1}$$

Where:

O_{ij} represents the observed frequency in cell i, j

E_{ij} denotes the expected frequency in cell i, j computed as:

$$E_{ij} = \frac{(Row\ Total)_i \times (Column\ Total)_j}{Grand\ Total} \tag{2}$$

The degrees of freedom are determined using:

$$df = (r-1) \times (c-1) \tag{3}$$

3.6 Logistic Regression Analysis

In the last phase of the analysis, LRA was used to guess how much of the change in a dependent variable could be explained by a set of independent variables. LRA was chosen for this study because some of the assumptions, such as normality, were not met[100]. The dependent variable in this model was the Delay Class, which is an ordinal categorical variable with four ordered categories (Low Delay, Moderate Delay, High Delay, and Extreme Delay). The independent variables included project type (Maintenance/Rehabilitation, Improvement, New Construction), total road length (continuous), project complexity features (bridges and viaducts, tunnels, drainage and culvert systems, overpasses and underpasses, and environmental protection works), accessibility level (High, Medium, Low), and selected institutional/financial factors. So, LRA is used to figure out how the causes of delays and the project's complexity affect different types of delays.

The goodness of fit statistics will tell you if the model made by regression analysis fits the data well enough based on the results of LRA. The overall fit of the model in LRA will be determined by the Omnibus test of model coefficients, the Hosmer and Lemeshow (H-L) test, Cox & Snell R2 or Nagelkerke R2, and the classification results[101]. Each of the tests above gives information about how well the generated predictive model fits. The Omnibus test, for example, shows a big improvement in model fit after adding independent variables when the P-value is less than 0.05. The Hosmer-Lemeshow (H-L) test says that the logistic model fits well with real outcomes if the P-value is greater than 0.05. The Cox & Snell R2 and Nagelkerke R2 are both Pseudo R2, which means that they don't really explain the proportion of variation of independent variables yet. Instead, they are used to estimate the variation in the criterion variables. Finally, classification results show how accurate the predicted probabilities are in terms of sensitivity (True Positive), specificity (True Negative), and overall model accuracy[101]. There is no particular test that is thought to be the best for checking the fit of a logistic regression model. However, the H-L test is often used as an important evaluation metric because it compares the observed and predicted probabilities of the outcome for different groups of people[102].

Chapter 4

RESULTS AND DISCUSSION

4.1 Descriptive Analysis

The descriptive statistics present the summary of the dataset, including the total road length, cost, duration, cost overruns, and delays. The mean actual cost is $231.67 million, but there is a lot of variation, as shown by a standard deviation of $383.82 million. Most projects last about 80 months, but some last more than 22 years.

Cost overruns can be very different, with some projects saving a lot of money (–82.83%) and others going way over budget (318.75%). Delays can also be very different, with some projects being late by as much as 417% and others being late by as little as 2.5%. This shows that there are serious scheduling problems in some cases. The total length of the road also varies a lot, from less than a kilometre to more than 172,000 kilometres. This shows how different the projects are. These differences show how complicated and varied the projects in the dataset are, which is why statistical analysis is so important for figuring out performance patterns (Table 2).

Table 2: Descriptive Statistical Analysis

Descriptive Statistics				
	Minimum	Maximum	Mean	Std. Deviation
Actual cost ($ million)	1.79	4589.20	231.67	383.82

Actual duration (month)	10.60	266.00	79.99	23.39
Cost overrun (%)	-82.83	318.75	8.11	36.80
Cost overrun ($ million)	-270.20	2675.00	21.34	177.57
Delay (%)	2.50	417.00	57.51	48.37
Delay (month)	1.00	122.00	26.94	17.88
Estimated cost ($ million)	1.27	2694.00	214.99	288.15
Estimated duration (month)	9.00	244.00	53.78	18.57
Total length of the Road	0.37	172423.00	1929.01	7730.50

The descriptive statistics reveal significant variability in project performance, indicating that road construction projects differ greatly in scale, cost efficiency, and schedule adherence. High standard deviations in cost, duration, and overruns suggest that while some projects perform close to expectations, others experience extreme deviations, pointing to underlying management, planning, or contextual challenges. Negative cost overruns alongside extreme positive overruns indicate that both substantial savings and severe budget excesses occur, reflecting inconsistent cost control practices. Similarly, the wide range of delays highlights that time management is a critical issue, with some projects facing severe scheduling problems. The variation in road lengths underscores the diversity of project scopes, suggesting that scale-related factors may influence both cost and duration outcomes. Collectively, these patterns indicate that performance is highly context-dependent and that statistical analysis is essential to identify the factors driving such disparities.

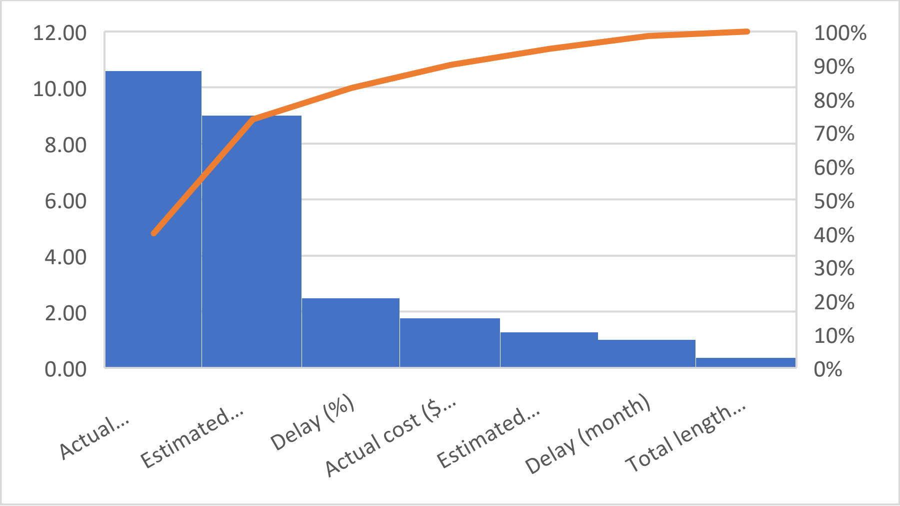

Figure 2: Statistical Analysis Chart

From a construction management point of view, these variations highlight the necessity of robust cost estimation, scheduling techniques, and risk management strategies. Projects that suffer from extreme delays or overruns may lack effective project control mechanisms, stakeholder coordination, or adaptive planning. The dataset emphasizes how critical it is to apply advanced project management tools such as Earned Value Management (EVM), risk modelling, and lean construction methods to enhance predictability and efficiency.

Also from a transportation management perspective, these differences are equally important. Projects with long delays or cost escalations not only affect contractors and financiers but also disrupt broader transportation planning goals. Delayed road infrastructure delivery can slow down regional economic growth, hinder connectivity, and reduce the efficiency of freight and passenger transport systems. Moreover, variations in road length and scope underscore the need for transportation managers to align infrastructure delivery with long-term mobility strategies, logistics demands, and sustainable development objectives.

4.2 Frequency Analysis

Frequency analysis is a way to show how project characteristics and delay factors are spread out, showing how often they happen and how important they are in the dataset.

4.2.1 Country Frequency Analysis

The frequency analysis of project distribution by country (Table 3) present that the dataset is heavily concentrated in a small number of countries, with 54.9% of all projects originating from a single dominant country group, followed by a gradual distribution across numerous other nations. A lot of the data comes from China, India, Indonesia, and a few other Asian countries. On the other hand, many countries, especially in Africa, Latin America, and small island states, only have one to a few recorded projects. The cumulative relative frequency values show that the top 15 to 20 countries account for most of the cases. This means that project financing is concentrated in certain areas, which is an uneven distribution. This means that the road infrastructure projects in the dataset are not evenly spread out around the world. Instead, they are mostly in certain high-priority or high-investment areas. This could be because of the strategic priorities of donor institutions, the needs of regional development, or the fact that there are a lot of large-scale infrastructure programs in those areas.

This uneven distribution can be interpreted as the outcome of both economic and institutional factors. Donor institutions and international financing bodies tend to prioritize countries with demonstrated capacity to implement large-scale projects, stronger governance structures, and well-developed regulatory frameworks. Such environments reduce risks for project execution, encourage co-financing, and improve the likelihood of timely completion. Conversely, countries with weak institutional support and limited technical expertise attract fewer projects due to higher risks of mismanagement, cost escalation, and implementation delays. As a result, regions with low project density face challenges in acquiring sufficient experience, knowledge transfer, and exposure to best practices in infrastructure development.

From a construction management perspective, the concentration of projects in certain countries reflects stronger institutional frameworks, greater capacity for large-scale implementation, and better technical expertise. In contrast, regions with fewer projects often face weaker institutional support, limited resources, and less exposure to best practices, increasing the risk of delays, overruns, and quality issues.

From a transportation management perspective, clustering in countries like China and India shows a focus on network connectivity, trade facilitation, and logistics development. Regions with sparse project activity, however, face bottlenecks, limited accessibility, and slower socio-economic growth, relying more heavily on external aid and donor alignment with national transportation policies.

Table 3: Country Frequency Analysis

Country			
	Frequency	Relative Frequency	Cumulative Relative Frequency Percent
	856	54.9	54.9
Afghanistan	3	0.2	55.1
Albania	6	0.4	55.5
Algeria	4	0.3	55.8
Angola	1	0.1	55.8
Argentina	10	0.6	56.5
Armenia	5	0.3	56.8
Azerbaijan	6	0.4	57.2
Bangladesh	13	0.8	58.0

Barbados	2	0.1	58.2
Belize	2	0.1	58.3
Benin	3	0.2	58.5
Bhutan	7	0.4	58.9
Bolivia	5	0.3	59.2
Bosnia & Herzegovina	2	0.1	59.4
Botswana	3	0.2	59.6
Brazil	13	0.8	60.4
Bulgaria	1	0.1	60.5
Burkina Faso	4	0.3	60.7
Burundi	4	0.3	61.0
Cambodia	12	0.8	61.7
Cameroon	5	0.3	62.1
Cape Verde	2	0.1	62.2
Central Africa	2	0.1	62.3
Chad	5	0.3	62.6
Chile	3	0.2	62.8
China	86	5.5	68.4
Colombia	6	0.4	68.7
Comoros	2	0.1	68.9
Congo	1	0.1	68.9
Costa Rica	3	0.2	69.1
Cote d'lvoire	3	0.2	69.3
Côte d’Ivoire	1	0.1	69.4
Croatia	1	0.1	69.4
Cyprus	2	0.1	69.6
Djibouti	2	0.1	69.7
Dominican Republic	5	0.3	70.0
Ecuador	1	0.1	70.1
Egypt	1	0.1	70.2
Eritrea	1	0.1	70.2
Ethiopia	3	0.2	70.4
Fiji	4	0.3	70.7
Gabon	1	0.1	70.7
Gambia	1	0.1	70.8
Georgia	12	0.8	71.6
Ghana	12	0.8	72.3
Guatemala	2	0.1	72.5
Haiti	4	0.3	72.7
Honduras	7	0.4	73.2
Hungary	1	0.1	73.2
India	58	3.7	77.0
Indonesia	22	1.4	78.4

Israel	1	0.1	78.4
Ivory Coast	1	0.1	78.5
Jamaica	4	0.3	78.8
Jordan	2	0.1	78.9
Kazakhstan	7	0.4	79.3
Kenya	6	0.4	79.7
Kiribati	2	0.1	79.8
Korea	3	0.2	80.0
Kosovo	1	0.1	80.1
Kyrgyz Republic	11	0.7	80.8
Lebanon	1	0.1	80.9
Lesotho	4	0.3	81.1
Liberia	3	0.2	81.3
Macedonia	1	0.1	81.4
Madagascar	4	0.3	81.6
Malawi	2	0.1	81.8
Malaysia	2	0.1	81.9
Mali	5	0.3	82.2
Mauritania	2	0.1	82.3
Mauritius	2	0.1	82.5
Mexico	5	0.3	82.8
Moldova	1	0.1	82.9
Mongolia	7	0.4	83.3
Morocco	4	0.3	83.6
Mozambique	3	0.2	83.8
Myanmar	1	0.1	83.8
Nepal	19	1.2	85.0
New Guinea	21	1.3	86.4
Nicaragua	3	0.2	86.6
Niger	1	0.1	86.6
Nigeria	8	0.5	87.2
North Macedonia	1	0.1	87.2
Oman	3	0.2	87.4
Pakistan	12	0.8	88.2
Palestine	1	0.1	88.3
Panama	3	0.2	88.4
Paraguay	5	0.3	88.8
Peru	1	0.1	88.8
Peru	8	0.5	89.3
Philippines	10	0.6	90.0
Poland	4	0.3	90.2
Romania	2	0.1	90.4
Rwanda	4	0.3	90.6

Samoa	1	0.1	90.7
Senegal	6	0.4	91.1
Serbia	3	0.2	91.3
Seychelles	1	0.1	91.3
Sierra Leone	3	0.2	91.5
Solomon Island	3	0.2	91.7
Somalia	2	0.1	91.8
South Sudan	3	0.2	92.0
Sri Lanka	15	1.0	93.0
Swaziland	1	0.1	93.1
Tajikistan	6	0.4	93.5
Tanzania	6	0.4	93.8
Thailand	9	0.6	94.4
Timor-Leste	2	0.1	94.5
Togo	4	0.3	94.8
Tonga	2	0.1	94.9
Tunisia	6	0.4	95.3
Turkey	4	0.3	95.6
Uganda	10	0.6	96.2
Ukraine	2	0.1	96.3
Uruguay	5	0.3	96.7
Uzbekistan	3	0.2	96.9
Vanuatu	3	0.2	97.0
Venezuela	2	0.1	97.2
Viet Nam	15	1.0	98.1
Vietnam	9	0.6	98.7
Yemen	7	0.4	99.2
Yugoslavia	3	0.2	99.4
Zaire	3	0.2	99.6
Zambia	5	0.3	99.9
Zimbabwe	2	0.1	100.0

4.2.2 Delay Classes Frequency Analysis

The average frequency of the coded categories shows that a small number of factors make up most of the dataset. EEF (21.0%), MEL (16.1%), CCI (11.5%), and FP (11.0%) make up more than half of all recorded instances. The cumulative relative frequency reveals the top five categories represent more than 62% of the total. This means that these are the areas where most of the occurrences happen. On the other hand, some categories, like CEC, MEEF, PSC, and DI, have very low frequencies, with each one making up less than 2% of the total. This unequal split suggests that some factors happen much more often across projects, which could point to common themes or problems in the dataset, while others happen less often and may only happen in certain situations or contexts (Table 4).

From a construction management point of view, the concentration of these factors points to the most common challenges in delivering road projects. Issues such as external environment factors (EEF), material and equipment logistics (MEL), contractor or consultant inefficiencies (CCI), and financial problems (FP) reveal recurring weaknesses in planning, procurement, and resource management. These challenges often translate into cost overruns and schedule delays, showing the need for stronger supply chain practices, more careful contractor selection, and tighter financial oversight. Less frequent factors, though not widespread, still matter—some, like cost estimation (CEC) or policy and stakeholder coordination (PSC), may emerge only in specific situations but require tailored solutions.

From a transportation management point of view, these recurring issues have a direct impact on the expansion and reliability of road networks. When materials or funds are delayed, the completion of vital transport corridors slows down, affecting both mobility and economic activity. Similarly, poor coordination between stakeholders undermines the overall efficiency of infrastructure programs. Even the less common issues can have meaningful, localized effects, shaping how well certain regions achieve their goals for connectivity, accessibility, and long-term development.

Table 4: Delay Classes Frequency Analysis

	Frequency	Relative Frequency	Cumulative Relative Frequency
CCI	398	11.5	11.5
CE	234	6.8	18.3
CEC	29	0.8	19.1
CT	125	3.6	22.7
DI	67	1.9	24.7
DSI	182	5.3	29.9
EEF	728	21.0	51.0
FP	381	11.0	62.0
HRP	136	3.9	65.9
IRI	149	4.3	70.2
LAI	127	3.7	73.9
MEEF	53	1.5	75.4
MEL	557	16.1	91.5
PS	76	2.2	93.7
PSC	62	1.8	95.5
SCI	155	4.5	100.0

The Pareto chart in Figure 2 that only a few categories make up most of the occurrences in the dataset, which follows the 80/20 rule. The most common categories are EEF, MEL, CCI, and FP. Together, they make up a large part of the total cases. The cumulative frequency curve shows that the top few factors quickly reach the 80% mark. Categories like CEC, MEEF, PSC, and DI don't show up as often and don't add much to the total. This pattern shows that project problems or traits are mostly caused by a small number of factors. This means that focused efforts in these key areas could fix most of the problems that keep coming up.

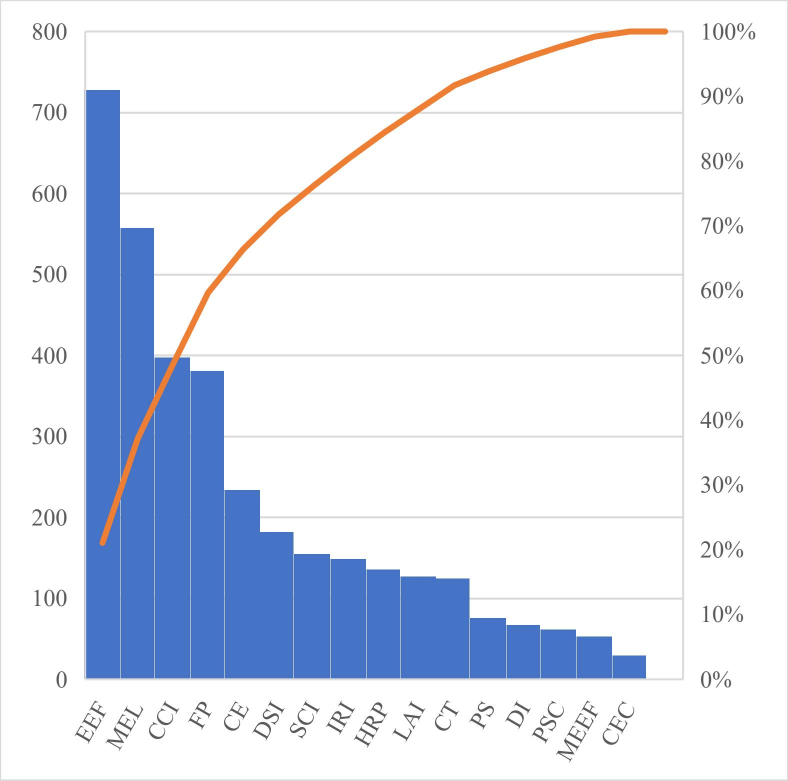

Figure 3: Delay Classes Frequency Bar Chart

From an interpretive perspective, this unequal split reflects the fact that certain project dimensions are structurally more prone to generating recurring problems, whereas others represent unique or isolated circumstances. For construction and infrastructure projects, the dominant categories are often linked to external environmental forces, management and execution limitations, cost and coordination inefficiencies, and financial planning weaknesses. The persistent appearance of these categories implies systemic challenges that cut across geographic and institutional contexts.

The implications of this distribution are significant. The dominance of a few categories suggests that concentrated efforts to improve performance in these areas could lead to disproportionately large improvements in project outcomes. Addressing weaknesses in the most frequently occurring categories may therefore provide a more efficient and impactful strategy than attempting to spread resources evenly across all potential factors. Conversely, the low-frequency categories, while less influential on a global scale, remain important to consider in specific contexts, as they may reflect localized or project-specific risks that could still threaten success if overlooked.

4.2.3 Project Type Frequency Analysis

The frequency distribution of project types in Table 5 shows that Improvement (39.2%) and Maintenance/Rehabilitation (38.8%) projects include the majority of the dataset, with these two types of projects making up almost four-fifths (78.8%) of all recorded cases. The percentage of New Construction projects is smaller at 21.2%, and the share of the initial minor category is only 0.8%. The cumulative relative frequency backs up the idea that most road infrastructure projects are focused on upgrading or maintaining existing assets rather than building new ones. This distribution suggests that the strategy is to focus on keeping and improving the current infrastructure networks.

From a construction management perspective, the dominance of maintenance and improvement projects underscores the importance of asset preservation and lifecycle management. Project managers need to prioritize existing networks, assess conditions accurately, and coordinate works in live traffic environments while minimizing disruptions.

From a transportation management perspective, the focus on upgrades reflects a strategy to sustain mobility and maximize existing capacity. Rather than continuous expansion, many countries prioritize maintaining safe and reliable corridors that support trade and daily mobility. New construction still matters but remains secondary to keeping current networks efficient and sustainable.

Table 5: Project type Frequency Analysis

	Frequency	Relative Frequency	Cumulative Relative Frequency
Improvement	611	39.2	40.0
Maintenance/Rehabilitation	605	38.8	78.8
New Construction	330	21.2	100.0

The bar chart shows that most of the projects in the dataset are Improvement and Maintenance/Rehabilitation projects, with more than 600 cases each and making up almost 80% of all projects. There are only about 330 new construction cases, which shows that there is a strong focus on upgrading and maintaining existing infrastructure (Figure 3).

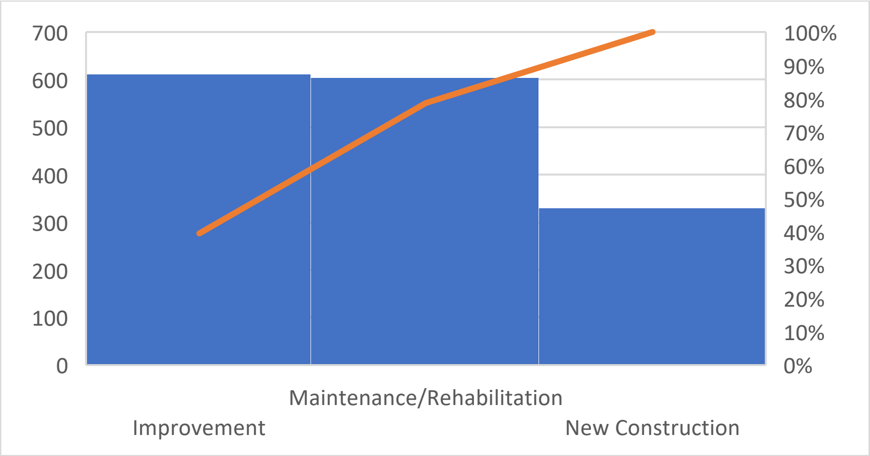

Figure 4: Project Type Frequency Bar Chart

The dominance of improvement and rehabilitation projects suggests that road infrastructure investment is strongly aligned with asset management principles. Many countries appear to prioritize sustaining the functionality of existing systems over committing to the high financial and environmental costs associated with new construction. This trend may also reflect budgetary constraints, where limited resources are allocated toward interventions that deliver immediate and cost-effective benefits, such as reducing deterioration, improving safety, and optimizing performance.

4.2.4 Project Complexity Frequency Analysis

The frequency analysis of project complexity types in Table 6 present that Drainage and Culvert Systems (31.4%), Environmental Protection works (30.7%), and Bridge and Viaduct structures (28.3%) are the most common types of projects. These three types of projects make up more than 90% of all cases. Overpass and underpass projects (6.8%) and tunnel work (2.8%) are much less common. This shows that people are more interested in building surface and environmental infrastructure than in building complicated underground structures.

In terms of construction management, the high share of drainage, environmental, and bridge-related works shows a strong emphasis on risk control, durability, and resilience. These features are essential for handling water flow, stabilizing slopes, and ensuring safe crossings—all vital for the long-term performance of road networks. Delivering such projects requires close coordination between civil works, environmental safeguards, and structural engineering.

Looking at it from a transportation management angle, the distribution highlights priorities of safety, sustainability, and keeping mobility uninterrupted. Good drainage and slope protection reduce disruptions and accidents, while bridges and viaducts ensure connectivity across difficult terrain. By contrast, tunnels and underpasses, though crucial in some regions, remain less common because they require more investment and advanced technical capacity.

Table 6: Project Complexity Frequency Analysis

	Frequency	Relative Frequency	Cumulative Relative Frequency
Bridge and Viaduct	441	28.3	28.3
Drainage and Culvert Systems	489	31.4	59.7
Environmental Protection (Noise Barrier, Animal Crossing, Slope Protection, Retaining Wall)	479	30.7	90.4
Overpass and Underpass	106	6.8	97.2
Tunnel	43	2.8	100.0

The bar chart (Figure 4) shows that Drainage and Culvert Systems, Environmental Protection works, and Bridge and Viaduct structures occupy most of the data set. Each has a frequency of 400 or more, and together they make up more than 90% of all cases. There are a lot fewer flyover and underground projects, as well as tunnel projects. This shows that the main focus is on building infrastructure on the surface and in the environment, not underground.

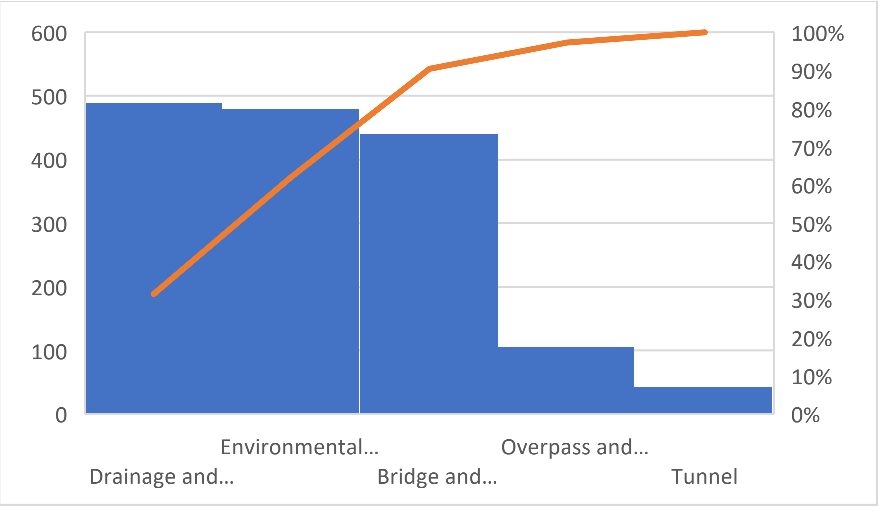

Figure 5: Project Complexity Bar Chart

The frequency analysis shows that Drainage and Culvert Systems, Environmental Protection works, and Bridge and Viaduct structures dominate, together making up over 90% of projects. This indicates that infrastructure priorities focus on surface and environmental works, which are essential for flood control, ecological balance, and transport connectivity.

By contrast, Overpass, Underpass, and Tunnel projects are far less common. This is likely due to their higher technical complexity, greater costs, and higher risks, which make them less attractive compared to surface projects that deliver more immediate and widespread benefits.

The bar chart confirms this distribution, emphasizing that the main focus lies in practical and sustainable infrastructure above ground, while underground construction remains secondary due to its challenges.

4.3 Association Test

Association tests are used to look at the links between categorical variables. This makes it possible to find important links between project characteristics and delay outcomes.

4.3.1 Project Type-Delay Class Association Test

The crosstabulation evaluation of the relation between project type and delay class shows that delays happen in all types of projects. The High Delay category is the most common in Improvement and Maintenance/Rehabilitation projects, and both types show almost the same patterns. Moderate and low delays also happen a lot in these two groups, which shows that the severity of the delays is evenly spread out. Even though there are fewer new construction projects overall, they still show a range of delays across all classes. This suggests that delays are a common problem for all types of projects. The Chi-Square test results ($p < 0.001$) show a very strong link between project type and delay class. This means that the type of project affects how likely and bad delays are, possibly because of differences in the project's scope, complexity, and execution conditions (Table 7, 8).

From a construction management angle, this finding highlights the need for tailored scheduling, monitoring, and risk management strategies depending on whether the project involves maintenance, improvement, or new construction.

From a transportation management angle, the results underline how delays in any project type—whether upgrading existing roads or building new ones—can disrupt broader goals of network reliability, mobility, and timely service delivery.

Table 7: Project Type-Delay Class Crosstabulation

Project Type-Delay Class Crosstabulation				
	Delay Class			
	Extreme Delay	High Delay	Low Delay	Moderate Delay
Improvement	13	246	155	197
Maintenance/Rehabilitation	10	247	155	192
New Construction	11	138	82	99

Table 8: Project Type-Delay Class Chi-Square Tests

Chi-Square Tests			
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	1050247.604[a]	12	0.000
Likelihood Ratio	23236.483	12	0.000

The findings highlight that project type plays a significant role in determining both the likelihood and severity of delays. The fact that improvement and maintenance/rehabilitation projects experience a greater share of high delays may be attributed to the complex nature of working with existing infrastructure, where unforeseen conditions, integration with operational systems, and dependency on prior works can lead to prolonged disruptions. The distribution of moderate and low delays across these categories also indicates that such projects are inherently prone to multiple forms of schedule challenges.

In contrast, new construction projects, despite being fewer in number, still present delay cases across all severity levels. This reinforces the idea that delays are a systemic issue in construction, not confined to a particular type of project. The statistical significance of the Chi-Square test further validates this association, showing that project type is not merely a contextual factor but a decisive element influencing the risk of delay. This may stem from variations in project scope—where maintenance or rehabilitation projects deal with uncertainties of existing structures, while new construction may face issues of planning, design changes, or resource mobilization.

4.3.2 Project Length-Delay Class Association Test

The crosstabulation analysis of the relationship between total road length class and delay class shows that High Delay is the most common category across all length ranges. Moderate and Low Delays are next, and Extreme Delays are the least common. There doesn't seem to be a clear pattern linking the length of a project to the severity of delays. The distribution of delays seems to be pretty consistent across short, medium-short, medium-long, and long projects. The Chi-Square test results ($p > 0.05$) show that there is no statistically significant link between the total length of the road and the delay class. This means that the length of a project does not have a measurable effect on how delays are spread out (Table 9, 10).

From a construction management angle, this suggests that challenges leading to delays are less about physical scale and more about factors like planning quality, coordination, financing, and contractor performance.

From a transportation management angle, the finding means that both small and large projects face similar risks of delay, and disruptions to mobility or connectivity can occur regardless of the size of the investment.

Table 9: Total length Class-Delay Class Crosstabulation

Total length Class-Delay Class Crosstabulation				
	Delay Class			
	Extreme Delay	High Delay	Low Delay	Moderate Delay
Short Length (≤ 162.00 Km)	5	84	39	49
Medium-Short Length (> 162.00 and ≤ 434.00 Km)	5	67	47	55
Medium-Long Length (> 434.00 and ≤ 1311.50 Km)	2	63	52	58
Long Length (> 1311.50 Km)	2	74	44	56

Table 10: Total length Class-Delay Class Chi-Square Tests

Chi-Square Tests			
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	8.833[a]	9	0.453
Likelihood Ratio	8.914	9	0.445

The absence of a significant relationship can be explained by several factors. First, long projects often benefit from structured resource allocation, detailed scheduling, and phased implementation strategies, which can help mitigate risks that might otherwise accumulate over larger scopes of work. Conversely, shorter projects may face similar types of logistical, financial, or administrative issues, meaning they are not inherently less prone to delays. Second, many delay factors in infrastructure projects are driven by external conditions—such as environmental constraints, regulatory approvals, stakeholder coordination, and contractor performance—which affect projects of all lengths relatively equally.

This finding underscores that project length alone is not a reliable predictor of delay severity. Unlike project type or complexity, which showed statistically significant associations with delay class, length does not appear to introduce distinct risks that shape scheduling outcomes. From a managerial perspective, this suggests that efforts to reduce delays should focus less on the total length of the project and more on addressing complexity-related risks and project-specific characteristics.

4.3.3 Project Accessibility Class-Delay Class Association Test

The crosstabulation evaluation of the relation between accessibility class and delay class shows that High Delay is the most common type of delay at all levels of accessibility, followed by Moderate and Low Delays. Extreme Delays are the least common type of delay. The patterns of delays on High, Medium, and Low Accessibility Roads are pretty similar, which means that the severity of the delays doesn't change much based on how accessible the road is. The Chi-Square test results ($p > 0.05$) show that there is no statistically significant link between road accessibility and delay class. This means that the level of accessibility does not have a big effect on how delays happen in these projects (Table 11, 12).

From a construction management point of view, the result indicates that delays are likely driven more by factors such as planning, financing, and coordination rather than the accessibility of the project site.

From a transportation management point of view, it suggests that mobility risks remain similar across different accessibility levels, meaning both highly accessible and remote roads can face comparable project delivery challenges.

Table 11: Accessibility Class-Delay Class Crosstabulation

Accessibility Class-Delay Class Crosstabulation				
	Delay Class			
	Extreme Delay	High Delay	Low Delay	Moderate Delay
High Accessibility Road	13	221	137	162
Low Accessibility Road	7	124	91	114
Medium Accessibility Road	8	192	136	167

Table 12: Accessibility Class-Delay Class Chi-Square Tests

Chi-Square Tests			
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	3.429[a]	6	0.753
Likelihood Ratio	3.448	6	0.751

Several factors may explain this finding. First, while accessibility can influence initial project mobilization, the long-term progression of road projects is often dominated by systemic issues such as funding interruptions, administrative bottlenecks, procurement inefficiencies, and contractor performance. These factors can equally disrupt projects regardless of accessibility. Second, projects in high-accessibility areas may face their own unique challenges, such as higher traffic volumes, stakeholder interferences, or complex utility relocations, which offset the potential benefits of ease of access. Conversely, projects in less accessible areas may encounter logistical difficulties but can sometimes proceed with fewer external disruptions.

The absence of a strong link between accessibility and delay severity suggests that improvements in transport access alone are not sufficient to reduce project delays. Delay mitigation strategies should therefore focus on strengthening project governance, enhancing monitoring systems, and addressing contractual and managerial challenges that affect all projects equally, regardless of location.

4.3.4 Project Complexity-Delay Class Association Test

The crosstabulation analysis of the correlation between project complexity and delay class shows that High Delay is the most common category for all types of complexity. This is especially accurate for Drainage and Culvert Systems, Environmental Protection works, and Bridge and Viaduct structures, which make up most of the cases. There are a lot fewer cases of Overpass and Underpass projects, as well as Tunnels, but all types of delays are still present, except for Extreme Delay for Tunnels. The results of the Chi-Square test ($p < 0.001$) show that there is a statistically significant link between the complexity of a project and the class of delays. This means that the type of structural or environmental complexity in a project affects how delays are spread out (Table 13, 14).

For construction management, this highlights the need for specialized planning, coordination, and technical expertise to manage complex works effectively.

For transportation management, it suggests that delays in complex projects—like bridges or environmental works—can have a disproportionate impact on network reliability, safety, and long-term mobility goals.

Table 13: Complexity-Delay Class Crosstabulation

Complexity-Delay Class Crosstabulation				
	Delay Class			
Complexity	Extreme Delay	High Delay	Low Delay	Moderate Delay
Bridge and Viaduct	8	177	118	138
Drainage and Culvert Systems	9	205	125	150
Environmental Protection (Noise Barrier, Animal Crossing, Slope Protection, Retaining Wall)	9	179	137	154
Overpass and Underpass	1	42	35	28
Tunnel	0	18	15	9

Table 14: Complexity-Delay Class Chi-Square Tests

Chi-Square Tests			
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	1051946.741	20	0.000
Likelihood Ratio	23394.342	20	0.000

The reasons for this relationship are linked to the inherent technical and managerial challenges associated with different complexity types. For instance, Drainage and Culvert Systems often involve widespread site works and environmental interactions, which can expose projects to delays caused by weather conditions, soil variability, or unforeseen underground obstructions. Environmental Protection projects typically require compliance with strict environmental regulations and coordination with multiple stakeholders, which can slow down approval processes and construction timelines. Bridge and Viaduct projects, given their structural demands and reliance on specialized equipment and techniques, are prone to technical uncertainties and delays in procurement or execution.

By contrast, Overpass and Underpass projects, while fewer in number, generally require less extensive resource mobilization than large-scale bridge or viaduct works, though they still face risks from traffic management and utility relocation. Tunnel projects, though technically challenging, are relatively rare in the dataset, and their smaller sample size may explain why Extreme Delays were not observed. Nonetheless, the presence of High, Moderate, and Low Delays even in tunnel cases highlights that complexity, regardless of type, remains a consistent driver of delay.

These results suggest that project managers and decision-makers must adopt tailored risk management strategies that align with the specific type of complexity in a project. For example, environmental projects may require more proactive stakeholder engagement and regulatory coordination, while bridge and viaduct projects may benefit from stronger procurement planning and technical supervision.

4.4 Inferential Analysis

4.4.1 Project Length-Delay Percentage Inferential Analysis

Table 15 results show the normality analysis of the Delay (%) variable is tabulated as Tests of Normality. The probability associated with the Kolmogorov Smirnov test (Statistic = 0.132, df = 702, p = 0.000) and the Shapiro Wilk test (Statistic = 0.805, df = 702, p = 0.000) was less than 0.05 and thus the null hypothesis of normality can be rejected. The rather small Shapiro Wilk statistic also demonstrates that the Delay (%) variable deviates greatly toward non-normality.

Table 15: Normality Test of Inferential Length-Delay%

Tests of Normality						
	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Delay (%)	0.132	702	0.000	0.805	702	0.000

These are supported by graphical representations in Figure 5. A positively skewed Histogram shows that most projects are delayed within a range of around 2.5 to 60 percent. Frequency curve decreases significantly with an increase in delay values and a small number of outliers are more than 200 per cent and runs close to 400 per cent, thus showing outliers exist. True to this skewness, the Normal Q-Q plot is odd against the expected normal pattern: the points fail to follow the diagonal reference line, especially around the two tails, with the upper tail slanting steeply upwards due to many high-delay outliers.

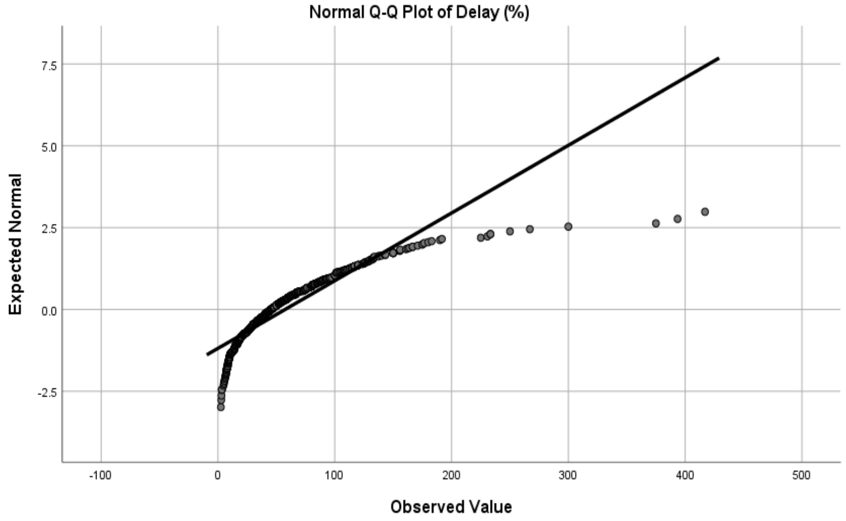

Figure 6: Normal Q-Q plot

There are big variances in the mean rank values for delay percentage across all total length classes. The Short Length category has the greatest mean rank (378.28), followed closely by the Medium-Short Length category (358.87) and the Long Length category (351.10). The Medium-Long Length category has the lowest mean rank (317.49). This initial finding indicates that shorter initiatives generally encounter comparatively more delays than medium-long programs (Table 16).

Table 16: Ranks of Inferential Length-Delay%

Ranks			
Total length Classes	N	Mean Rank	
	Short Length	177	378.28
	Medium-Short Length	174	358.87
	Medium-Long Length	175	317.49
	Long Length	176	351.10

Figure 6 bar chart shows the average rank values for each length category. The orange bars show how the mean rank changes. The difference in mean ranks between Short Length and Medium-Long Length makes the probable length-delay association stronger.

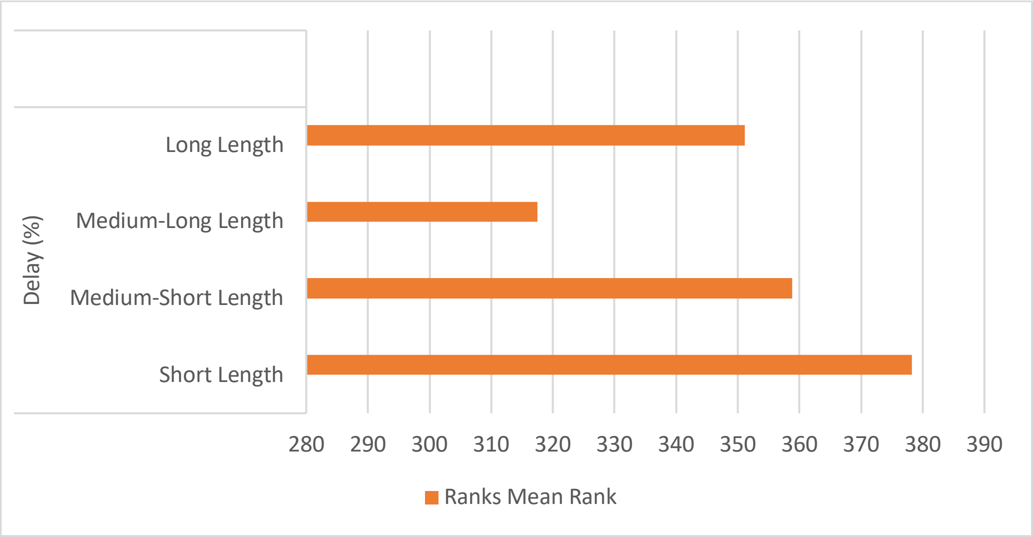

Figure 7: Bar Chart of Mean Rank

The Kruskal–Wallis H test result (H = 8.242, df = 3, p = 0.041) shows that there is a statistically significant variation in the percentages of delays among the four length categories. Since $p < 0.05$, the null hypothesis that the distributions are equal can be rejected. This means that the length of the project class does have an effect on the percentage of delays (Table 17).

Table 17: Kruskal-Wallis Test Statistics of Inferential Length-Delay%

Test Statistics	
	Delay (%)
Kruskal-Wallis H	8.242
df	3
Asymp. Sig.	0.041

Post-hoc pairwise comparisons in Table 18 reveal that the sole statistically significant adjusted difference exists between Medium-Long Length and Short Length projects (Adj. Sig. = 0.029). This shows that these two groups have the biggest disparity in delay percentage ranks, with short projects usually having longer delays. After normalization, other comparisons indicate no significant differences, even though several raw significance levels were less than 0.05.

Table 18: Pairwise Comparisons of Inferential Length-Delay%

Pairwise Comparisons of Total length Classes					
Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.
Medium-Long Length-Long Length	-33.617	21.647	-1.553	0.120	0.723
Medium-Long Length-Medium-Short Length	41.382	21.709	1.906	0.057	0.340

Medium-Long Length-Short Length	60.797	21.617	2.812	0.005	0.029
Long Length-Medium-Short Length	7.766	21.678	0.358	0.720	1.000
Long Length-Short Length	27.180	21.586	1.259	0.208	1.000
Medium-Short Length-Short Length	19.415	21.648	0.897	0.370	1.000

The network plot (Figure 7) shows the average rank differences across groups in a visual way. The biggest difference in visual size is between Short Length (highest rank) and Medium-Long Length (lowest rank), which is what the post-hoc results show. The relative closeness of the other groups means that the distinctions are not as clear.

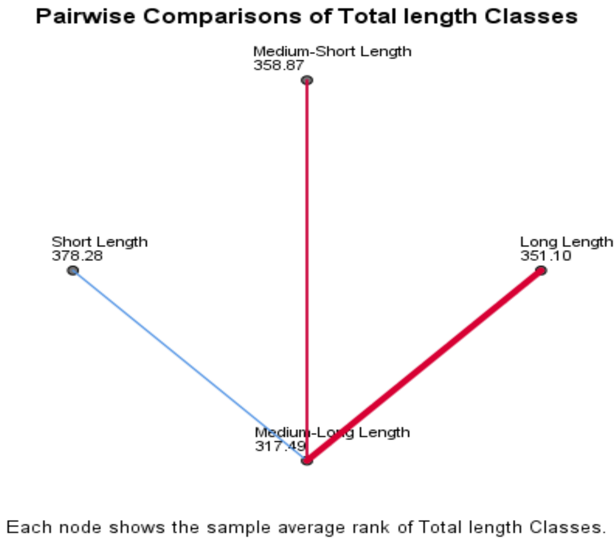

Figure 8: Pairwise Comparisons Network Plot

Table 19 makes it obvious what the hypothesis testing result is: the delay % is not the same across length classes. The choice is to reject the null hypothesis based on the Kruskal–Wallis result (p = 0.041).

Table 19: Hypothesis Test of Inferential Length-Delay%

Hypothesis Test Summary			
Null Hypothesis	Test	Sig.	Decision
The distribution of Delay (%) is the same across categories of Total length Classes.	Independent-Samples Kruskal-Wallis Test	0.041	Reject the null hypothesis.

Table 20 goes over the sample size (N = 702), the test statistic (H = 8.242), the degrees of freedom (df = 3), and the p-value (0.041) again. This confirms the preceding findings and shows how important the result is.

Table 20: Independent-Samples Kruskal–Wallis Test of Inferential Length-Delay%

Independent-Samples Kruskal-Wallis Test Summary	
Total N	702
Test Statistic	8.242
Degree Of Freedom	3
Asymptotic Sig. (2-sided test)	0.041

From a construction management perspective, these findings suggest that shorter projects may suffer delays because they are often perceived as “simpler” and may not receive the same level of planning rigor, risk assessment, or resource allocation as larger initiatives. Smaller projects can also suffer from funding gaps, frequent design changes, or administrative bottlenecks, which accumulate into significant delays.

From a transportation management standpoint, delays in short projects can be highly disruptive, particularly when these projects involve urban road segments or key connectors. Even modest projects, if delayed, can reduce mobility, create bottlenecks, and undermine public confidence in infrastructure delivery. Therefore, short projects should not be underestimated; they require careful scheduling, stakeholder coordination, and timely execution to preserve network efficiency.

The normality tests indicate that the Delay (%) variable does not follow a normal distribution, as both tests yield significant p-values below 0.05. This non-normality suggests the data is heavily skewed and contains extreme outliers, particularly on the higher end of the delay spectrum. The positive skew implies that while most projects experience moderate delays, a small proportion face exceptionally high delays, distorting the distribution. Consequently, non-parametric methods are more suitable for subsequent analysis.

The distribution of delay percentages across project length categories reveals that shorter projects tend to experience higher delays on average compared to longer ones. The highest mean rank observed in the Short Length category suggests greater susceptibility to time overruns. This trend indicates an inverse relationship between project length and delay, implying that shorter projects may face proportionally more scheduling challenges or inefficiencies than their longer counterparts.

The Kruskal–Wallis H test confirms a statistically significant difference in delay percentages among the four project length categories, establishing that project length influences delay outcomes. This finding highlight that not all project types are equally affected by delays and that project duration may be a key determinant in understanding delay patterns.

Post-hoc analysis further refines this interpretation by identifying that the significant difference lies specifically between the Short Length and Medium-Long Length categories. This indicates that shorter projects encounter considerably higher delays compared to medium-long ones, while other categories show no statistically meaningful distinctions after adjustment. The visual network comparison supports this interpretation, emphasizing the pronounced disparity between these two groups.

Overall, the rejection of the null hypothesis confirms that project delay distributions vary according to project length. These findings collectively suggest that shorter projects are more prone to delay, potentially due to constrained resources, less robust planning, or underestimation of complexity. This emphasizes the need for focused delay mitigation measures in shorter-duration projects.

4.4.2 Project Type-Delay Percentage Inferential Analysis

The Kruskal-Wallis H test examining the associations between different types of projects and the percentage of delays. It shows that the mean ranks are different, with New Construction projects having the highest mean delay rank (430.25) and Improvement projects having the lowest (334.15). Other groups, like Maintenance & Improvement (342.18) and Maintenance, Improvement & New Construction (354.83), are in a similar range, which means that the groups are fairly close in terms of how well they handle delays. The statistical test ($H = 3.718$, $p = 0.715$) shows that there is no significant difference at the 5% level, which means that the type or combination of project types does not have a big effect on the percentage of delays. This means that the formal project type classification probably doesn't have much of an effect on how bad the delays are (Table 21, 22).

From a construction management perspective, this finding suggests that delays are influenced more by underlying factors such as design changes, resource constraints, procurement inefficiencies, or stakeholder coordination challenges, rather than by the project’s nominal type. Even though new construction projects appear to have higher mean delay ranks, the absence of statistical significance points to systemic issues—such as scheduling, budgeting, and contractor performance—that cut across all project categories.

From a transportation management viewpoint, the lack of strong differentiation underscores that delays can disrupt mobility and service continuity regardless of project type. Whether expanding an existing road or building a new corridor, inefficiencies have similar impacts on network connectivity, traffic flow, and user satisfaction. This highlights the need for consistent delay-mitigation strategies across all project types, rather than focusing on specific categories alone.

The results indicate that although there are observable variations in mean delay ranks across different project types, these differences are not statistically significant. The higher mean rank for New Construction projects suggests they tend to experience comparatively greater delays, while Improvement projects show relatively lower delay percentages. However, the Kruskal–Wallis test result ($H = 3.718$, $p = 0.715$) confirms that these variations occur by chance rather than due to inherent differences between project types. This implies that project type alone does not play a decisive role in determining delay severity. In practice, this suggests that delays are likely influenced more by other factors—such as project management efficiency, resource allocation, or external conditions—rather than by the formal classification of project type.

Table 21: Mean Rank Type-Delay%

Ranks		
Project Type	N	Mean Rank
Maintenance	63	360.90
Improvement	20	334.15
New Construction	18	430.25
Maintenance & Improvement	289	342.18
Maintenance & New Construction	10	364.65
Improvement & New Construction	59	353.02
Maintenance, Improvement & New Construction	243	354.83

Table 22: Statistics of Type-Delay%

Test Statistics	
	Delay (%)
Kruskal-Wallis H	3.718
df	6
Asymp. Sig.	0.715

4.5 Prediction Analysis

Prediction analysis uses statistical models to figure out which project characteristics are most likely to cause delays and how much they affect project results.

4.5.1 Project Complexity-Delay Class Prediction Analysis

The results in Table 24 presents that the final ordinal regression model is statistically significant ($\chi^2 = 11.741$, df = 5, p = 0.039) when compared to the model that only has an intercept. This means that adding the chosen complexity predictors makes the model much better at explaining differences in delay class. Even though the improvement is statistically significant, the next pseudo-R-square values show that the model only explains a small amount of the variance, which means that other factors besides the tested complexity variables probably also play a role in classifying delays. In this model, the dependent variable was the Delay Class (Low, Moderate, High, Extreme). The independent variables were project complexity features, including the presence of tunnels, bridges and viaducts, overpasses and underpasses, drainage and culvert systems, and environmental protection requirements such as noise barriers, slope protection, and animal crossings.

Table 23: Prediction Complexity-Delay Class Model Fitting Information

Model Fitting Information				
Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	191.173			
Final	179.432	11.741	5	0.039

The Prediction Complexity – Delay Class (Goodness-of-Fit) in Table 25 results show that the model fits the data well because the p-values for both the Pearson (p = 0.972) and Deviance (p = 0.943) statistics are high. These results, which are not significant, suggest that there is not a big difference between the predicted and actual delay classifications. This means that the model accurately represents the relationships that were seen. This backs up the ordinal regression model's ability to explain how complexity features affect delay class.

Table 24: Prediction Complexity-Delay Class Goodness-of-Fit

Goodness-of-Fit			
	Chi-Square	df	Sig.
Pearson	44.167	64	0.972
Deviance	47.220	64	0.943

Table 25 shows that an ordinal regression model was used to look at the link between project complexity and delay severity, with Delay Class as the dependent variable. The model generated parameter estimates for the thresholds delineating delay categories and for the predictors of project complexity. In most cases, the threshold coefficients for the delay categories were statistically significant. The first threshold (Delay Class = 1) yielded a negative and significant coefficient (Estimate = –0.782, p = 0.009), signifying a diminished probability of projects remaining in the lowest delay category. The second threshold (Delay Class = 2) exhibited a positive yet marginally significant effect (Estimate = 0.567, p = 0.057), indicating that the distinction between Class 2 and superior classes is less pronounced. In contrast, the third threshold (Delay Class = 3) was very significant (Estimate = 4.206, p < 0.001), which showed that there was a clear difference at the highest delay level. These findings substantiate the efficacy of employing ordered delay classes as the dependent variable in the regression model. Regarding explanatory variables, the existence of tunnels, bridges/viaducts, overpasses/underpasses, and drainage/culvert systems did not yield statistically significant coefficients, suggesting that these engineering complexities were not consistently linked to increased delay severity. The addition of environmental protection features, such as noise barriers, slope protection, and animal crossings, had a positive and statistically significant coefficient (Estimate = 0.475, p = 0.003). This means that projects that needed environmental protection measures were much more likely to be delayed. The odds ratio, which is about 1.61, shows that projects with these features were about 61% more likely to be put in more severe delay classes than projects without these features. The ordinal regression model showed that most technical complexities don't have a big effect on the chance of a delay getting worse. However, environmental protection requirements are a major factor in explaining differences between delay severity classes.

Table 25: Prediction Complexity-Delay Class Case Parameter Estimates

Parameter Estimates							
	Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
[Delay Class = 1]	-0.782	0.298	6.875	1	0.009	-1.367	-0.197
[Delay Class = 2]	0.567	0.297	3.628	1	0.057	-0.016	1.150
[Delay Class = 3]	4.206	0.397	112.329	1	0.000	3.428	4.983
[Tunnel=0]	0.065	0.303	0.045	1	0.831	-0.530	0.659
[Tunnel=1]	0			0			
[Bridge and Viaduct=0]	0.076	0.150	0.255	1	0.613	-0.218	0.369
[Bridge and Viaduct=1]	0			0			
[Overpass and Underpass=0]	0.119	0.208	0.329	1	0.566	-0.288	0.527
[Overpass and Underpass=1]	0			0			

[Drainage and Culvert Systems=0]	-0.198	0.157	1.588	1	0.208	-0.506	0.110
[Drainage and Culvert Systems=1]	0			0			
[Environmental Protection Noise Barrier Animal Crossing Slope Protection=0]	0.475	0.158	9.013	1	0.003	0.165	0.784
[Environmental Protection Noise Barrier Animal Crossing Slope Protection=1]	0			0			

The results in Table 26 show that the test of parallel lines was employed to assess the proportional odds assumption, which contrasts the null hypothesis model (which assumes equal slopes across response categories) with the general modelling. The results indicated a chi-square value of 6.940 with 10 degrees of freedom and a significance value of 0.731. The null hypothesis cannot be rejected due to the fact that the p-value is significantly greater than the 0.05 threshold. This suggests that the ordinal regression model is valid and suitable for the analysis, as the proportional odds assumption is supported.

Table 26: Prediction Complexity-Delay Class Test of Parallel Lines

Test of Parallel Lines				
Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	179.432			
General	172.492	6.940	10	0.731

From a construction management point of view, the results show that technical structures such as bridges or tunnels, while complex, do not necessarily increase delay severity. The main challenge lies in projects that involve environmental protection measures, which often require extensive regulatory approvals, additional design considerations, and specialized methods that can disrupt timelines. This underlines the importance of early environmental planning, stakeholder consultation, and regulatory alignment to minimize risks and keep projects on track. From a transportation management point of view, delays in environmentally sensitive projects can have cascading impacts, particularly when they occur along critical corridors where ecological protection must be balanced with road connectivity. The findings emphasize that while sustainability goals and environmental safeguards are essential, they require careful scheduling and integrated planning to avoid undermining broader network performance.

4.5.2 Project Delay Cause-Delay Class Prediction Analysis

Table 27 reveals that the final model was compared to the intercept-only model in order to evaluate the model fitting information. The final model produced a reduced value of 1506.472, while the intercept-only model produced a –2 log likelihood value of 1522.188. With 16 degrees of freedom and a significance value of 0.473, the chi-square test was conducted to determine the difference between the two models. The result was 15.717. The improvement in fit between the intercept-only and final model is not statistically significant, as the p-value is greater than 0.05. This implies that, despite the fact that the final model offers a marginally better fit than the baseline, the disparity is insufficiently substantial to be considered statistically significant. However, the model's adequacy is still supported by the overall goodness-of-fit and assumption checks, which can be interpreted in terms of its parameter estimates. In this model, the dependent variable was the Delay Class (Low, Moderate, High, Extreme). The independent variables were delay cause indicators coded as location-based indices, including CCI, CE, CEC, CT, DI, DSI, EEF, FP, HRP, IRI, LAI, MEEF, MEL, PS, PSC, and SCI. The independent variables in this model were delaying cause indicators coded as location-based indices. These included FP (Financial Problems), CEC (Cost Estimation and Control), MEEF (Market/External Economic Factors), PS (Planning and Scheduling), DSI (Design Stage Issues), DI (Documentation Issues), CE (Construction Execution), CT (Contracting and Tendering), PSC (Project Scope and Changes), HRP (Human Resources and Productivity), MEL (Material, Equipment, and Logistics), SCI (Stakeholder and Communication Issues), EEF (External and Environmental Factors), CCI (Contractor/Consultant Related Issues), IRI (Institutional Related Issues), and LAI (Land Acquisition Related Issues). These indices collectively represent the main categories of delay causes extracted from project reports and coded systematically for analysis.

Table 27: Prediction Cause-Delay Class Model Fitting Information

Model Fitting Information				
Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	1522.188			
Final	1506.472	15.717	16	0.473

To see how well the ordinal regression model explained the data that was seen, in Table 28, the goodness-of-fit statistics were looked at. The Pearson chi-square (χ^2 = 1779.364, df = 1793, p = 0.586) and Deviance chi-square (χ^2 = 1425.983, df = 1793, p = 1.000) tests yielded non-significant outcomes. The significance values are much higher than 0.05, so we can't reject the null hypothesis that the model fits the data well.

These results show that the model fits well, which means that the predicted classification of projects into delay categories matches the data that was actually seen.

Table 28: Prediction Cause-Delay Class Goodness-of-Fit

Goodness-of-Fit			
	Chi-Square	df	Sig.
Pearson	1779.364	1793	0.586
Deviance	1425.983	1793	1.000

Table 29 presents that the ordinal regression model was utilized with location-based indices as explanatory variables for delay severity. The first threshold (Delay Class = 1) was negative and significant (Estimate = –0.648, $p < 0.001$), while the second threshold (Delay Class = 2) was positive and significant (Estimate = 0.707, $p < 0.001$). The third threshold (Delay Class = 3) had the biggest positive and very significant coefficient (Estimate = 4.349, $p < 0.001$). This means that there was a strong separation at the highest delay level. Most of the location predictors did not show statistical significance, which means they probably didn't have a big effect on how bad the delay was. It is important to note that EEF (Estimate = 0.175, $p = 0.017$) and FP (Estimate = 0.188, $p = 0.049$) were both statistically significant. These positive coefficients suggest that projects with greater exposure to environmental and financial parameters were more prone to categorization in elevated delay classes. On the other hand, other indicators like CCI, CE, CT, DI, DSI, HRP, IRI, LAI, MEEF, MEL, PS, PSC, and SCI were not statistically significant ($p > 0.05$). This means that these factors did not have a big effect on how severe the delays were in the dataset. In general, the results show that most locational indices don't have a big impact on delay classification. However, EEF and FP have big impact on delay classification.

Table 29: Prediction Cause-Delay Class Parameter Estimates4

Parameter Estimates							
	Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
[Delay Class = 1]	-0.648	0.174	13.904	1	0.000	-0.989	-0.308
[Delay Class = 2]	0.707	0.174	16.542	1	0.000	0.366	1.048
[Delay Class = 3]	4.349	0.317	188.020	1	0.000	3.728	4.971
CCI	0.023	0.095	0.060	1	0.807	-0.163	0.209
CE	0.024	0.120	0.038	1	0.845	-0.212	0.260
CEC	-0.305	0.325	0.880	1	0.348	-0.942	0.332
CT	-0.134	0.165	0.666	1	0.415	-0.457	0.188
DI	-0.124	0.219	0.319	1	0.572	-0.554	0.306
DSI	0.151	0.137	1.225	1	0.268	-0.117	0.420
EEF	0.175	0.073	5.729	1	0.017	0.032	0.319
FP	0.188	0.095	3.877	1	0.049	0.001	0.375
HRP	0.103	0.169	0.372	1	0.542	-0.229	0.435
IRI	-0.062	0.156	0.159	1	0.690	-0.369	0.244
LAI	0.100	0.180	0.308	1	0.579	-0.253	0.453
MEEF	0.023	0.229	0.010	1	0.920	-0.426	0.473
MEL	0.091	0.089	1.043	1	0.307	-0.083	0.265
PS	0.078	0.217	0.130	1	0.718	-0.348	0.505
PSC	0.109	0.240	0.207	1	0.649	-0.360	0.579
SCI	0.017	0.145	0.013	1	0.908	-0.268	0.302

In Table 30 the test of parallel lines determines the proportional odds assumption, which says that the relationship between each pair of outcome groups must be the same statistically. The null hypothesis in this model posits that the slope coefficients are uniform across all delay classes. The results show that the chi-square statistic is 17.657, has 32 degrees of freedom, and is significant at 0.981. The null hypothesis cannot be rejected because the p-value is much higher than 0.05. This means that the proportional odds assumption is true, which shows that the ordinal regression model is a good fit for the data.

Table 30: Prediction Cause-Delay Class Case Test of Parallel Lines

Test of Parallel Lines				
Model	-2 Log Likelihood	Chi-Square	df	Sig.
Null Hypothesis	1506.472			
General	1488.815	17.657	32	0.981

From a construction management point of view, the results show that most delay causes—such as contractor inefficiencies, procurement issues, or scheduling problems—do not significantly increase the severity of delays when analysed in isolation. Instead, the real drivers are financial problems (FP) and external/environmental factors (EEF). These are often harder to control within the project itself, as they involve market volatility, funding shortfalls, and regulatory or environmental approvals. For managers, this highlights the importance of stronger financial risk management, early contingency planning, and proactive engagement with environmental and regulatory processes. By anticipating these risks and building flexibility into contracts and budgets, project teams can better shield projects from being pushed into higher delay categories.

From a transportation management point of view, the findings suggest that financial and environmental disruptions can have broader consequences for road network development. Funding shortages or regulatory slowdowns delay not only individual projects but also the rollout of key corridors, undermining regional mobility and slowing down socio-economic benefits. Road projects affected by environmental approvals, for example, are often located in sensitive areas that also happen to be strategically important for connectivity. This means that sustainability goals must be carefully balanced with timely project delivery. Integrating transport policy with financial planning and environmental governance can therefore help reduce systemic risks and improve overall network reliability.

Chapter 5

CONCLUSION

This study aimed to investigate the fundamental causes and determinants of delays in road infrastructure projects financed by development banks, utilising a comprehensive dataset of 702 projects funded by the World Bank and the Asian Development Bank. The research has yielded a comprehensive, evidence-based comprehension of how diverse project attributes and contextual elements influence delay outcomes, utilising a blend of descriptive, inferential, and predictive statistical analyses.

The descriptive findings highlighted the heterogeneity of road infrastructure delivery across nations and project types by revealing notable variation across projects in terms of cost, duration, and delay percentage. Because of differences in management techniques, resource allocation, and governance capability, some projects demonstrated extraordinary efficiency, while others suffered from significant time and cost overruns. According to frequency analysis, the majority of observed delays are caused by a limited number of factors, specifically financial issues (FP), contractor and consultant inefficiencies (CCI), material and equipment logistics (MEL), and environmental and external conditions (EEF). This pattern draws attention to systemic issues that persist across regions in the processes of financial disbursement, risk management, and procurement.

Furthermore, inferential tests demonstrated that while project length and accessibility do not show a statistically significant relationship with delay classes, project type and complexity have a significant impact on delay severity. According to these findings, a project's technical and structural features have a bigger impact on schedule performance than its actual size or location. The predictive relevance of these variables was validated by logistic regression analysis, confirming that institutional-financial factors and complexity-related features are powerful predictors of delay outcomes. Overall, by offering a quantitative framework that connects project attributes with delay severity, the study adds to both academic literature and real-world project management. To reduce schedule risks, the findings support focused interventions like complexity-sensitive planning, increased contractor capacity, better procurement transparency, and early risk identification.

These findings highlight the need for strong governance systems, flexible financing options, and monitoring frameworks that can identify and address the underlying causes of delays for development banks and policymakers. Stakeholders can improve the timeliness, effectiveness, and sustainability of upcoming road infrastructure investments by coordinating managerial, technical, and financial procedures with empirical data.

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