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Article

Analyzing the critical delay factors for construction projects in the public sector using relative importance index and machine learning techniques

Sirinthip Ouansrimeang, Kittipol Wisaeang*

Mahasarakham Business School, Mahasarakham University, MahaSarakham 44150, Thailand
*** Corresponding author:** Kittipol Wisaeang, Kittipol.w@acc.msu.ac.th

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Abstract: This study aims to identify the causes of delays in public construction projects in Thailand, a developing country. Increasing construction durations lead to higher costs, making it essential to pinpoint the causes of these delays. The research analyzed 30 public construction projects that encountered delays. Delay causes were categorized into four groups: contractor-related, client-related, supervisor-related, and external factors. A questionnaire was used to survey these causes, and the Relative Importance Index (RII) method was employed to prioritize them. The findings revealed that the primary cause of delays was contractor-related financial issues, such as cash flow problems, with an RII of 0.777 and a weighted value of 84.44%. The second most significant cause was labor issues, such as a shortage of workers during the harvest season or festivals, with an RII of 0.773. Additionally, various algorithms were used to compare the Relative Importance Index (RII) and four machine learning methods: Decision Tree (DT), Deep Learning, Neural Network, and Naïve Bayes. The Deep Learning model proved to be the most effective baseline model, achieving a 90.79% accuracy rate in identifying contractor-related financial issues as a cause of construction delays. This was followed by the Neural Network model, which had an accuracy rate of 90.26%. The Decision Tree model had an accuracy rate of 85.26%. The RII values ranged from 68.68% for the Naïve Bayes model to 77.70% for the highest RII model. The research results indicate that contractor financial liquidity and costs significantly impact construction operations, which public agencies must consider. Additionally, the availability of contractor labor is crucial for the continuity of projects. The accuracy and reliability of the data obtained using advanced data mining techniques demonstrate the effectiveness of these results. This can be efficiently utilized by stakeholders involved in construction projects in Thailand to enhance construction project management.

Keywords: delay causes; relative importance; construction projects; machine learning

1. Introduction

Construction delays refer to the period exceeding the contractually agreed completion date or the mutually agreed delivery date among the project's parties. These delays can arise from various causes, such as price fluctuations, poor material performance, insufficient materials, financial liquidity issues, etc. The causes of these delays vary from project to project. Delays can lead to significant changes in the project, including increased costs, extended timelines, and even contract termination (Senouci et al., 2016). Despite using advanced technology and improved management techniques in current construction projects, these projects still face delays and extended construction timelines. Similarly, in Thailand, as in other developing countries, there are significant issues with delays and cost overruns (Chaitongrat et al., 2024). Construction projects typically involve multiple stakeholders, including the client, the project manager, and the contractor. Each party has specific responsibilities and rights. The client is responsible for delivering the site or other agreed-upon items as stipulated in the contract, including paying the construction fees to the contractor on time. The designer's role involves designing the specifications and details of materials as specified. The project manager or consultant is tasked with verifying the construction designs, materials, and ensuring compliance with the requirements and contract, as well as providing necessary information and recommendations for the efficient progress of the construction project. The contractor is responsible for planning the construction, executing it, procuring materials, equipment, and labor to ensure adherence to specifications and contract terms. Additionally, they are responsible for preparing documentation, procedures, and other necessary presentations for approval by the project manager or consultant acting on behalf of the client (Marzouk and El-Rasas, 2014).

The significant impact of project delays on both the project itself and the stakeholders, including the client and the contractor, has been extensively studied internationally. For instance, Polat (2024) conducted research focusing on the root causes affecting contractors in Turkey concerning construction project value. They categorized the influential variables into three main groups: construction value-related, time-related, and risk-related. All three groups of variables were found to be highly significant. The variable ranked first in importance was design problems. From this study, it can be inferred that design issues are a major cause affecting contractors and consequently impacting various project stakeholders, including project owners, contractors, designers, and project managers. In addition, this research further categorized the causal variables by stakeholder involvement in construction projects. Aziz (2013) conducted a study that prioritized variables contributing to construction delays in Egypt following changes in the country. They classified these variables into 9 groups, totaling 99 variables: consulting, contractor, design, equipment-related, external factors, labor-related, material-related, project owner, and project characteristic groups. The ranking outcome revealed that the variable of delayed payment for work progress in the project owner group ranked first. This group also encompassed variables originating from contractors and design controllers. Additionally, a study on government procurement processes in Malaysia (Aliza et al., 2011) emphasized the significance of contractors submitting the lowest bids to win competitive tenders, potentially leading to issues of corruption and subpar work quality. They proposed a procurement model with subdivisions related to competitive bidding, governmental decision-making, and transparency to foster efficient national development.

Compared with Thailand's procurement process outlined in the Public Procurement Act, which mandates ethical management, transparency, and integrity, bid competitions solely based on the lowest price affect both project duration and quality control. Such bidding processes must consider price, construction cost, construction period, and warranty period. Bidders propose these aspects for the contracting authority's evaluation. Moreover, the causes of project delays begin even before contract initiation until project completion, categorized into internal and external factors. Internally, factors like contract details, agreement formation, construction design, planning, pricing, delivery, payment disbursement, time extensions, and design modifications can be controlled throughout the project lifecycle. Externally, uncontrollable factors such as natural disasters, riots, economic fluctuations, laws, and regulations of relevant agencies, as well as other related organizations, contribute to project delays (Pooworakulchai, 2016). Therefore, analyzing the causes of construction project delays from the initial stages before bidding until contract management involves critical components such as personnel, documentation, and environmental context (Pooworakulchai, 2017).

This research aims to study the analysis of causes of construction project delays and the groups affected by the root causes of delays, which include directly involved individuals in construction projects, such as contractors, employers, project supervisors, and external factors, in the northeastern region of Thailand. Sampling is done based on representatives from each population group, comprising engineers, government officials, contractor engineers, and project supervisors, all directly involved in construction projects from initiation to completion. This aims to demonstrate the continuity of delay causes affecting collaborative project execution and to investigate delay causes in government construction projects, including prioritizing delay causes and conducting more in-depth evaluations of delay causes using the Relative Importance Index (RII) (Khatib et al., 2020). Furthermore, various algorithms are analyzed to compare the Relative Importance Index (RII) and machine learning methods, including Decision Trees (DT), Deep Learning, Neural Networks, and Naïve Bayes, to validate the accuracy rates of construction project delays efficiently (Arena et al., 2021; Chamidah et al., 2020).

2. Review of literature

2.1. The problem of cost overruns and delays

Delays primarily refer to the unexpected extension of the planned overall timeframe or events that extend the duration of activities, potentially impacting the overall project schedule. Delays can arise from numerous interrelated causes, leading to more complex situations. The causes of delays may vary depending on the location, type, size, and project scope. Senouci et al. (2016) conducted various case studies in different countries, tracking several factors contributing to delays in construction projects. Examples of these cases include:

An examination of increased budgets and delays in public sector construction projects was conducted in Qatar. The study highlighted budget increases and delays in government construction projects. Research findings, both domestic and international, indicate a significant need to understand and develop methods to analyze and synthesize emerging issues. The data used in the study of construction projects in Qatar comprised 122 projects, including road projects, building construction, and drainage projects. Regression analysis revealed that the relationship between construction budgets and increased costs could predict construction costs, particularly for building and drainage system projects. For building construction projects, budget increases were attributed to the contractors’ costs, while for drainage projects, the budget decreased as the contractors’ costs increased. The study concluded that the contractors' costs are the primary factor influencing project delays, which significantly impact the project timeline. Additionally, Chidiebere and Ebhohimen (2018) concluded that rework issues have an impact of nearly 79.98% on the efficiency of construction projects in Nigeria, particularly in cost, time, and quality. Similarly, Niazi and Painting (2017) studied the key causes of increased construction costs in Afghanistan. Generally, the success of construction can be measured by the budget; however, the success of a construction project depends on several factors or causes. These issues and causes are prevalent in developing countries, where budget constraints and management issues significantly contribute to lower construction project performance. In Afghanistan, construction budget increases mainly due to problems among project stakeholders, including material suppliers, subcontractors, and main contractors. The study identified several significant factors leading to increased construction budgets in Afghanistan, including corruption, delayed payments by project owners, difficulties in payments by contractors, security issues, changes during construction, and inflation.

Mohamed and Tarek (2014) conducted a study analyzing the causes of delays in construction projects in Egypt. They focused on significant delay issues, frequently occurring during construction and often leading to disputes and litigation. The study involved interviews with experts and surveys completed by stakeholders, including project owners, consulting or supervising firms, and contracting organizations. The survey data were analyzed using the frequency, risk, and importance indexes to rank the significant and risky causes of construction delays in Egypt. The study categorized the causes into seven groups:

1) Causes related to the project owner
2) Causes related to the supervisors
3) Causes related to the contractors
4) Causes related to construction materials
5) Causes related to labor and construction equipment
6) Causes related to the project itself
7) External factors

Based on the case study in Egypt, the following recommendations were made for project owners, supervisors, and contractors:

1) Project owners: Prioritize creating feasible project designs that are aligned with actual site conditions to minimize disputes between project owners and contractors.
2) Supervisors: Focus on avoiding delays caused by contractor responsibilities, especially regarding the approval and inspection of materials and equipment. Additionally, manage and oversee the construction on behalf of the project owner.
3) Contractors: Emphasize financial planning and cash flow management. Anticipate and address potential obstacles that may cause delays in the construction project. Select experienced and skilled labor or subcontractors and manage the construction work effectively using a robust management system under a well-structured construction plan and schedule.

Ultimately, the construction industry in Egypt plays a crucial role in the country's growth. According to statistics from the Ministry of Planning, it is one of the most productive sectors of the Egyptian economy, accounting for 15% of the GDP. The average construction GDP of Egypt is estimated to be 23,047.06 million EGP from

2007 to 2018, with a peak of 59,846.30 million EGP in the fourth quarter of 2018 (Al-Janabi et al., 2020). Despite the importance of this sector, construction projects in Egypt face numerous delays linked to various causes.

Marzouk and El Rasas (2014) surveyed mail and interviews among construction industry experts in Egypt to identify the causes of these delays. The causes were categorized based on the perspectives of different parties:

1) Owner's perspective: Poor site management, financial issues of the contractor, and Changes during construction.
2) Contractor's perspective: Owner's interference, Delays in payment by the owner Owner's delays in reviewing and approving design documents, Work stoppages, and slow decision-making.
3) Consultant's perspective: Change orders by the owner during construction. Ground conditions, Low productivity levels of labor, and Unqualified labor.

These findings highlight the multifaceted nature of construction delays in Egypt and the need for tailored strategies to address them from different stakeholder perspectives.

Based on previous studies, the problem of construction delays in Thailand bears similarities. Rasa and Khongsombat (2020) examined the issue of requesting contract amendments for the reasons stated in the contract. They observed that contract parties encounter problems related to contract details within construction projects in Thailand because of uncertainties regarding the impacts of legal changes, economic fluctuations, and material shortages. Consequently, there is a need to extend timelines or adjust project values to ensure fairness to both parties. To successfully complete construction projects, there must be a mechanism for requesting contract amendments to navigate these challenges effectively. Furthermore, Jiradech Serthakampu and Nath Sukhsin (2019) studied the causes of delays in large-scale building construction projects and found that structural works are the most impactful category contributing to delays. The primary reason cited for these delays is inadequate planning and coordination. Additionally, contract modifications, such as scope changes, were significant factors. This research enables project managers to utilize the gathered data to make informed decisions in planning construction activities for effective project outcomes.

From the literature review, the top five ranked causes of construction project delays, based on their significance as identified and ranked in research reports, are as follows: (1) financial/capital issues, (2) payment according to work progress, (3) cash flow, (4) project owner's budget and (5) poor overall project planning and sequencing methods.

Conversely, the least ranked causes of construction project delays, based on their significance, are (1) poor project planning and sequencing methods, (2) contractor-related issues, (3) an inexperienced workforce, (4) owner's inexperience, and (5) external risks/intervention of external stakeholders.

These significant causes of construction project delays can be classified as related to the project owner, contractor, or project manager, as well as external factors. The least ranked causes of construction project delays, often less referenced or considered, have been excluded from further categorization due to their minimal significance. The classification is presented in **Table 1**.

Table 1. Summary of previous studies related to factors responsible for cost overrun and delays.

Group	References	Causes of delay
Contractor	(Shrivas and Singla, 2022; Sunjka and Jacob, 2013)	(1) Inefficient planning and scheduling of construction activities. (2) Poor project and site management. (3) Issues with availability of reserved materials, equipment, and procurement delays. (4) Financial issues of the contractor such as liquidity and financial status. (5) Inexperienced contractors or subcontractors, leading to poor-quality construction. (6) Labor issues include seasonal labor shortages, harvesting, or festival seasons. (7) Estimating project operating expenses of the contractor made a mistake. (8) Supervision and monitoring during construction of the contractor is unsuitable. (9) Problems of subcontractors that the contractor cannot control during construction, such as construction skills and lack of work. (10) The contractor's inspection of the construction area was not thorough before entering construction and presenting work.
Project Owner	(Assaf and Al-Hejji, 2006; Apolot, 2011; González, 2014)	(1) Changes in orders, bill of quantities, or additional works during construction. (2) Delays in decision-making by the employer in issuing instructions not in line with project scope and timeframes. (3) Contractual issues between the employer and the contractor during construction. (4) Design-related issues by the employer, such as conflicting or inconsistent designs or bills of quantities. (5) Approval delays and permissions for the contractor to proceed with work. (6) Employer's team selection and evaluation before contract. (7) Late handover of employer's site, unavailability of site for construction within the specified timeframes. (8) Specify the lowest price criteria in tendering for the selection of the winning bidder.
Project Manager	(Chen, 2019; Sanni-Anibire et al., 2022)	(1) Poor communication and coordination between construction operations. (2) Over-reliance on each other by construction managers towards the employer and contractor. (3) Complexity of construction work leading to delays by project managers. (4) Lack of training and knowledge development in regular construction management. (5) Inexperience in construction management.
External Factors	(Mahamid et al., 2012; Johnson and Babu, 2020)	(1) Inadequate quality control resulting in construction delays. (2) Political situations or crises affecting Construction. (3) Inflation, price fluctuations of materials significantly different from those used in the bidding. (4) Unstable economic conditions leading to financial instability. (5) Natural disasters and uncontrollable weather conditions affecting construction.

Table 2. Techniques, methods or tools for prioritizing causes of delays in construction projects.

References	Techniques/methods or tools	Quantity
(Bajjou and Chafi, 2020; Cakmak and Cakmak, 2014; Chen, 2019; Fugarand Agyakwah-Baah, 2010).	Literature review	4
(Kaliba et al., 2010; Marzouk, and El-Rasas, 2014; Muneeswaran, 2020; Rachid, et al., 2019)	Interviews/Experts opinion	4
(Kim et al., 2019; Thomas, et al., 2006)	Case Studies	2
(Al Hadithi, 2018; Amoatey and Ankrah, 2017; Aziz and Abdel-Hakam, 2016; Bagaya and Song, 2016; Das and Emuze, 2017)	Questionnaire Surveys	5
Shrivas and Singla, 2022	Interpretive structural modeling, ISM	1
(Das and Emuze, 2017; Han et al., 2013; Wang and Yuan, 2017)	System Dynamics	3
(Arena et al., 2021; Antoniou et al., 2023; Chamidah et al., 2020; Naik and Radhika, 2015; Fatima et al., 2014; Yitmen and Soujeri, 2010).	Artificial neural networks (ANN), Decision Tree (DT), Deep Learning, Artificial Neural Networks and Probability Principles Naïve Bayes	6
(Akogbe et al., 2013; Arantes et al., 2015; Aziz and Abdel-Hakam, 2016; Bajjou and Chafi, 2020; Durdyev, 2017; Kamal et al., 2022; Sanni-Anibire, 2022; Shah, et al., 2021)	Relative importance index (RII), Frequency Index, Severity Index and Importance Index.	8

From the literature review, it was found that Techniques, methods or tools for prioritizing causes of delays in construction projects. A lot has been presented. But techniques, methods or tools for prioritizing causes of delays in construction projects that are popular and are being used include the groups of relative importance index (RII), frequency index (Frequency Index), severity index (Severity). The index and Importance Index are shown in the summary in **Table 2**.

2.2. Summary of previous studies focusing on factors of cost overrun and delays

This section provides a summary of findings from previous studies that have examined factors that cause overbudget delays and delays in construction projects. The results of the study are compiled and presented in **Table 1**. The study found several key factors that cause delays and overspending in construction projects. One of the key findings is the relationship between budget increases and delays in government construction projects. This is related to an increase in the construction budget and expenses that can predict overall construction costs. The most important factors that cause delays in construction projects are divided into 4 groups: (1) causes of delays caused by contractors, totaling 10 factors, (2) causes of delays caused by groups of employers, totaling 8 factors, (3) causes of delay from a group of supervisors, 5 factors, and (4) causes of delays from a group of external factors, 5 factors, totaling 28 factors that cause delays in government construction projects. During times of financial crisis, a company's survival is put to the test. Developing a robust financial plan that considers the investment strategy for financial liquidity is essential. This plan should involve studying the best practices for managing financial resources and reducing the company's debt burden. By doing so, the risk of running into monetary liquidity problems can be minimized, thus ensuring the long-term stability and success of the business. As highlighted in the research conducted by Tashfeen et al. (2023), a well-planned and executed financial management strategy can help companies weather financial storms and emerge stronger than ever before. Additionally, the studies have identified several other causes of construction price increases, particularly in developing countries. These include (1) design-related problems by the employer, (2) poor communication and coordination between onstruction management, (3) unstable economic conditions leading to financial flexibility issues, and (4) inefficient planning and allocation of the construction schedule (Marzouk and El-Rasas, 2014). Another major issue that is frequently observed in construction projects is significant delays. These delays can lead to disputes and lawsuits, resulting in substantial financial losses for all parties involved. The most common factors that contribute to such delays include (1) financial problems of contractors, (2) problems with subcontractors that the contractor cannot control during construction, such as construction skills or work shortages, (3) incorrect estimation of project expenses by the contractor, and (4) inexperienced contractors or subcontractors leading to poor quality construction (Doloi et al., 2012). The result of successful teamwork comes from the emotional intelligence of project managers. According to a study by Watanabe et al. (2024), effective team relationships, confidence, and cooperation among team members are crucial to success in challenging project situations. This research has had a significant impact on project management, particularly in the area of emotional intelligence. It has contributed to the development of future project leaders by emphasizing the importance of fostering better relationships within teams and improving emotional intelligence skills through training. Several other factors can also contribute to construction delays, such as a lack of experienced construction managers, selecting the lowest bidder, a shortage of funds, a lack of proper management, improper planning and scheduling, a lack of skilled workers, construction site limitations, and project scale. Notably, there may be differences in opinions among project owners, supervisors, and contractors regarding the causes of construction project delays. Therefore, studyi these factors is crucial to prevent or avoid project delays that may lead to the failure of the construction project.

The findings of these studies are instrumental in providing essential data and information for other developing countries (Islam and Suhariadi, 2018). In countries with large populations still developing, unemployment is a major problem. However, if the economy is functioning well and there is a steady flow of capital, particularly from banks, it becomes possible to address this challenge. Banks providing loans to entrepreneurs at reasonable interest rates help create financial liquidity and enable rapid profit generation. This, in turn, can contribute to resolving unemployment issues (Kiani et al., 2020). Controlling the responses to incidents in developing countries is a complex issue requiring much attention. Budgets are a crucial factor that requires significant investments, and any delay in the process can considerably impact the national budget A study of the critical factors or causes that contribute to these delays has revealed six main groups of causes (Khair et al., 2018). Various theories have been developed for contractors to follow to ensure exceptional outcomes and sustain a company’s success. This process is critical to establishing a strong link between the user’s performance assessment and the employer. A contractor’s success heavily depends on their work performance, which can be easily presented to potential clients through their brand. Therefore, contractors must focus on delivering high-quality results to determine the growth of their profits. These insights have been highlighted and discussed in a research paper by Watanabe and Shafiq (2023). To optimize the utilization of resources, companies must logistics and supply chain management processes. Additionally, they have a well-defined framework for efficient operational management. It is also crucial for companies to adhere to ethical practices to demonstrate organizational agility in management, as highlighted by Shafiq et al. (2021) in their research conducted in 2021.

These groups include budget, management knowledge, experience, teamwork, technical skills, and external factors. Delays are prevalent, especially in large construction projects such as power generation systems and large water towers, which may also include general construction, inspection projects, and auctions. These delays can be categorized as follows: (1) approvals and permits delayed by the employer, such as material approval for construction site entry; (2) dependency relationships between supervisors towards the employer and contractors; (3) unstable project and construction site management; (4) unstable project and construction site management; and (5) employer’s selection of work team, evaluation before contracting (Prasad et al., 2019). Delays are considered expensive for all parties involved in the projects and often result in clashes, claims, total desertion, and difficulties in feasibility, ultimately slowing down the construction sector’s growth (Haseeb et al., 2011). The importance of the construction sector for any economy is well established in the existing literature.

Construction activity significantly contributes to the global economy as it is essential in global GDP (gross domestic product) and employment creation (Tariq and Shujaa Safdar Gardezi, 2023). In summary, addressing the causes of these delays is critical to ensuring the growth and success of construction projects in developing countries. Proper management, teamwork, and technical skills can minimize these delays, resulting in more successful projects and a more prosperous economy.

2.3. Knowledge gap & research contributions

Understanding the causes of cost overruns and delays is essential for project completion. A comprehensive examination of the factors contributing to these issues can help identify the root cause and prevent them from occurring. Several research studies have identified various factors that lead to project delays and cost overruns. One critical factor contributing to these issues is financial problems. Budgetary and financial constraints faced by contractors can cause a significant delay in the project. Delayed payments, insufficient funds, and unexpected expenses are some of the financial challenges that can hinder the project's progress. Another factor is labor-related issues. Shortages in skilled labor, subcontractor disputes, and other labor-related problems can also contribute to project delays and increased costs. Changes in project scope can also lead to delays and cost escalation. Alterations in orders, item lists, or additional work during construction can affect the project timeline and increase costs. Supply chain challenges, such as delays in the availability of materials, equipment, and procurement processes, can significantly hinder progress and increase costs. Design-related issues, poor communication, stakeholder coordination, and unstable economic conditions can also contribute to project delays and cost overruns, particularly in developing countries. Inefficient planning and allocation of construction schedules, lack of experienced managers, improper project management, and inadequate planning and scheduling are significant contributors to delays and cost overruns. Contracting practices such as selecting the lowest bidder, lack of experienced contractors or subcontractors, and disputes arising from inexperienced or low-quality artistry can also lead to project delays and increased costs. Differences in stakeholder perspectives can also cause delays. Differing opinions regarding the causes of delays among project owners, supervisors, and contractors highlight the importance of addressing diverse perspectives in mitigating project risks.

To ensure that a construction project is completed on time and within budget, it is essential to understand the various factors contributing to these issues. These factors can range from external factors, such as weather conditions and regulatory requirements, to internal factors, such as labor shortages and material availability. A comprehensive understanding of these factors is crucial for project management and can also provide valuable insights for stakeholders operating in similar contexts, especially in developing countries where such challenges are often more pronounced. By identifying and addressing these factors early on, project managers can take proactive steps to prevent or mitigate potential delays and cost overruns, ultimately ensuring the success of their construction projects.

2.4. Techniques and methods to prioritize the importance of the causes of delay

The field of research is constantly evolving, and researchers are always looking for ways to improve their performance and accuracy. One such approach is to initiate a module to report reasons for delays in their research projects and monitor their performance. To achieve this, predictive models are tested in real time, and the structure is continuously refined. To further improve the accuracy of forecasting and identify the causes of delays in government construction work, data treatment techniques such as Deep Learning, Neural Network (NN), Naïve Bayes (NB), and Decision Tree (DT) are utilized. A recent survey by Chamidah et al. (2020) aimed to determine how log data selection affects forecast performance over different periods. The study provides a helpful summary for improving forecasting accuracy. The study found that the following forecasting methods are widely used: NN, DT, DL, and NB. However, it is essential to note that acceptable standards for the accuracy of a single model in all contexts have yet to be established (Arena et al., 2021). The main focus of current research in prediction is creating a method for building holistic systems in machine learning that use data mining techniques. This includes learning machines that are grouped to enhance the accuracy of the overall system (Antoniou et al., 2023). It is widely accepted that any combination of classifiers is designed for an individual forecasting challenge, and this often results in better prediction rates than a single classifier in the case of a single classifier.

As a result, researchers have explored various techniques and methods to prioritize the importance of the causes of these delays. Several popular tools and processes are commonly used to assess the significance of different factors related to project delays. These include the Relative Importance Index (RII), Frequency Index, Severity Index, and Importance Index. The RII is a commonly employed tool in construction research to evaluate the impact of various variables that are critical to project progress or outcomes, particularly in the study of project delays. It assesses the importance of financial issues, labor readiness, contractor-subcontractor relationships, or project management problems (Aziz and Abdel-Hakam, 2016; Arantes et al., 2015; Bajjou and Chafi, 2020; Durdyev et al., 2017). Researchers often analyze the scores obtained through surveys and assign average scores to indicate the importance of each participating group using the RII formula. This is an effective tool for data analysis (Fashina et al., 2021). In addition to the RII, other less commonly used methods include System Dynamics and questionnaire surveys. System Dynamics is an effective tool for modeling and analyzing changes within various systems and assessing the impacts of different factors on the system's behavior. It aids researchers in understanding the complexity of problems and assists in developing efficient management plans and problem-solving methods within the system. Utilizing System Dynamics as a tool for analyzing issues related to construction project delays can help researchers comprehend the problem and find effective ways to reduce delays (Das and Emuze, 2017; Han et al., 2011; Wang and Uan, 2017). Similarly, questionnaire surveys involve compiling data from distributed surveys administered to key project stakeholders, including contractors, project owners, and consultants. Subsequently, the collected data is analyzed using frequency indices and correlations between variables. This approach can help researchers gain valuable insights into the causes of project delays and develop effective strategies to mitigate them (Amoatey and Ankrah, 2017; Asah-Kissiedu, 2009; Bagaya and Song, 2016; Hamzah et al., 2011).

In conclusion, the various techniques and methods used to prioritize the importance of causes of construction project delays, such as the RII, System Dynamics, and questionnaire surveys, can help researchers understand the complexity of the problem and find effective ways to reduce delays. By analyzing the significance of different factors related to project delays, researchers can develop efficient management plans and problem-solving methods to ensure successful project outcomes.

3. Materials and proposed methods

This comprehensive study has meticulously analyzed data from extensive literature reviews on the factors contributing to delays in public construction projects in different countries. The study is divided into two parts: the first part entails a meticulous analysis of data from literature reviews, and the second part involves an in-depth examination of data gathered from survey questionnaires.

3.1. The framework for analyzing data

Based on a recent study, there is a diagram available that showcases a sequential framework. This framework examines the underlying reasons behind project delays, depicted in **Figure 1**.

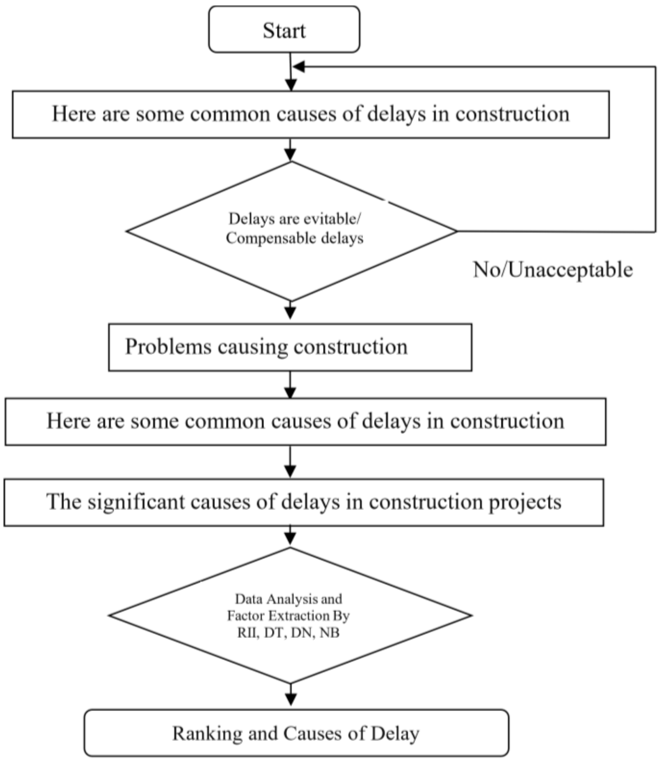

Figure 1. The framework for examining the underlying reasons behind project delays.

Step 1 of the construction project analysis involves data analysis. In Step 2, the factors that cause delays and damages in various aspects affecting individuals at different levels are studied. These factors include project management, work control, and operational and labor levels. Apart from the factors causing delays, delays in construction projects can stem from various sources that impact the project duration. All parties, including contractors, project managers, and owners, can contribute to the delays. Delays caused by construction contractors can be related to materials, money, workforce, machinery, and management. These factors have ripple effects on other aspects. Causes of delays stemming from the construction contractor's management include material shortages, which can arise from various causes (Poontan, 2012). In Step 3 problems are categorized based on compensation or construction time extension, apart from the earlier delays. They can be divided into two groups. These groups include issues that cause construction delays requiring compensation or contract extension by the employer or project owner. Step 4 involves analyzing the problems that cause construction delays that require compensation or contract extensions by the contractor. These problems include conflicting details in the construction drawings, delay in payment disbursement as per schedule, issuance of change orders altering construction drawing details, and delay in the approval of construction drawings. Step 5 highlights that the fundamental causes of construction project delays in each country vary across research reports.

Nonetheless, the significant causes of construction project delays are related to project owners, contractors, or project managers. Therefore, the considerable causes of construction project delays still need further investigation and research. This is within the context of differing circumstances, including varying project formats, especially those of government or public sector construction projects with complex regulations or requirements. Showing the prioritized sequence of the top 5 causes from 43 research reports, financial issues, specifically payment disbursement, cash flow, and project owner's budget, is the most prevalent cause of construction project delays (Apolot, 2011; Koushki et al., 2005; Khabisi et al., 2016; Rachid et al., 2019; Tafazzoli and Shrestha, 2017; Vacanas and Danezis, 2021). In Step 6, causes are ranked according to their relationship with contractors, project owners, project managers, and external factors, excluding the least prioritized causes of delays. The highest-ranked causes will then be used as the factors to study the following importance index (Amoatey and Ankrah, 2017; Bajjou and Chafi, 2020; Choudhry et al., 2014; Larsen et al., 2016; Shah et al., 2021; Srdic and Šelih, 2015). Finally, in Step 7, the factors contributing to project delays are analyzed by selecting each group's most frequently encountered causes. This analysis uses the Relative Importance Index (RII) technique in state construction projects.

3.2. Analysis of data from survey questionnaires

The article under consideration has employed survey questionnaire techniques to investigate the leading causes of delays in public construction projects based on the data obtained from the survey above. The research has gathered quantitative data from individuals directly involved in public construction projects. The study employed a purposive sampling method to select the sample group. The sample group consists of

30 public construction projects, and a total of 380 respondents have participated in the study, including state procurement officials, procurement inspection committee members, state agency project supervisors, contractors, and project management consultants. The questionnaire used in this research has been designed to collect foundational data for research investigation. It has enabled the respondents to express their opinions on the causes of delays in public construction projects based on their experience, construction budget estimates, and judgments. The survey questionnaire has been structured based on the identified causes of delays in public construction projects derived from the literature review. The questionnaire has been divided into two parts, which include general organizational information and causes of delays categorized into four groups: causes of delays from the client group, causes of delays from the contractor group, causes of delays from the project management group, and causes of delays from external factors. Before distribution, the questionnaire was validated by experts for content validation, ensuring the accuracy and clarity of sentences in sequence. While a questionnaire survey has been conducted to evaluate the reliability or validity of the survey questionnaire regarding construction delay causes, it is essential to analyze the collected data using Cronbach's Alpha method, which is crucial for this study (Cronbach, 1951). This can be done using Equation (1) below to compute Cronbach's alpha (Cronbach, 1951).

Cronbach's alpha,

$$\alpha = \frac{k}{k-1}\left[1 \frac{\sum \mathrm{V}_i 2}{\mathrm{V}_i 2}\right] \tag{1}$$

where K is the number of items being observed. It takes into account the variance of scores within each item, denoted by V_i, as well as the variance of scores across all observed items, represented by V_x. SPSS is used to perform statistical analysis and evaluate the reliability of survey questions. Specifically, version 22 of the software allows for calculating Cronbach's alpha reliability coefficient, which measures the internal consistency of survey questions. In addition, the software provides the option to specify coefficients to ensure that the data is consistent and the analysis results are reliable.

This particular study aims to evaluate and prioritize the reasons behind delays in innovative projects related to the public sector's construction domain. To accomplish this, the researchers have opted to utilize the Relative Importance Index (RII) analysis method, which has been deemed appropriate and effective in previous studies (Arantes et al., 2015; Bajjou and Chafi, 2020; Durdyev et al., 2017; Khatib et al., 2020; Sanni-Anibire et al., 2020). The method used to collect data for the analysis involved gathering responses through a questionnaire from multiple groups. The questionnaire responses were then assigned an average score to represent the scoring of each participating group. The calculations for the analysis were carried out using the RII formula as described in Equation (2) (Elhusseiny, et al., 2021).

Relative importance index,

$$\mathrm{RII} = \frac{\sum w}{A \times N} \tag{2}$$

In this study, the scores respondents assign to each cause are represented by the variable W. The importance level of each cause is indicated by a numerical value, where 5 represents the highest importance level, 4 indicates high importance, 3 indicates moderate significance, 2 indicates low importance, and 1 indicates the lowest importance level. Variable *A* represents the maximum weight assigned to each cause, set at 5 for this study. Finally, the total number of samples used in the study is defined by the variable *N*, which equals 380.

This research project has been approved in compliance with Mahasarakham University's ethical guidelines and standards for conducting reputable academic research. Before completing the questionnaire, the participants were informed verbally and in writing about the purpose of the study and provided their consent. The participants were informed that their participation in the research survey was voluntary and that they were free to decline participation without any consequences. They were also informed about the confidentiality of their responses and assured that their answers would not be disclosed to any third party.

4. Results and discussion

4.1. Survey questions

The researchers conducted a survey questionnaire comprising 380 sets, distributed to a select group of individuals associated with state construction projects. The sample group was chosen based on targeted sampling, including only delayed projects. The 30 chosen projects were categorized into four groups based on the reasons for delays in the state construction work: employers, contractors, project supervisors, and external factors. The researchers used proportional sampling from the total sample group size of 38,000 individuals, resulting in 380 respondents divided equally among the four groups. The survey was conducted in three rounds, with 150 responses received in the first round, 160 reactions in the second round, and 70 responses in the third round, resulting in a 100% response rate from the sample group. This response rate is considered acceptable for the analysis and reporting of this research (Woodside and Miller, 1993).

4.2. Cronbach's alpha reliability testing

Cronbach's alpha coefficient was used to scrutinize the data to ensure the accuracy of the survey findings. This statistical measure was employed to evaluate the consistency of the respondents' answers. The study used proportional standards to assess the reliability of the data. The four groups that were identified as having an impact on construction delays were analyzed to obtain the results of the reliability testing. Additionally, the internal consistency of the construction delays was assessed using Cronbach's alpha coefficient, obtained from **Table 3**.

The results of Cronbach's alpha reliability test for project delay in state construction projects among four groups are presented in **Table 4**. The questionnaire designed to test the reliability of external factors related to project delays shows that respondents have an excellent confidence level, with internal consistency reliability coefficients of 0.801. This indicates that the delays caused by external factors are reported to have outstanding reliability. The reliability coefficients for delays associated with contractors, project owners, and project controllers are 0.785, 0.774, and 0.743, respectively. This suggests that the respondents report the delays related to contractors, project owners, and project controllers with equal reliability.

Table 3. Cronbach's alpha reliability coefficient consistency translation (Fashina et al., 2021).

S/N	Cronbach's alpha, α	Internal consistency
1	$\alpha \geq 0.8$	Excellent
2	$0.8 > \alpha \geq 0.7$	Good
3	$0.7 > \alpha \geq 0.5$	Satisfactory
4	$\alpha < 0.5$	Poor

Table 4. Cronbach's alpha reliability test results for the causes of delay in state construction projects across four groups.

Causes	Number of questions	Cronbach's alpha	Internal consistency
Delays caused by the contractor group	10	0.774	Good
Delays caused by the employer group	8	0.785	Good
Delays caused by the project manager group	5	0.743	Good
Delays caused by external factors group	5	0.801	Excellent

The study has found that external factors significantly cause delays in construction projects. The research shows that the delays attributed to contractors, project owners, and project controllers have been ranked excellently. Further data analysis revealed that these delays exhibit good internal consistency, as reflected in their respective Cronbach's alpha values of 0.785, 0.774, and 0.743. This suggests a consistent relationship among these entities. The reliability test results for all 28 items related to delay causes indicate excellent internal consistency, with Cronbach's alpha coefficient at 0.849. This suggests that the respondents to the questionnaire items about all 28 delay causes have exhibited outstanding reliability to the extent that 84.9% of the variance in the responses can be attributed to the delay causes. Overall, the findings suggest that the data about all four delay causes are reliable, consistent, and trustworthy, and these factors significantly affect delays in construction projects.

4.3. Analysis of the causes of delay in public sector construction projects

This particular research study aims to conduct a thorough analysis of the Relative Importance Index (RII) of the various factors that contribute to the delay in public sector construction projects. Moreover, the aim is to rank the importance of these delay causes. The ultimate goal of this research project is to utilize the research findings to analyze construction management practices within government agencies, contractors, and project controllers. This will be achieved by employing the RII technique to determine the Relative Importance Index and ranking for various delay causes. The data obtained through questionnaire responses will be thoroughly analyzed, and average scores representing the ratings of each group of participants will be determined, which will aid in obtaining a clearer understanding of the causes of delay. These calculations will be conducted using the RII technique. The 28 items related to construction delay causes will be categorized into four main groups for this research study. Before discussing the analysis results, the ranked causes within each item based on the RII and average scores will be presented. The degree of delay for each RII ranking will be categorized according to the classification table of RII, as shown in **Table 5**. This comprehensive analysis will provide valuable insights into the various factors contributing to the delay in public sector construction projects, and the findings can be implemented to improve construction management practices within government agencies, contractors, and project controllers.

Table 5. Classification of RII categories.

Proportional scale	Level of delay	RI
1	Very low	0.0 ≤ RII ≤ 0.2
2	Low	0.2 ≤ RII ≤ 0.4
3	Average	0.4 ≤ RII ≤ 0.6
4	High	0.6 ≤ RII ≤ 0.8
5	Very high	0.8 ≤ RII ≤ 1.0

4.4. Analysis of the survey of delay causes related to each item

The analysis of survey data on the causes of delays for each item in a case study that included 28 items is presented in **Table 4**. The table shows how various factors cause delays, with RII values ranging from 0 to 1. Higher RII values indicate greater significance. By examining the RII results, each characteristic can be assigned relative rankings. According to the data provided by Akogbe et al. in 2013, the top three most significant delays, each with a score exceeding 0.7, are financial problems of contractors, labor-related issues, and changes in orders, item lists, or additional work during construction from the employer. Financial problems of contractors are ranked 1st, with an RII of 0.777 and a weighted score of 84.44%. This shows a high level of delay caused by financial problems that contractors encounter. Labor-related problems are ranked 2nd, with an RII of 0.733 and a weighted score of 82.78%. This also shows that the employer is ranked 3rd, with an RII of 0.723 and a weighted score of 80.56%. This demonstrates a high level of delay caused by changes or additional work requested by the employer during the construction phase. The analysis of construction project delay results on an individual cause delay basis is presented in **Table 6**.

Table 6. Analysis results of delays caused in construction projects for individual factors.

Delay Cause	Weight (*W*)	Relative Importance Index (RII)	RI	Ranking
Financial problems of contractors	84.44%	0.777	High	1
Labor-related problems	82.78%	0.733	High	2
Changes in orders, item lists, or additional work during construction	80.56%	0.723	High	3
Issues related to delayed availability of materials, equipment, and procurement	78.89%	0.719	High	4
Design-related problems by the employer	80.00%	0.719	High	4
Poor communication and coordination between construction management	78.33%	0.712	High	5
Unstable economic conditions leading to financial flexibility issues	78.33%	0.712	High	5
Inefficient planning and allocation of construction schedule	79.44%	0.706	High	6

Table 6. (*Continued*).

Delay Cause	Weight (*W*)	Relative Importance Index (RII)	RI	Ranking
Problems with subcontractors that the contractor cannot control during construction, such as construction skills or work shortages	77.22%	0.700	High	7
Incorrect estimation of project expenses by the contractor	73.33%	0.699	High	8
Inexperienced contractors or subcontractors lead to poor quality construction	76.67%	0.698	High	9
Employer's minimum price criteria for winning bids, bid submission	76.67%	0.696	High	10
Lack of experience in construction management	77.22%	0.696	High	10
Inadequate pre-construction site inspection and submission of work proposals by the contractor	77.88%	0.694	High	11
Inflation, differences in material prices from bid submission prices	71.67%	0.688	High	12
Employer's decision-making in ordering delays	72.78%	0.688	High	12
Contract-related issues during construction	70.56%	0.685	High	13
Inadequate supervision and monitoring during construction by the contractor	71.11%	0.682	High	14
Complexity of construction work leading to delays by supervisors	71.11%	0.678	High	15
Lack of training, knowledge development, and consistent control abilities in construction management	73.89%	0.676	High	16
Inconsistent quality control adversely affects construction projects, leading to delays.	77.22%	0.675	High	17
Employer's late handover of construction sites	70.56%	0.674	High	18
Approvals and permits delayed by the employer, such as material approval for construction site entry	72.78%	0.672	High	19
Dependency relationships between supervisors towards the employer and contractors	71.67%	0.663	High	20
Unstable project and construction site management	72.22%	0.659	High	21
Employer's selection of work team, evaluation before contracting	70.00%	0.647	High	22
Natural disasters and uncontrollable weather affecting construction work	71.11%	0.641	High	23
Political situations or crises affecting construction	71.11%	0.639	High	24

4.5. Analysis results of delay caused by the contractor group

The analysis of the delay results caused by the contractor group, which highlights the key factors responsible for delays in construction projects is shown in **Table 7**. The highest-rated cause of delay is attributed to the financial problems faced by contractors, with an RII (Relative Importance Index) value of 0.777 and a weight of 84.44%. This indicates that economic issues are a significant factor that leads to project delays. The second-ranked issue is labor-related problems, with an RII of 0.733 and a weight of 82.78%. This suggests that labor shortages or inefficiencies in the workforce can also contribute to project delays. The third-ranked problem is the delayed availability of materials and equipment required for construction operations, with an RII of 0.719 and a weight of 80.00%. This indicates that the timely availability of materials and equipment is crucial to ensure timely project completion. All these issues are considered high-level delays that can significantly impact project timelines and budgets. Inefficient construction operations planning and scheduling also contribute significantly to project delays, with an RII of 0.706 and a weight of 79.44%. This suggests that proper planning and scheduling of construction activities are essential to ensure that the project progresses as per the planned timeline. Overall, the data indicates that financial issues, labor problems, delayed availability of materials and equipment, and inefficient planning and scheduling are the significant factors that lead to project delays.

Table 7. Analysis of the results of the delay caused by the contractor group.

Delay cause	Weight (*W*)	Relative Importance Index (RII)	RI	Ranking
Financial problems of contractors	84.44%	0.777	High	1
Labor-related problems	82.78%	0.733	High	2
Issues related to delayed availability of materials, equipment, and procurement	80.00%	0.719	High	3
Inefficient planning and allocation of construction schedule	79.44%	0.706	High	4
Problems with subcontractors that the contractor cannot control during construction, such as construction skills or work shortages	77.22%	0.700	High	5
Incorrect estimation of project expenses by the contractor	73.33%	0.699	High	6
Inexperienced contractors or subcontractors lead to poor-quality construction	76.67%	0.698	High	7
Inadequate pre-construction site inspection and submission of work proposals by the contractor	77.78%	0.694	High	8
Inadequate supervision and monitoring during construction by the contractor	71.11%	0.682	High	9
Unstable project and construction site management	72.22%	0.659	High	10

4.6. Analysis results of delay caused by the employer group

According to the data provided in **Table 8**, the highest-rated cause of delay is attributed to the changes in orders, item lists, or additional work during the construction phase, with an RII (Relative Importance Index) value of 0.723 and a weightage of 80.56%. The delay caused by employer design issues, such as conflicting

Table 8. Analysis results of delay caused by the employer group.

Delay cause	Weight (*W*)	Relative Importance Index (RII)	RI	Ranking
Changes in orders, item lists, or additional work during construction	80.56%	0.723	High	1
Design-related problems by the employer	78.89%	0.719	High	2
Employer’s minimum price criteria for winning bids, bid submission	76.67%	0.696	High	3
Approvals and permits delayed by the employer, such as material approval for construction site entry	72.78%	0.672	High	4
Employer’s decision-making in ordering delays	72.78%	0.688	High	5
Contract-related issues during construction	70.56%	0.685	High	6
Employer’s late handover of construction sites	70.00%	0.674	High	7
Approvals and permits delayed by the employer, such as material approval for construction site entry	72.78%	0.672	High	8

or conflicting work quantities, has been rated as the second most significant cause, with an RII of 0.719 and a weightage of 78.89%. The third highest-rated cause of delay is setting the lowest bid criteria for winning bids, with an RII of 0.696 and a weightage of 76.67%. Additionally, the delays caused by approvals and permits for contractors to proceed, such as requesting material approval for construction site entry, have been rated as a significant cause of delay with an RII of 0.672 and a weightage of 72.78%. All these causes, as revealed by the respondents, have been rated as significantly contributing to delays in a construction project and require careful consideration to ensure timely completion.

4.7. Analysis results of delay caused by the project manager group

According to the data in **Table 8**, the highest-rated delay causes were changes in orders, product lists, or additional work during the construction process, with an RII (Relative Importance Index) value of 0.723 and Weight of 80.56%. Delays are caused by employer design problems, such as inconsistent or conflicting workloads. It is ranked as the second most important cause, with an RII of 0.719 and a weight of 78.89%. The third most important cause of delay is setting a minimum bid threshold for winning bids with an RII. equal to 0.696 and weight 76.67%. The contractor performs actions such as requesting approval of materials for entering the construction site. It was rated as the leading cause of delay with an RII of 0.672 and a weight of 72.78%. In addition, delays caused by supervisors lacking training, knowledge development, and ability to control construction work regularly have an RII value of 0.676 and weight equal to 73.89% and approval and permission (see **Table 9**). All these causes, as revealed by the respondents, have been rated as a critical contributors to delays in construction projects and require careful consideration to ensure timely completion.

Table 9. Analysis of the results of the delay caused by the project manager group.

Delay cause	**Weight (*W*)**	**Relative Importance Index (RII)**	**RI**	**Ranking**
Poor communication and coordination between construction management	78.33%	0.712	High	1
Lack of experience in construction management	77.22%	0.696	High	2
Complexity of construction work leading to delays by supervisors	71.11%	0.678	High	3
Lack of training, knowledge development, and consistent control abilities in construction management	73.89%	0.676	High	4
Dependency relationships between supervisors towards the employer and contractors	71.67%	0.663	High	5

4.8. Analysis results of delay caused by external factors group

The survey analysis report on external factors contributing to delays is presented in **Table 10**. The findings reveal that unstable economic conditions leading to financial flexibility issues are the top-ranked cause of delay, with an RII (Relative Importance Index) value of 0.712 and a weight of 78.33%. This means that this factor has the highest impact on delays and is considered the most critical issue faced by the construction industry. The second-ranked cause is inflation and differences in material prices from bid submission prices, with an RII of 0.688 and a weight of 71.67%. This factor highlights the importance of accurate estimating and procurement of materials to avoid cost overruns. Lastly, the third-ranked cause is inconsistent quality control, resulting in construction delays, with an RII of 0.675 and a weight of 77.22%. This factor emphasizes the need for effective quality management practices and the importance of maintaining consistency in quality control measures. All of these factors contribute significantly to delays and should be addressed to ensure timely completion of construction projects.

Table 10. Analysis results of delay caused by external factors group.

Delay cause	Weight (*W*)	Relative Importance Index (RII)	RI	Ranking
Unstable economic conditions leading to financial flexibility issues	78.33%	0.712	High	1
Inflation, differences in material prices from bid submission prices	71.67%	0.688	High	2
Inconsistent quality control adversely affects construction projects, leading to delays.	77.22	0.675	High	3
Natural disasters, and uncontrollable weather affecting construction work	71.11%	0.641	High	4
Political situations or crises affecting construction	71.67%	0.639	High	5

5. Machine learning

In recent years, more research has been done on predicting delay factors in public-sector construction. However, many researchers are using the strategy to build stock options and become a way for people to profit from construction. It is the most common financial investment and attracts many investors from around the world (Wang and Yan, 2023; Yan et al., 2023). there is still a need for a prediction tool that can accurately forecast delays over various periods. To address this gap, our research team has developed a prediction tool that uses data mining techniques such as Neural Network, Naïve Bayes, and Decision Tree (Chamidah et al., 2020). By analyzing a wide range of data, we hope to provide practical confirmation of how variable data selection can impact forecast performance and offer valid generalizations for improving forecasting accuracy (Arena et al., 2021). Our research focuses on developing holistic machine learning systems that can use data mining techniques to predict delays in government construction work. We aim to create a set of learning machines that can work together to enhance overall system performance. Combining appropriate classifier sets for each forecasting challenge often results in better prediction rates than using a single classifier (Antoniou et al., 2023). Although there are no established standards for the accuracy of a single model in all contexts, current research in construction delay prediction has shown promising results using machine learning techniques. We aim to continue building upon this research to create a more accurate prediction tool that can help improve construction project management and avoid costly delays.

5.1. Naïve Bayes (NB)

Naïve Bayes (NB) is a well-known probabilistic classification algorithm. It is a simple but efficient algorithm with a wide variety of real-world applications, ranging from product recommendations through medical diagnosis to controlling autonomous vehicles. Due to the failure of real data to satisfy the assumptions of NB, there are available variations of NB to cater to general data. With the unique applications for each variation of NB, they reach different levels of accuracy. This manuscript surveys the latest applications of NB and discusses its variations in different settings.

Furthermore, recommendations are made regarding NB's applicability while exploring the algorithm's robustness. Finally, an attempt is made to discuss the pros and cons of the NB algorithm and some vulnerabilities with related computing code for implementation.

Let $X_1, X_2, \ldots, X_n$ be an n-dimensional vector of random variables (features) form a domain D_x, and $X_1, X_2, \ldots, X_n$ be their corresponding instances. Let Y be an unobserved random variable from domain D_Y = 0, 1. Though it is unknown, let's assume that there is a function from D_X to D_Y. The aim is to estimate the target value y_i of Y for a given instance x_i of X. In other words, the aim is to select the class Y that maximizes the posterior probability, $P(Y = y|X = x)$. $P(Y = y)$ and $P(X = x|Y = y)$ are prior and class conditional probabilities. As the NB assumes conditional independence, $P(X_1 = x_1, X_2 = x_2, .., X_n = x_n|Y = y) = \prod_{i=1}^{n} P(X = x_i|Y = y)$. Let C be the number of classes of Y. According to Bayes' theorem, the function is Equation (3).

$$\begin{aligned} &P(Y = y|X = x) \\ &= \frac{P(Y = y, X = x)}{P(X = x)} \\ &= \frac{P(Y = y)P(X = x|Y = y)}{P(X = x)} \\ &= \frac{P(Y = y)P(X_1 = x_1, X_2 = x_2, \ldots, X_n = x_n|Y = y)}{\sum_i^c P(y_i, X = x)} \\ &= \frac{P(Y = y)\prod_{i=1}^{n} P(X = x_i|Y = y)}{\sum_i^C P(y_i, X = x)} \end{aligned} \tag{3}$$

In practice, it is not interested in the $P(X = x)$. Instead of estimating $P(X = x)$, it is normalized in order to have the $P(Y = y|X = x) = 1$. Usually, from a practical point of view, $P(X = x|Y = y)$ is assumed to follow a Gaussian distribution, though the literature shows some exceptions (George et al., (1995). replace the flexible Gaussian assumption with a kernel density estimation. In addition to the above Gaussian assumption, one of the main assumptions is that the value of any given feature is dependent on the value of any other feature. There are different opinions about the practicality of this assumption, which has made the algorithm more viable. Moreover, one can exploit the Naive assumption to speed up the execution of the algorithm. For example, attribute probabilities can be calculated in parallel using different CPUs, machines, or clusters in the real-world deployment of NB-based applications.

This success of the NB algorithm has motivated the research community to search for variations of NB (Langley and Sage, 1994; Kononenko, 1991; Pazzani, 1996).

5.2. Decision Trees (DT)

Decision tree regression is a highly effective method for forecasting numerical values. It works by partitioning the dataset into subsets based on the features' values, constructing a tree-shaped model. This type of decision tree is excellent for elucidating the different elements that influence the expected numerical outcomes. Additionally, decision trees for regression are beneficial in various applications. However, to ensure strong generalization performance and manage model complexity, pruning techniques, and hyperparameter tuning are frequently used to avoid overfitting. The algorithm follows a systematic approach that begins with the root node, representing the modal features of the structure from the initial study and creates a subtree structure to assess potential harm.

5.3. Hyperparameter setting

Some parameters need to be adjusted to effectively use the clustering algorithm based on the proposed objective function optimization for the accuracy of the evaluation model using a 70:30 test split. Where 70% of the dataset is used for training and 30% for testing. The test data were used to adjust the hyperparameters of the model.

1) From our experiment, we found that changing Deep Learning parameters requires setting the following parameters: Number of fold = 10, Sampling type linear sampling, Use local random seed, hidden layer size 70/30, Criterion = Profit and Loss, $L1 = 1.0 \times 10^{-5}$, $L2 = 0.1$, and Max $w2 = 10.0$.
2) We have adjusted the parameters for the Neural Network algorithm to ensure an efficient comparison. The hidden layer sizes are set to 2; training cycles are set to 200, learning rate = 0.01, and momentum = 0.9.
3) The parameters for the Decision Tree algorithm were also adjusted, with the criterion set to gain ratio, maximal depth set to 10, confidence set to 0.1, minimal gain set to 0.01, minimal leaf size set to 2, and minimal size for spilled.
4) Lastly, the parameters are adjusted for the Naïve Bayes algorithm by setting the number of folds to 10, the Sampling type to automatic, and selecting Use local random seed and Laplace correction, respectively. Tuning parameters is crucial in choosing the appropriate size for these algorithms. By considering these parameters and taking these factors into account, we can achieve the best performance when using a clustering algorithm based on optimizing the objective function for setting the parameters of the algorithm.

5.4. Comparative of all algorithms for relative importance index

The following section provides a detailed analysis of the modeling results and subsequent training conducted with the preprocessed dataset. The objective was to study delays in public construction projects by collecting and analyzing data to prioritize and categorize delay-causing factors using machine learning models. To achieve this, four machine learning algorithms, namely Deep Learning, Neural Networks, Decision trees, and Naïve Bayes, were compared based on their performance and detailed Relative Importance Index results. The parameters were significantly changed to provide a comprehensive understanding of the results. In addition, a detailed analytical perspective was provided on the experimental environment used in each study. The aim was to offer a clear and concise assessment of the performance of machine learning models to help make informed decisions for future research. The accuracy of each model was measured to evaluate its effectiveness, and a comparison was made using the Relative Importance Index (RII) values, as shown in **Table 11**. The results presented in **Table 11** indicate that the DL model was identified as the best-performing baseline model, with an accuracy of 90.79%. The NN model also performed well, with an accuracy of 90.26%, while the DT model had an accuracy of 85.26%. However, the NB model had the lowest accuracy of 68.68%. The highest value of RII was 77.70%, indicating the effectiveness of the machine learning models in identifying and categorizing the factors that cause delays in public construction projects. Overall, this study provides valuable insights into the effectiveness of various machine learning models and their potential applications in public construction projects.

Table 11. A comparison of all algorithms for the Relative Importance Index.

Results	Deep learning			Neural network			Decision tree			Delay cause	Naïve Bayes		
	True yes	**True no**	**% Class**	**True yes**	**True no**	**% Class**	**True yes**	**True no**	**% Class**		**True yes**	**True no**	**% Class**
Pred. yes	230	16	92.50	236	24	90.77	235	42	84.84	Relative Importance Index (RII)	198	68	74.44
Pred. no	19	115	85.82	13	107	89.17	14	89	86.41		51	63	55.26
Class recall (%)	92.37	87.79	-	94.78	81.68	-	94.38	67.94	-		79.52	48.09	-
Accuracy (%)	90.79 (+/−6.36)			90.26 (+/−7.85)			85.26 (+/−6.23)			77.70%	68.68 (+/−7.49)		
Recall (%)	92.40			94.80			94.37			-	79.50		
Precision (%)	93.86			91.14			85.09			-	75.20		
F-measure (%)	90.43			92.88			89.37			-	76.90		

6. Discussion

This research paper compares the RII method and four machine learning algorithms; DT, DL, NN, and NB classifiers—to determine the most effective method for identifying construction project delays. The study explores various algorithms such as artificial neural networks, naive Bayes, and decision trees with attribute selection. Among these algorithms, the DL model emerged as the best-performing baseline model, with an accuracy of 90.79%. The NN model demonstrated an accuracy of 90.26%, while the DT model had an accuracy of 85.26%. Conversely, the RII method had an accuracy value of 77.70%, and the NB model had an accuracy of 68.68%. The study provides a comprehensive comparison of all algorithms for course delay. Furthermore, the research paper examines the causes of construction project delays using the RII method and evaluates 28 factors. The study ranks the factors into four groups based on their level of importance, with the most significant cause of delays being financial issues among contractors. The second most critical factor was the availability of labor, particularly during harvesting seasons (RII = 0.733), which contributed to delays by 82.78%. The third most important factor was alterations in orders, specifications, or additional tasks during construction (RII = 0.723), leading to delays of 80.56%. This indicates that financial issues among contractors have the most significant impact on project delays in state construction projects and are crucial factors that need to be addressed to enhance the management of such projects (Akogbe et al., 2013; Mahamid, 2013; Mohamad Zin and Olatunji, 2022; Sweis et al., 2008). According to the research findings, another significant cause of construction project delays is the readiness of materials and equipment required by contractors for project execution. Delays resulting from changes in orders, specifications, or additional work during construction also contribute to project timeline extensions beyond the planned schedule. The respondents' opinions align with these findings, which are consistent with previous studies conducted by Assaf and Al-Hejji (2006); Apolot (2011); Aigbavboa et al. (2016); Fallahnejad (2013); Hossain et al. (2022); Toufik and

Mohammed (2019). When separating delays into four groups, respondents perceive the following:

1) According to recent research conducted by Gurdamar (2016), financial issues among contractors remain the primary cause of delays in contractor groups, followed by labor-related problems and issues with materials and equipment readiness. These findings are consistent with the concept presented by Akogbe (2013) and suggest that contractor delays are often linked to financial liquidity, labor concerns, and the timely preparedness of materials and equipment before commencing work.
2) According to the employers' group, the respondents unanimously agreed that the most significant cause of delays in construction projects is the changes in orders, specifications, or additional work during the construction phase. This is closely followed by problems related to the employer's design and setting minimum price criteria for bidding. It is evident that employers' requirements for changes in orders, specifications, and additional work during construction significantly affect the construction timeline. Employers should carefully examine the designs before placing orders and issuing tenders. This step is crucial to ensure the design's accuracy and completeness and avoid future issues. Understanding the employers' requirements for issuing orders is of utmost importance, and it aligns with the recommendations of several studies. In developing countries, they are unable to adapt to rapidly changing environments. Due to a lack of adaptability skills or ability to deal with global change, we cannot compete quickly with the world's leading edge due to many factors, such as economic conditions, resources, and individual expertise. The primary objective of the hiring organization is to effectively manage work and communicate with each other to achieve their goals collectively. The coordinating agent in managing the team is considered an essential part that can be managed to prevent conflicts. If there are conflicting attitudes and behaviors between managers and workers and between groups, people with different attitudes face conflicts in professional environments, including Arantes et al. (2015), Farooq et al. (2019), Hossain et al. (2022), Kadry et al. (2017), Khtar et al. (2020) and Mahamid (2012).
3) The project management group recently conducted a study to determine the primary causes of delays attributed to project managers in construction projects. The study revealed that the most significant cause of delays is a need for more communication and coordination among the various construction parties involved. This finding suggests that effective construction management requires excellent communication skills and effective coordination with all relevant parties. Furthermore, the study found that a lack of experience in construction management and the complexity of construction tasks also contribute to project delays. Project managers must have the expertise to control complex construction tasks to ensure timely completion. The study's findings are consistent with those of several experts in the field of construction management. Agencies with funding limitations received pressure from stakeholders on responsibility, transparency, and efficient use of resources. There is a need to learn from the business side and implement strategies to address inefficiencies in resource use. Logistics and supply chain management are essential parts of relief budget

management. Therefore, it must be managed effectively and efficiently. Every type of employment training has a clear impact on employees. Organizations want the best results from their employees. It is something that training must be addressed—the more careful and dedicated. With frequent employee training, the organization will receive the evolving mindset of its employees. This will produce outstanding and long-lasting results. There is no doubt that training is the first step an organization must complete to get the results it wants from its employees. Including Chen et al. (2019), Kashif et al. (2020), Muhwezi et al. (2014), Shafiq and Soratana (2019), Vacanas and Danezis (2021).

4) According to the feedback received in the survey, the primary reason for delays caused by external factors is the unstable economic conditions that lead to financial instability. This finding suggests that economic conditions, national finances, and quality control play a crucial role in determining the impact of external factors on construction timelines. Additionally, inflation, material price fluctuations that differ from those quoted during bidding, and inadequate quality control are other significant contributors to construction delays. Notably, these observations align with the research works of Choudhry and Iqbal (2013), Samarghandi et al. (2016), and Shah et al. (2021).

7. Conclusion

This research aimed to identify the causes of delays in public construction projects. The researchers conducted a targeted sampling of 30 public construction projects that had experienced delays and categorized the causes into four groups: the client, the contractor, the project manager, and external factors. To determine the importance of each cause, the researchers used the Relative Importance Index (RII), which enabled them to rank and weight each cause. They distributed questionnaires to relevant stakeholders directly involved in the projects to collect data. In this work, the researchers compared the performance of four machine learning methods and the RII, including decision trees, deep learning, artificial neural networks, and naive Bayes classifiers. They found that the deep learning model was the best-performing baseline model. The study showed that financial problems encountered by contractors were the leading cause of delays, followed by labor shortages and changes in project instructions, specifications, or additional work requested by the client. These factors impacted project timelines, indicating that project success depends on the contractor's financial flexibility to effectively manage operations, including labor procurement. Effective communication and agreement with relevant parties regarding additional work orders are crucial for clients. Moreover, decision-making timeframes must be considered, as excessive client demands can prolong construction and extend project timelines beyond expectations. It is worth noting that the significant causes of construction project delays vary across research studies and are influenced by factors such as the country, project owner, contractor, or project manager. Therefore, further research is needed to study the fundamental causes of delays in construction projects in each country in different contexts. It is also important to study different project formats, especially those of government or public sector construction projects, which may have complex regulations or requirements.

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