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Research Paper Open Access

Development of a Data-Driven Performance Evaluation Framework for Identifying Inefficiencies in Traditional Construction Project Management Systems

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Abstract
The complexity of construction projects is growing because of numerous stakeholders involved, uncertainties in working environments, and necessity of coordination between different planning, scheduling, safety, communication, and resource management activities. Conventional methods of managing construction projects mostly rely upon empirical decision-making and routine monitoring that led to delays in work, increased costs, inefficient use of resources, and poor performances. The main objectives of this study are to identify problems and inefficiencies of traditional construction project management systems and to suggest a new framework for evaluating their performances based on statistical data. The study utilizes a quantitative research design where questionnaires were sent to 200 construction workers including project managers, site engineers, constructors, consultants, and supervisors. The questionnaire was structured according to five important management dimensions: planning, scheduling, safety monitoring, communication, and resource management. The collected data set was analyzed by means of reliability assessment, descriptive statistics, Relative Importance Index (RII), Principal Component Analysis (PCA), correlation, and regression. Reliability assessment of the evaluation framework proved high reliability due to obtaining a Cronbach's Alpha score equal to 0.92. According to the obtained results, unrealistically tight scheduling (RII = 0.90), lack of materials (RII = 0.90), poor planning (RII = 0.88), and delayed information exchange (RII = 0.88) are the most crucial sources of inefficiency. As a result of performing PCA, it can be said that four major factors account for 85.6% of the total variance, and failures related to planning and scheduling constitute 34.8%. Correlation analysis revealed high dependency between scheduling issues and delays (r = 0.86), as well as between problems related to resources and budget overruns (r = 0.81). Thus, the suggested performance evaluation framework involves statistical analysis to reveal important management obstacles. By implementing this method, construction industry players will be able to move from traditional management methods to evidence-based project performance improvement practices.

Keywords: Communication; Project Managers; Planning; Safety Monitoring; Resource; and Traditional Management

Introduction

Construction work is essential in the process of economic development, development of infrastructures, and changes in urban settings (Ekanayake et al., 2019). There are a lot of people involved in construction work, such as the owner, contractor, consultant, engineer, and worker (Hashimzai & Mohammadi, 2024). The successful completion of construction projects requires efficient management of activities such as planning, scheduling, resource allocation, safety control, communication, and performance measurement (Che Nen et al., 2020). However, although there is improvement in both the technology and the methods used in construction work, many projects fail because of inefficient project management (Galaz-Delgado et al., 2021).

Conventional construction project management is heavily reliant on manual planning, experience-based decisions, intermittent monitoring, and piecemeal communications (Africa & Sachs, 2016). Despite being extensively utilized, traditional approaches are deficient in real time information processing and prediction ability, as well as evaluation process (Henning & Wald, 2019). Decisions made by project managers are often based on their past experiences, thus failing to provide quantifiable results (Frimpong et al., 2003). This leaves much room for uncertainties in identifying possible risks during the construction process (Kamanga & Steyn, 2013). As the construction projects grow bigger, the disadvantages of conventional project management become increasingly apparent (Amoah et al., 2024).

Planning and scheduling have been found to be basic elements in achieving successful completion of construction projects (Adafin et al., 2020). Poor planning, inaccurate estimation of project duration, improper scheduling, and lack of proper risk assessment result into project delay and cost overruns (Ingle & Mahesh, 2022). The changes in design, ambiguity in project scope, and the absence of coordination among construction teams lead to complications associated with maintaining scheduled activities within most construction projects (Ika & Donnelly, 2017). Besides, inefficiency in the implementation of monitoring systems results into inability to identify any deviation from what is actually happening during project completion process compared to the project schedule (Mohagheghi & Lassenius, 2021).

The aspect of safety management becomes another key challenge that has been encountered during construction works (Mohammed & Syam Chambrelin, 2020). Construction environments are highly dynamic in nature, such that hazards continue changing with time during project execution (Musonda & Muya, 2011). Lack of proper safety management systems, including effective monitoring, accurate hazard identification, safety communication, and sufficient training lead to accidents and inefficiencies in construction performance by the work team members (Fashina et al., 2020a). Furthermore, poor communication channels affect decision-making processes and result into inefficiency within projects (Muhwezi et al., 2014).

The management inefficiencies associated with the available resources also play an important role in the success of a construction project (Rodrigues & Bowers, 1996). The availability and proper management of materials, labour, equipment, and funding will impact the efficiency and effectiveness of a construction project (Sambasivan & Soon, 2007). Management of resources may face challenges such as shortage of materials, labour problems, breakdown of equipment, wastage of materials, and many more (Ruqaishi & Bashir, 2015). This results in increasing the time and costs of the construction process (Lai et al., 2011). As a result, an efficient method should be developed for the identification of these inefficiencies related to resources (Wagner & Radujkovic, 2022).

Many researchers have attempted to address certain aspects of the construction process, and they have used various methods for assessing different aspects like delay analysis, safety risk analysis, and cost estimation in construction projects (Sepasgozar et al., 2019). However, a single model that would cover all these factors including planning and scheduling, safety risk, communication problems, and resource management issues in the construction projects is not yet developed (Leicht et al., 2020). Also, these conventional assessment methods are based on qualitative assessment without identifying any statistical relationship among management inefficiencies (Babalola et al., 2019).

In order to fill this research gap, the purpose of this study is to assess the existing inefficiencies and challenges in the traditional construction project management system via statistical analysis and project performance evaluation methods (Arantes et al., 2016; Park, 2005). This paper proposes an assessment framework by conducting survey among the experts in the construction industry and assessing the important factors related to management using reliability analysis, descriptive statistics, relative importance index (RII), factor analysis, correlation analysis and regression modelling (Fashina et al., 2021; Schoper, 2023). The proposed framework facilitates the identification of significant inefficiency factors and their impact on various performance factors such as time, cost, quality and safety (Ogunde et al., 2017; Che Nen et al., 2020).

What makes this study unique is that it considers various aspects of construction management inefficiencies within one performance evaluation framework (Moreno et al., 2024). Rather than analysing different inefficiencies separately, this paper proposes an assessment framework that analyses the joint impact of management factors such as planning, scheduling, safety management, communication and resource management (Lin et al., 2020). This research contributes to the existing body of knowledge about the significant construction project management barriers that are currently hindering efficient project execution (Serpella et al., 2014). Based on this research, construction projects can be managed more efficiently compared to experience-based traditional management approach (Li et al., 2018).

The aims of this research are, therefore, as follows: (i) to determine the challenges facing traditional construction project management, (ii) to assess the seriousness and significance of inefficiencies in the areas of planning, scheduling, safety, communication, and resources, (iii) to understand the connection between management challenges and project performance, and (iv) to establish a framework for the evaluation of project performance.

Literature Review

There is an increased level of difficulty associated with construction management processes owing to multiple stakeholders, changing environments, and coordination of many activities within projects. Traditional construction management methods rely on decision-making and monitoring based on personal experiences, as well as using standard planning methods. This practice creates numerous difficulties in project management in terms of project control, risk management, communication, and resources management. Increased complexity of construction projects demonstrates the need for the implementation of a systematic evaluation process, which would allow identifying weaknesses in the management processes and increasing their effectiveness (Ogunde et al., 2017). Another important trend is the introduction of the concept of projectification that highlights the need for efficient planning and project control practices to achieve success in any business environment (Schoper, 2023).

Project delays and project cost overruns have been found to be one of the common results of poor construction project management. Planning, poor scheduling, poor risk analysis, and poor resource allocation can highly influence the timing and efficiency of the budget of the project. One topic that has become significant in recent times is delay analysis since construction projects usually suffer from gaps between scheduled and actual progress in many cases. The traditional ways of conducting delay analysis usually have a gap regarding the integration of multiple factors in evaluating the cause of project delays. A holistic approach towards delay analysis involving elements of project management is required in order to improve decision-making and reduce project risks (Sepasgozar et al., 2019). In the same manner, risk analysis during project development can play an important role in finding the possible effects on the budget and performance of the project (Adafin et al., 2020).

Safety management, communication, and coordination play vital roles in determining the outcome of construction projects. In the traditional construction setting, inadequate communication, poor coordination among stakeholders, and lack of monitoring processes could be the source of inefficiencies. For instance, developing nations encounter such issues as poor management system, little adoption of technology, and organizational impediments, which hinder sustainability in construction work. The construction industry has recognized managerial constraints, inadequate communication, and resource limitation as significant obstacles (Ogunde et al., 2017). Hence, proper coordination and systematic evaluation approaches must be considered for effective project operations.

Emerging innovations in digital technologies and artificial intelligence have enabled possibilities to mitigate weaknesses of traditional approaches to construction management. AI techniques can be useful in making predictive analysis, providing monitoring processes, assessing risks, and assisting in better decision-making. Project management with the help of AI tools has demonstrated great opportunities for improvement in planning efficiency, resource optimization, and better project control. Nevertheless, some problems connected with access to data and implementation of technology remain relevant for construction practices (Hashimzai & Mohammadi, 2024). As a possible solution, one could also consider alternative techniques for project management, like agile project management (Mohammed & Syam Chambrelin, 2020).

While there exist studies that explore the individual areas of inefficiency such as delay causes, risk assessment, digitization and management techniques, few studies have explored how various inefficiency factors can be integrated into a performance evaluation framework. The current evaluation techniques tend to look at each project problem on an individual basis without assessing the impact of various issues such as project planning, scheduling, safety issues, communication and resource management on the overall project performance. The impact of delayed implementation of better project management practices especially in the infrastructure industry makes it crucial for developing an enhanced performance evaluation framework (Wagner & Radujkovic, 2022).

Materials and Methods

Methodological Framework of the Research

The present research utilizes the quantitative research methodology to explore the problems and inefficiencies that exist in traditional construction project management systems. In particular, the developed methodology aims at assessing the impact of important management-related dimensions including planning, scheduling, safety control, communication management, and resource management on project effectiveness (Ekanayake et al., 2019). As construction project management involves a number of interacting factors, a structured research design was developed combining the methods of questionnaire data collection with statistical analysis procedures (Galaz-Delgado et al., 2021). The proposed methodology involves steps such as critical inefficiencies' identification, creation of the dataset of performance indicators, testing of the reliability of variables, ranking of major challenges, identification of factors, and relationship analysis between management activities and project results.

According to the research method, construction management issues and problems need to be recognized initially using thorough literature analysis and expert opinions (Fashina et al., 2021). Next, those parameters are converted into specific measurable variables using a Likert-type five-point scale questionnaire (Kamanga & Steyn, 2013). Finally, data will be analysed statistically employing descriptive statistics, measurement of the reliability, calculation of RII, PCA, correlation analysis, and regression modelling.

Construction Management Problem Survey Questionnaire Formulation

The main data source for this research is obtained from a structured questionnaire survey conducted among construction managers and other personnel involved in projects (Ingle & Mahesh, 2022). Respondents comprise project managers, site engineers, contractors, consultants, and supervisors with experience in construction project planning, control, and management. The questionnaire was formed based on significant factors that were considered in previous researches on construction delays, risk management, project control, and digitalization (Henning & Wald, 2019).

The questionnaire was composed of five main management problem areas including planning problem, scheduling problem, safety management problem, communication problem, and resources management problem (Hashimzai & Mohammadi, 2024). A rating system was applied to rate the effect of each management factor, and this rating system used a five-point Likert scale from 1 to 5, where 1 was defined as 'very low' and 5 as 'very high' (Babalola et al., 2019). The score of each management problem was calculated according to its effect (Africa & Sachs, 2016).

The collected dataset can be represented as:

$$D = \{X_1, X_2, X_3, \ldots, X_n, Y\} \quad \ldots 1$$

where D represents the construction management dataset, X_n represents independent management factors, and Y represents the project performance indicators (Fashina et al., 2020a).

The independent variables considered in this study are:

$$X = [X_p, X_s, X_{sa}, X_c, X_r] \quad \ldots 2$$

where: X_p= Planning inefficiency factor, X_s= Scheduling inefficiency factor, X_{sa}= Safety management factor, X_c= Communication management factor, X_r= Resource management factor. The dependent project performance variable is expressed as:

$$Y = f(X_p, X_s, X_{sa}, X_c, X_r) \quad \ldots 3$$

where Y indicates the overall construction project performance influenced by the identified management factors (Mohammed & Syam Chambrelin, 2020).

Measurement of Factors Leading to Inefficiencies in Construction Management

The inefficiency measure under planning inefficiencies looks at how efficient planning prior to the implementation of a construction project was (Mohagheghi & Lassenius, 2021). These factors include ineffective planning for projects, poor scope definition, poor risk analysis, designing changes, and ineffective decision-making processes (Musonda & Muya, 2011). The level of planning performance was measured through the efficiency of the project team in objective setting, activity allocation, and implementation of activities in the planned timeframe. Schedule inefficiencies are factors that affect effective project planning and timing.

Examples of schedule inefficiency include inaccurate duration estimate, ineffective activity sequencing, conflicting schedules, and poor monitoring of progress in the project. Schedule inefficiencies bring about discrepancies between planned and actual schedules resulting in delays (Ruqaishi & Bashir, 2015). Safety management inefficiencies are weaknesses in traditional safety monitoring measures. Factors analyzed here include poor training in safety procedures, hazard recognition deficiencies, unsafe working practices, and poor monitoring of accidents. Safety performance measures were chosen due to the changing nature of construction sites (Wagner & Radujkovic, 2022).

Communication efficiency is an aspect of information exchange inefficiency among project stakeholders. Information transfer delay, poor coordination, inadequate documentation, and inefficiencies in the feedback process were identified as communication variables (Sambasivan & Soon, 2007). Communication efficiency was vital to avoiding conflicts and timely decision-making. Resource efficiency measures how effectively resources during construction projects are managed. These include material availability, labour availability, equipment availability, and financial resources (Muhwezi et al., 2014). Issues such as lack of materials, labour, and efficient utilization of equipment and resources were highlighted.

Reliability Analysis

Prior to conducting any further analysis on the statistical data, it was important to ensure that the questionnaires were consistent in their answers (Sepasgozar et al., 2019). To do so, the Cronbach's alpha coefficient test was conducted to measure the internal consistency of the variables under the same management construct. Cronbach's alpha is calculated as:

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} \sigma_i^2}{\sigma_t^2}\right) \quad \ldots 4$$

where, α= Cronbach reliability coefficient, k= number of questionnaire items, σ_i^2= variance of individual items, σ_t^2= total variance of all items (Leicht et al., 2020). The reliability value greater than 0.7 indicates acceptable consistency, while values above 0.8 indicate strong reliability of the measurement framework.

Descriptive Statistical Analysis

Descriptive statistics were used to analyse the significance and frequency of each individual determinant (Frimpong et al., 2003). Mean and standard deviation were computed for every single determinant to ascertain the degree of inefficiency experienced in construction management processes.

The mean score was calculated as:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \quad \ldots 5$$

Where, $\bar{x}$= average response score, x_i= individual response value, n= total number of respondents. The standard deviation was calculated using:

$$SD = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} \quad \ldots 6$$

where SD represents the variation of responses around the average value (Amoah et al., 2024). A high mean value indicates that the factor has a significant influence on construction project inefficiency.

Relative Importance Index (RII) Analysis

Relative Importance Index analysis was performed to rank the identified construction management challenges according to their significance. This method is widely used in construction research because it converts qualitative responses into quantitative importance values.

The RII value is calculated as:

$$\mathrm{RII} = \frac{\sum W}{A \times N} \quad \text{...7}$$

Where, W= weighting assigned by respondents, A= highest possible weight (5 in this study), N= total number of respondents (Adafin et al., 2020). The obtained RII values range between 0 and 1. Higher RII values indicate higher priority challenges requiring improvement. Based on RII ranking, the most critical inefficiency factors affecting construction project performance were identified.

Principal Component Analysis (PCA)

PCA was used for dimensionality reduction and identification of key dimensions that affect the construction management (Moreno et al., 2024). The reason for using PCA is because there is a relationship between inefficiencies in the field of construction. The standardized dataset matrix is expressed as:

$$Z = \frac{X - \mu}{\sigma} \quad \text{...8}$$

Where, Zrepresents standardized values, Xrepresents original observations, μrepresents mean value, σrepresents standard deviation (Ogunde et al., 2017). The covariance matrix is calculated as:

$$C = \frac{1}{n-1} Z^{T} Z \quad \text{....9}$$

The eigenvalue decomposition is expressed as:

$$Cv = \lambda v \quad \text{...10}$$

Where, λ represents eigenvalues, v represents eigenvectors. The components with higher eigenvalues represent major sources of construction management inefficiency.

Correlation Analysis

A correlation analysis was conducted to assess the relationship between management inefficiency and measures for performance evaluation (Ika & Donnelly, 2017). Such an analysis reveals whether there is any influence of certain management problems on delays, cost, and poor quality. Pearson correlation coefficient was calculated using:

$$r = \frac{n\sum XY - (\sum X)(\sum Y)}{\sqrt{[n\sum X^2 - (\sum X)^2][n\sum Y^2 - (\sum Y)^2]}} \quad \text{...11}$$

Where, r= correlation coefficient, X= management factor, Y= project performance indicator. The value of rranges between -1 and +1. A positive value indicates that an increase in inefficiency increases project problems, while a negative value indicates an inverse relationship (Rodrigues & Bowers, 1996).

Regression-Based Performance Evaluation Model

To examine the extent to which management variables affect construction project performance, a multiple regression model was used (Lin et al., 2020). This model can estimate the range of performance expected due to various inefficiencies. The regression equation is expressed as:

$$Y = \beta_0 + \beta_1 X_p + \beta_2 X_s + \beta_3 X_{sa} + \beta_4 X_c + \beta_5 X_r + \epsilon \quad \text{...12}$$

Where, Y= project performance index, β_0= regression constant, $\beta_1 - \beta_5$= regression coefficients, ϵ= error term, the coefficient values indicate the contribution of each management factor toward project performance reduction (Lai et al., 2011).

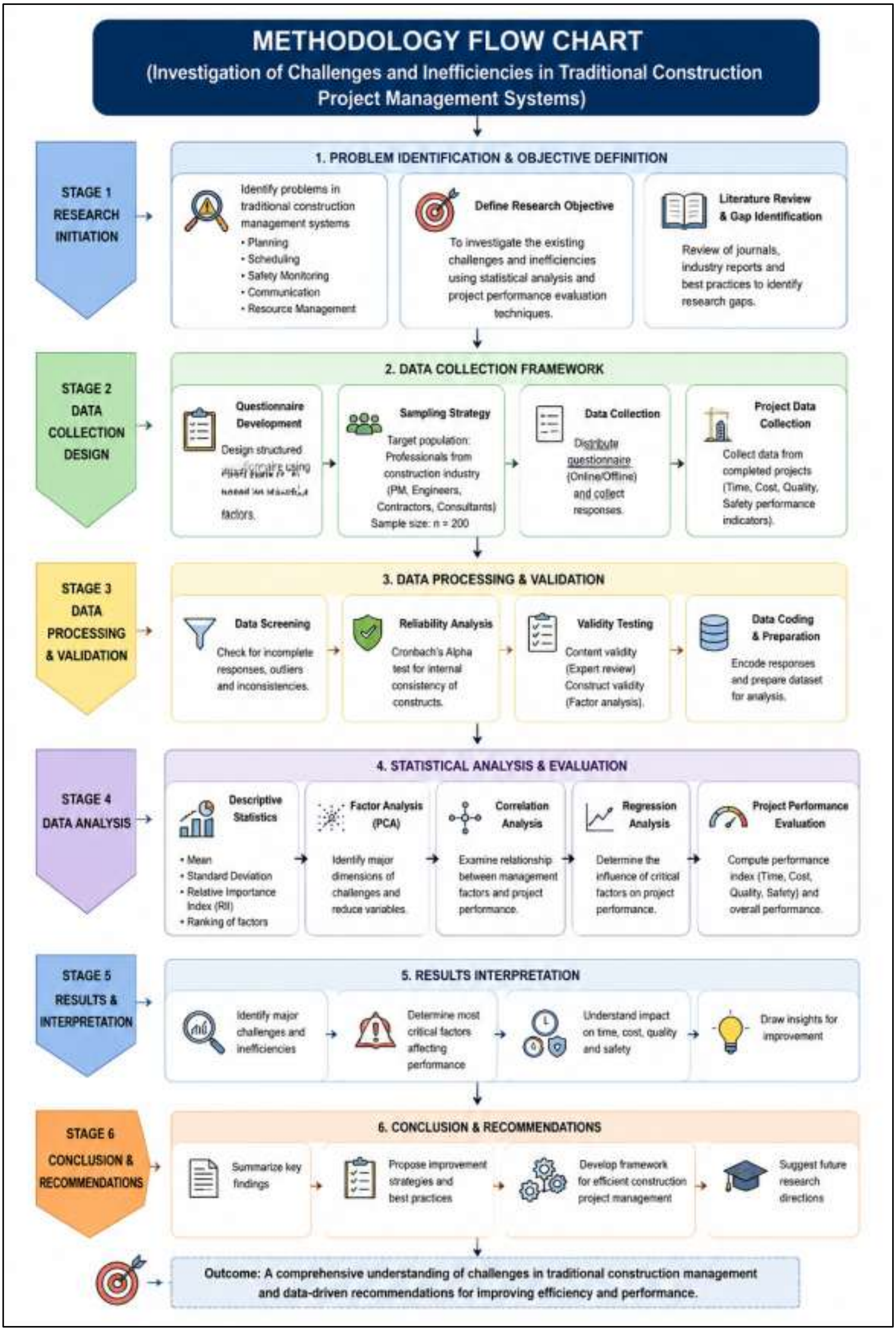


Fig. 1. Methodology flow chart for this study

Project Performance Evaluation Index Development

A composite index for measuring the performance of projects was formulated through the inclusion of various indices associated with project success such as time performance, cost performance, quality accomplishment, safety performance, and communication efficiency (Li et al., 2018). The performance index is calculated as:

$$\mathrm{PPI} = w_t T + w_c C + w_q Q + w_s S + w_m M \quad ...13$$

Where, PPI= Project Performance Index, T= time performance score, C= cost performance score, Q= quality score, S= safety score, M= communication score, and w_t, w_c, w_q, w_s, w_m represent assigned weights (Serpella et al., 2014). This index helps classify projects into low, medium, and high-performance categories.

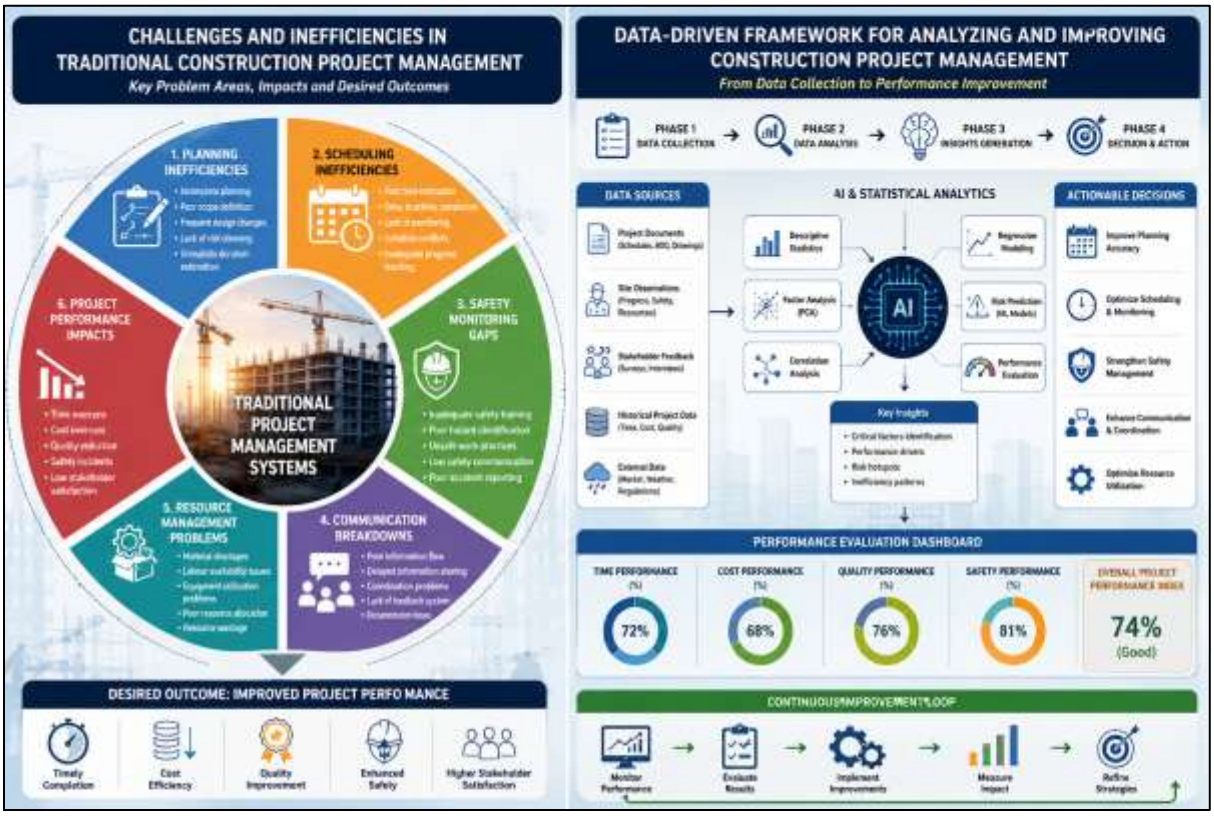


Fig. 2. Conceptual representation of traditional construction project management challenges and their impact on project performance and Proposed data-driven framework for evaluating and improving construction project management performance

Development of Data-Driven Improvement Framework

Based on the findings from the statistical analysis, the authors propose an improvement framework which incorporates the identification of the critical factors, their performance, and the means to improve them within the traditional management process. It aims at enabling construction professionals to change from using their experiences to base decisions to making decisions based on statistics. Such a methodology helps diagnose inefficiencies within construction management. Fig. 1 depicts the flowchart showing the systematic methodology adopted for data collection, recognizing issues associated with construction project management, use of statistics and performance measurement methods, and developing an improvement framework that will be proposed as part of this study. Fig. 2 is the conceptual model depicting how the construction project management issues relate to project performance indicators such as effective planning, scheduling, safety management, communication, and resource management.

Results and Discussion

Characteristic of Survey Respondents and Construction Project

The gathered data set was first analysed in order to have a grasp of the background information about respondents and the characteristics of construction projects used for this research paper. The number of respondents gathered reached up to 200 respondents who were involved in various project management tasks. In terms of profession, it can be seen that the biggest participation came from site engineers (29%), followed by project managers (21%), supervisors (18%), contractors (18%) and consultants (14%). This wide array of participation makes sure that the challenges mentioned came from a variety of angles during the implementation stage of construction projects.

When it comes to the experience of respondents, the most prevalent experience level was 5-10 years' experience (36%), followed by 10-15 years (27%). From the project features listed in Table 2, it can be seen that the database contains data from several construction sectors, such as residential (41%), commercial (23%), infrastructure (21%), and industrial constructions (15%). Among the three project sizes, medium-sized projects have the highest rate (44%), while small and large projects represent 32% and 24%, respectively. Since the project database consists of 46% of government and 54% of private projects, the evaluation approach has covered the construction context of both public and private sectors.

Traditional Construction Project Management Efficiency Factors Identification

The listed factors causing the inefficiency of the conventional construction project management system are shown below in Table 3 and Fig. 3. It is possible to conclude from the multidimensional analysis that scheduling, resource management, planning, communication, and safety-related inefficiency factors have a considerable effect on the reduction in project efficiency. From among all of the listed factors, unrealistic scheduling became the factor with the highest mean value (4.51). In other words, inappropriate time planning and inefficient scheduling can be considered among the key disadvantages of the current construction project management system. Poor time estimation had a very high impact on efficiency (4.46) and proved to be a cause of deviation from the planned schedule. Also, the listed factors related to resources had a considerable influence.

Material shortage had the second highest mean value (4.48), which proves that improper resource planning is a cause of disruptions and, hence, inefficiency. Communication-related issues also had a considerable impact, including information delays (4.44) and lack of coordination with stakeholders (4.35). It is clear from the results that construction management inefficiency does not arise as a result of only one aspect but from the interplay of several management concerns. Fig. 3 below depicts the profile of construction inefficiencies and shows that both scheduling and resource management are the most significant areas that need to be addressed.

Risk Assessment and Critical Challenge Ranking

The risk impact analysis shown in Fig. 4 and Fig. 11 above shows the connection between the frequency and seriousness of construction management inefficiencies. Problems in scheduling, lack of resources, and project planning appear in the high-risk area, which shows that these factors should be addressed urgently by construction managers. The risk assessment matrix proves that factors that often arise and have serious consequences have greater weight than other factors. The relative importance index analysis in Table 5 below further justifies these claims. Unreasonable scheduling took the first place with an RII score of 0.90, while materials shortage (0.90), poor project planning (0.88), and information delay (0.88) followed it. High rankings of planning and scheduling issues reveal the incapability of management in predicting the process of planning and managing operations. Additionally, the high importance of resource-related problems reveals the need to improve forecasting and distribution processes.

Reliability of Evaluation Framework and its Statistical Validation

As it is seen from the table of reliability analysis shown below, there is high internal consistency within selected variables. High Cronbach's alpha of 0.92 suggests that questionnaire designed to measure inefficiencies in construction project management is highly reliable. At the same time, each dimension of the questionnaire demonstrated a good level of reliability, with scheduling management having the best coefficient of internal consistency equal to 0.91, while resource management was second at 0.90 and planning management third at 0.89. Therefore, selected variables provide a good representation of the main dimensions of inefficient management of traditional construction projects, and therefore can be used for statistical analyses further.

Factor Analysis and Determination of Major Dimensions of Inefficiencies

The findings of the Principal Component Analysis are shown in Table 6 and Fig. 6. Four principal components that explain major causes of inefficiencies in construction management emerged from the analysis. The first component, referred to as planning and scheduling inefficiencies, had the highest variance of 34.8%, implying that problems associated with planning and scheduling have great influence on projects' performance. Resource management inefficiency is represented by the second component. It has an explained variance of 21.5%, implying that efficient management of resources such as labour force, materials, and equipment is critical to realizing construction efficiency. The third component represents communication barrier, having variance of 16.7%. Safety management problem was the fourth component contributing 12.6% variance. Total variance of 85.6% implies that the selected principal components successfully represent major sources of inefficiencies in traditional construction management systems.

Relation between Management Issues and Project Performance

The following table and figure illustrate the correlation analysis carried out in relation to the relationship between issues and project performance parameters. Delay had the highest correlation to scheduling issues ($r = 0.86$), indicating that poor scheduling practices have a significant impact on extending the completion time for any activity. There was a high correlation between resource issues and delay ($r = 0.84$) and cost overrun ($r = 0.81$). Planning inefficiency had a high correlation with delay ($r = 0.82$) and quality reduction ($r = -0.71$). The inverse relationship with quality implies that an increase in management issues leads to poor-quality construction. Communication issues also impacted delay and cost performance because of information and coordination issues. Fig.13 illustrates the three-dimensional correlation between delay, cost, and quality, showing that activities with a high delay and cost will tend to exhibit lower quality levels.

Fig. 3. Multi-dimensional Construction Management Inefficiency Profile

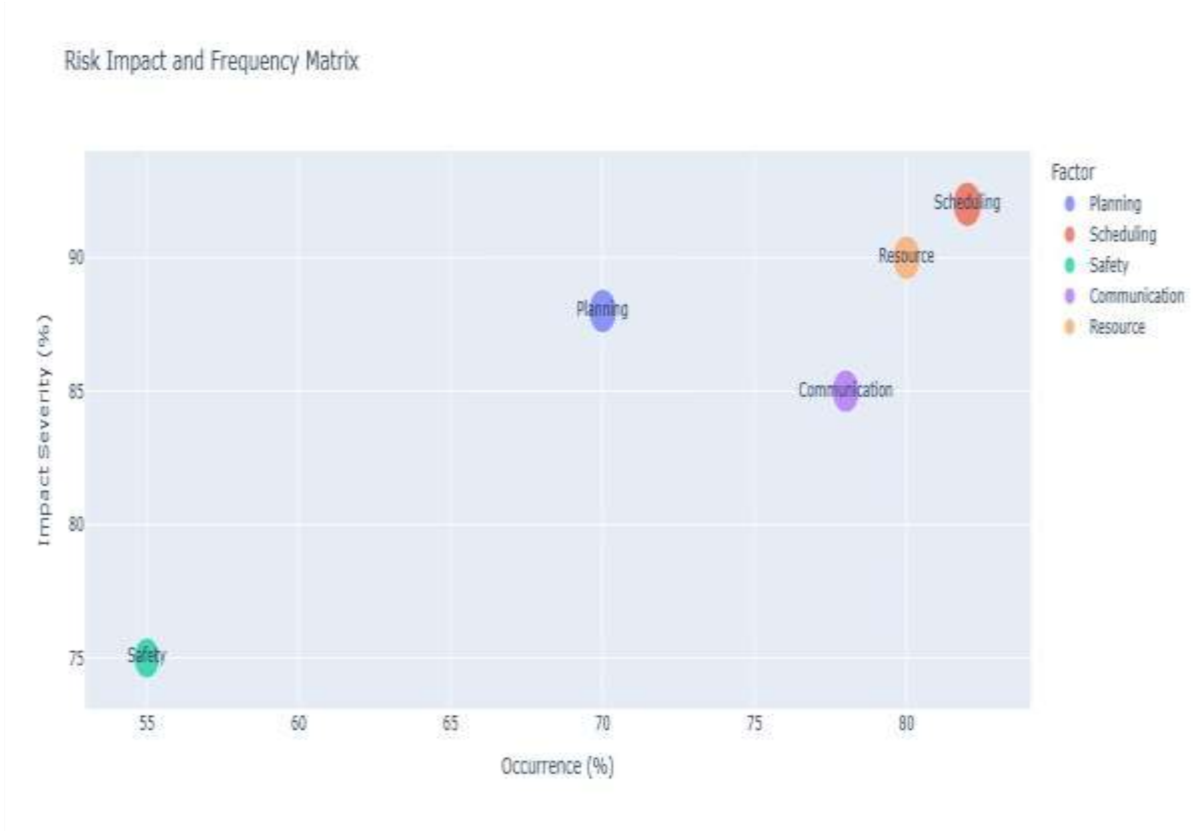
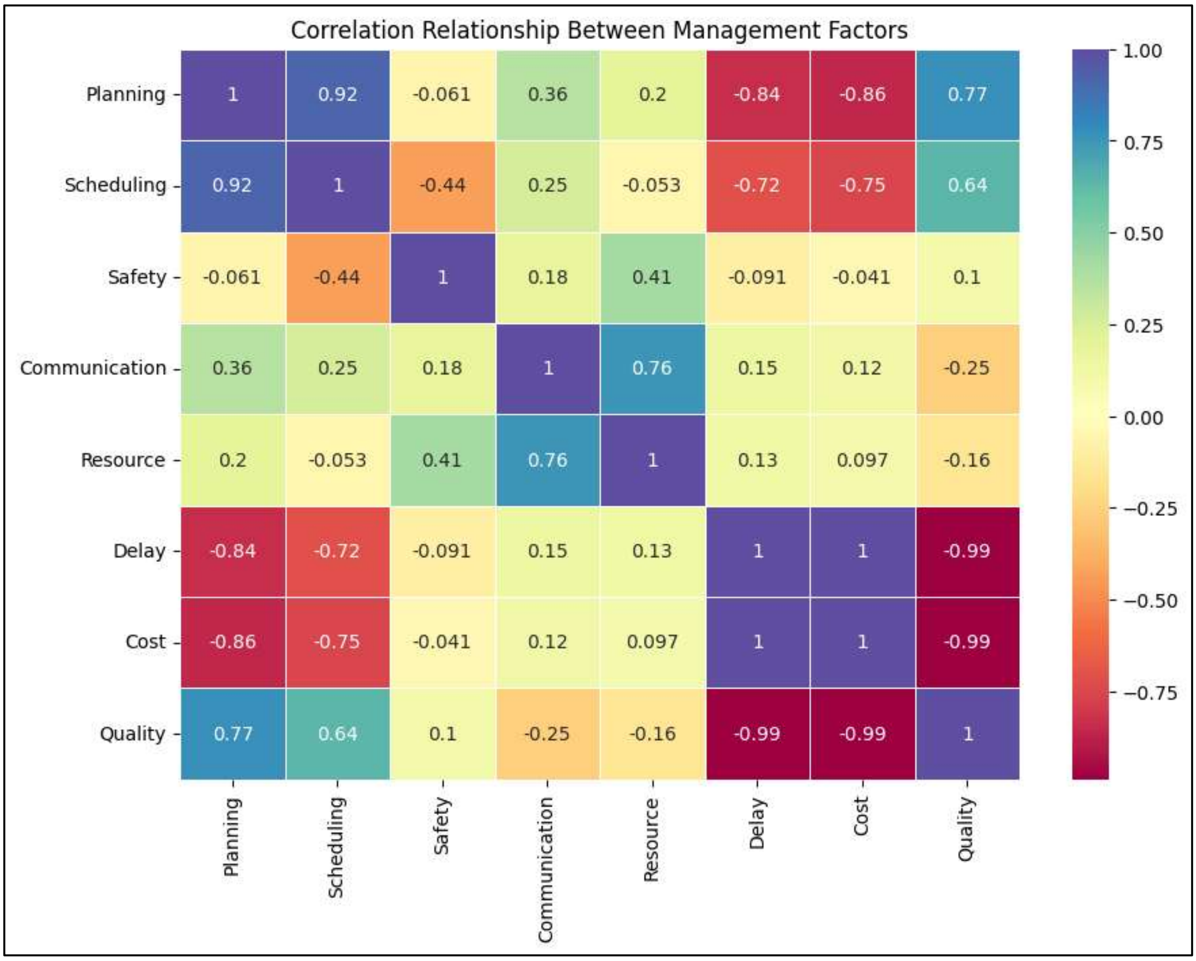


Fig .4. Risk Impact and Frequency Matrix

Regression-Based Project Performance Predictions

According to Table 8, which shows the results of regression analysis, the impact of each management factor on the total performance of the project was revealed. Scheduling appeared the most influential aspect with a regression coefficient ($\beta = 0.31$), while planning ($\beta = 0.28$) and resource management ($\beta = 0.27$) came second and third. This suggests that enhancing the skills in scheduling and managing resources could result in better performance of the construction projects. Communication management is another important factor having substantial influence ($\beta = 0.19$) and highlighting the significance of efficient communication between all the parties participating in the process. Finally, safety management turned out to be the least influential ($\beta = 0.14$), but still being an important source of project performance due to the fewer number of accidents. Thus, it is proved that construction performance depends on several factors.



	Planning	Scheduling	Safety	Communication	Resource	Delay	Cost	Quality
Planning	1	0.92	-0.061	0.36	0.2	-0.84	-0.86	0.77
Scheduling	0.92	1	-0.44	0.25	-0.053	-0.72	-0.75	0.64
Safety	-0.061	-0.44	1	0.18	0.41	-0.091	-0.041	0.1
Communication	0.36	0.25	0.18	1	0.76	0.15	0.12	-0.25
Resource	0.2	-0.053	0.41	0.76	1	0.13	0.097	-0.16
Delay	-0.84	-0.72	-0.091	0.15	0.13	1	1	-0.99
Cost	-0.86	-0.75	-0.041	0.12	0.097	1	1	-0.99
Quality	0.77	0.64	0.1	-0.25	-0.16	-0.99	-0.99	1

Fig .5. Correlation Relationship Between Management Factors

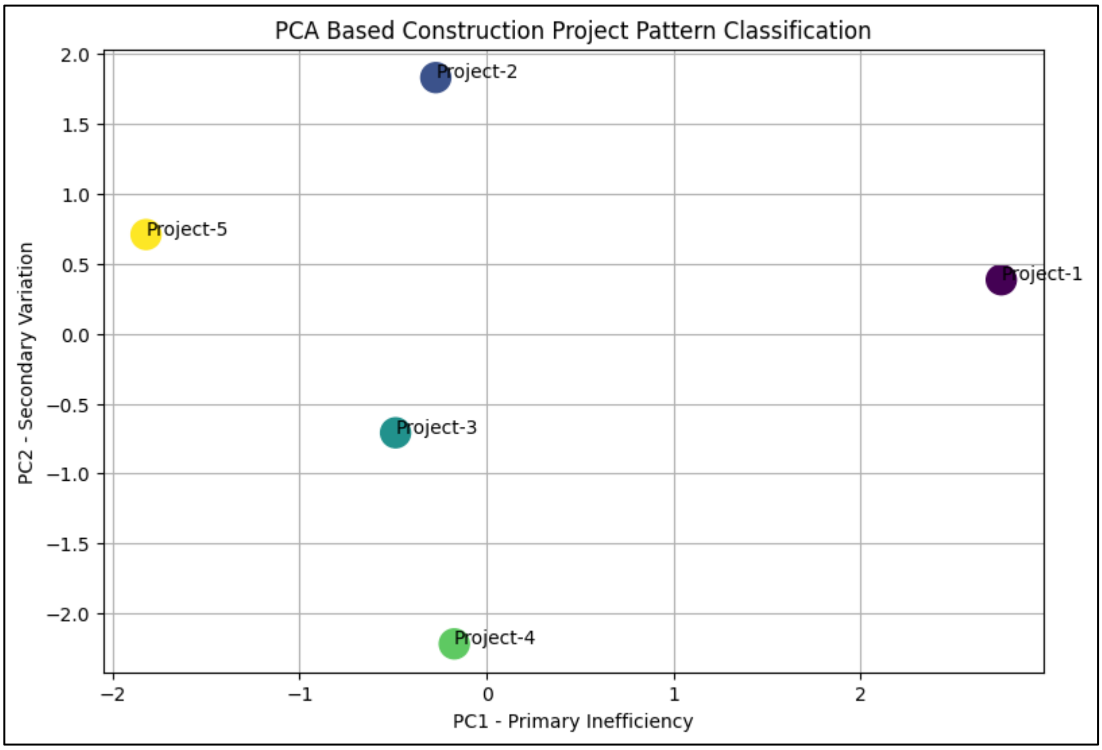


Fig .6. PCA Based Construction Project Pattern Classification

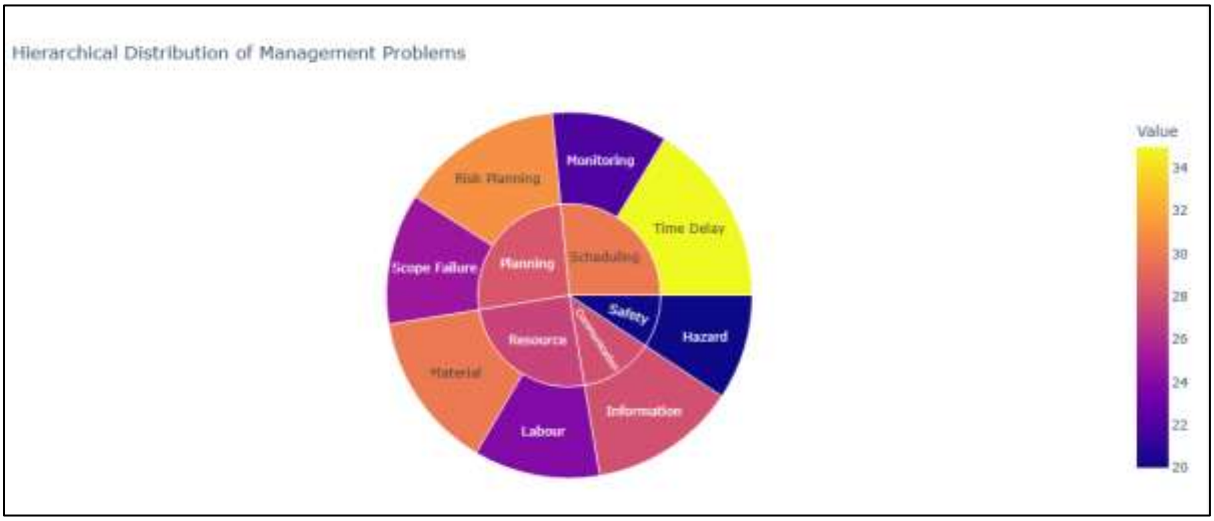


Fig .7. Hierarchical Distribution of Management Problems

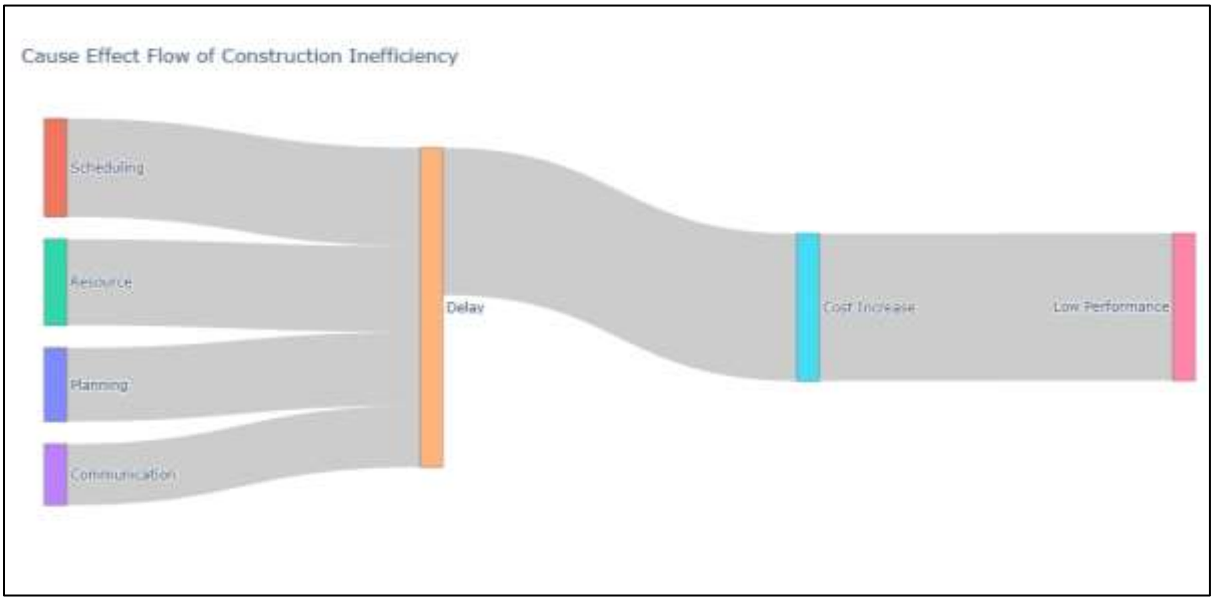


Fig .8. Cause Effect Flow of Construction Inefficiency

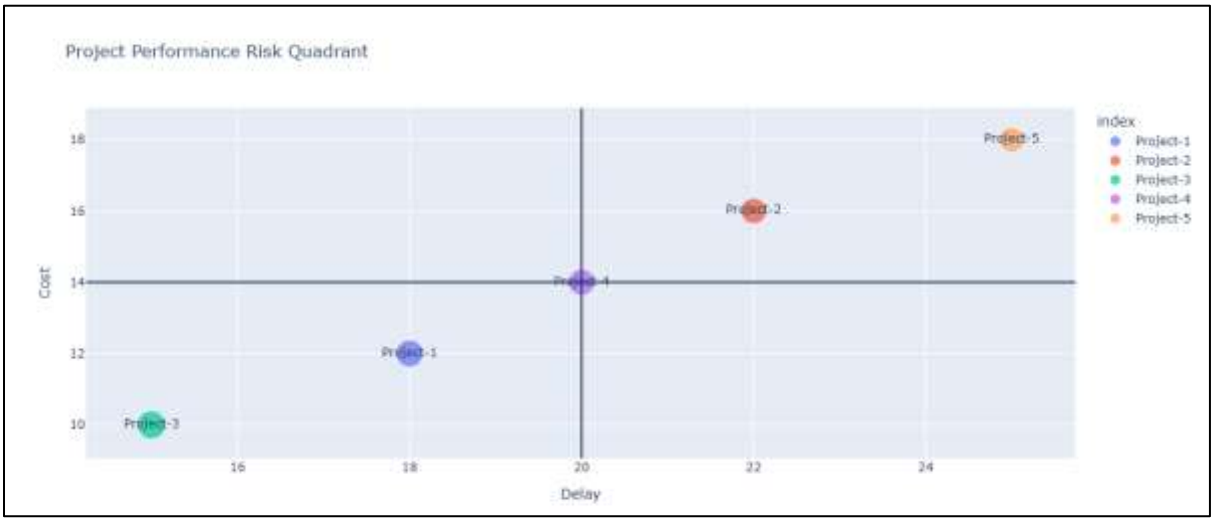


Fig .9. Project Performance Risk Quadrant

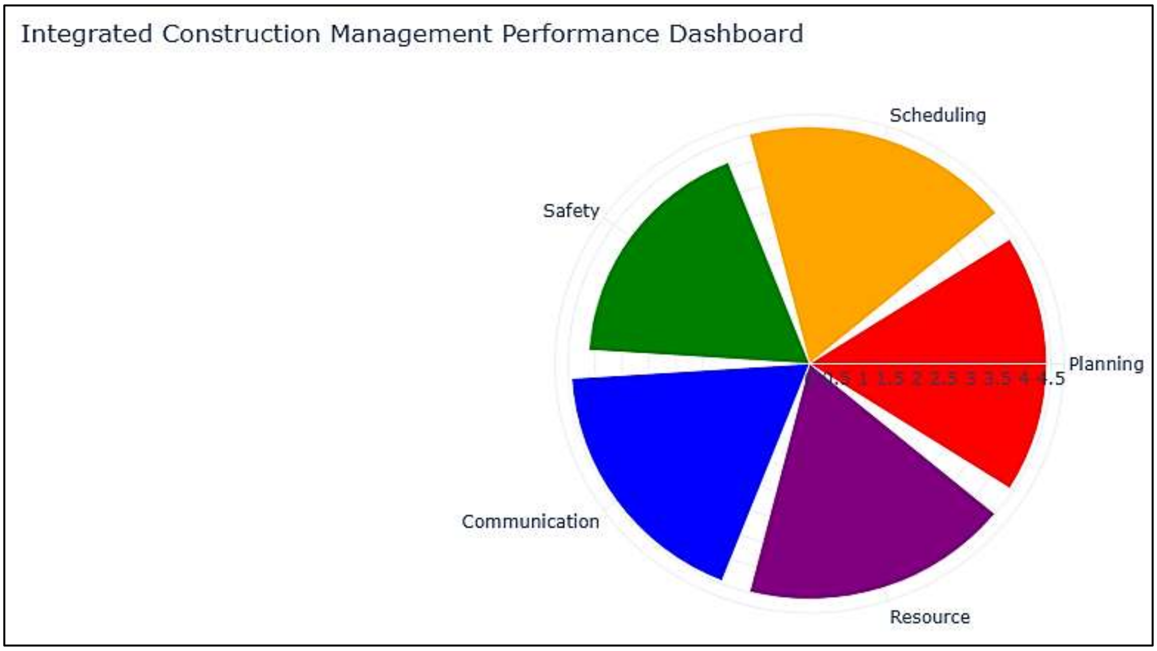


Fig .10. Integrated Construction Management Performance Dashboard

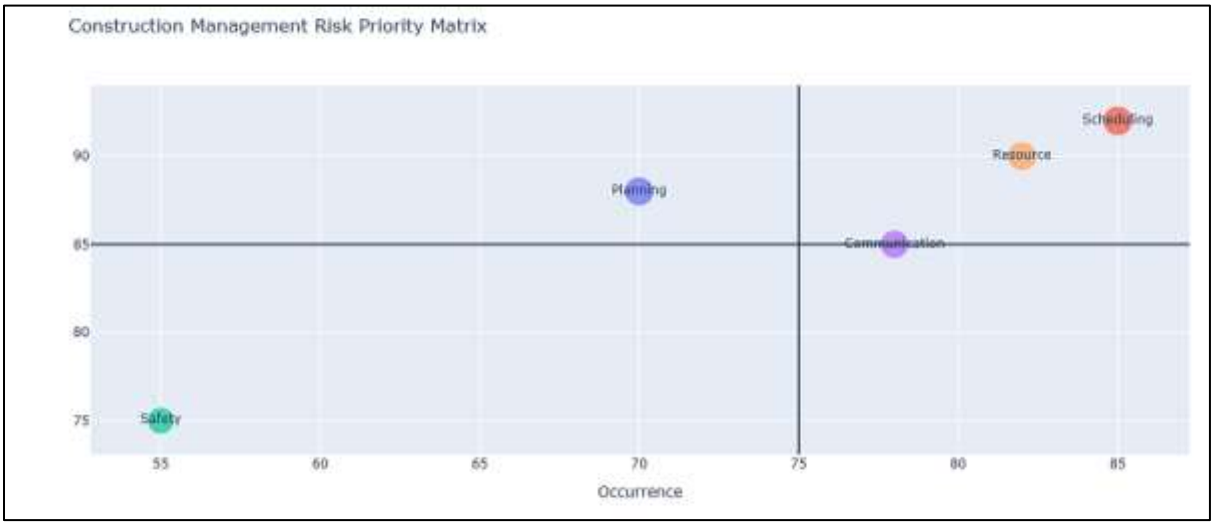


Fig .11. Construction Management Risk Priority Matrix

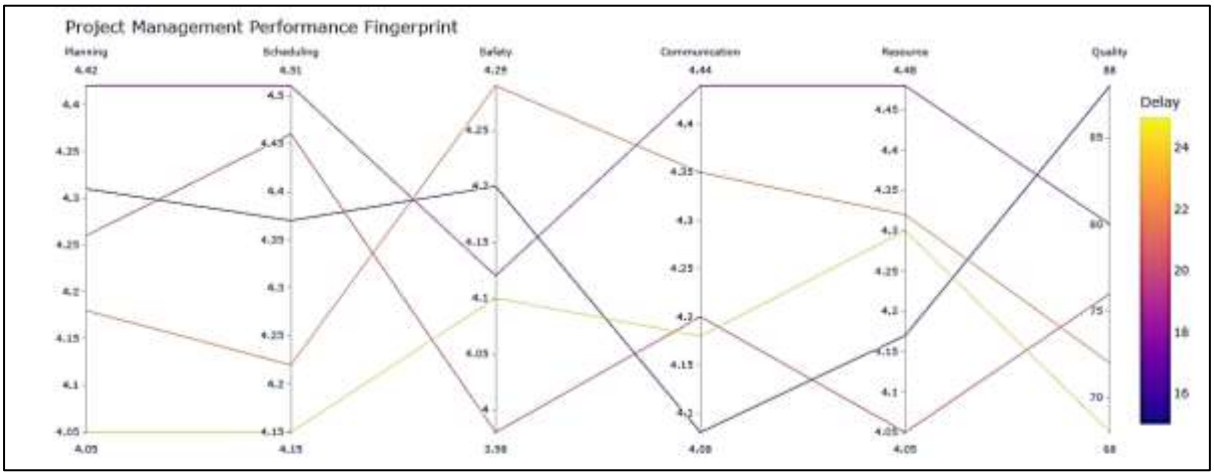


Fig .12. Project Management Performance Fingerprint

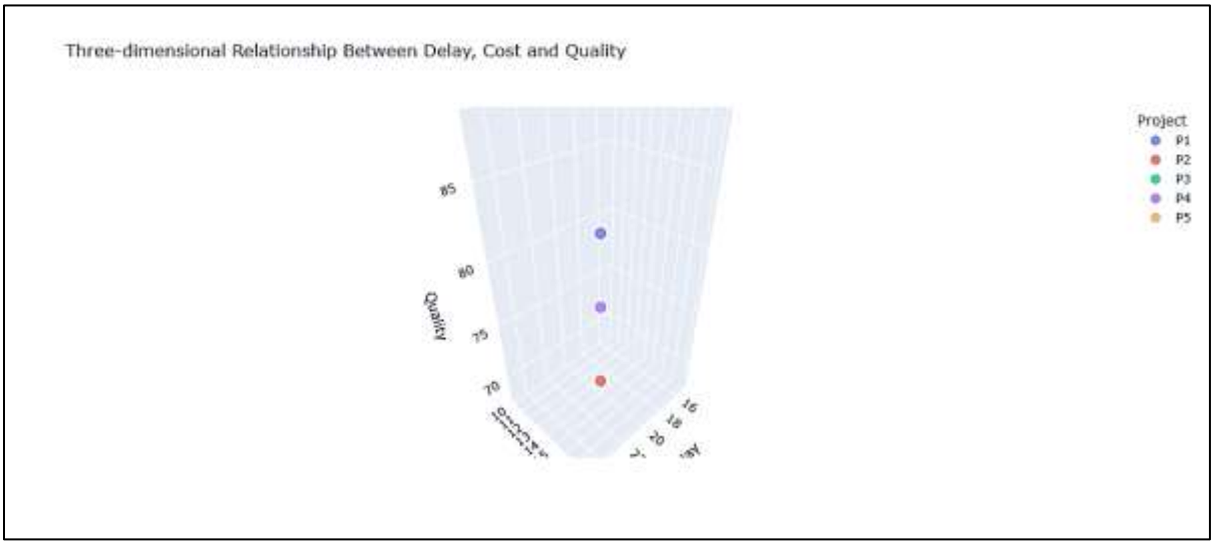


Fig .13. Three-dimensional Relationship Between Delay, Cost and Quality

Fig .14. Contribution of Management Failure Sources

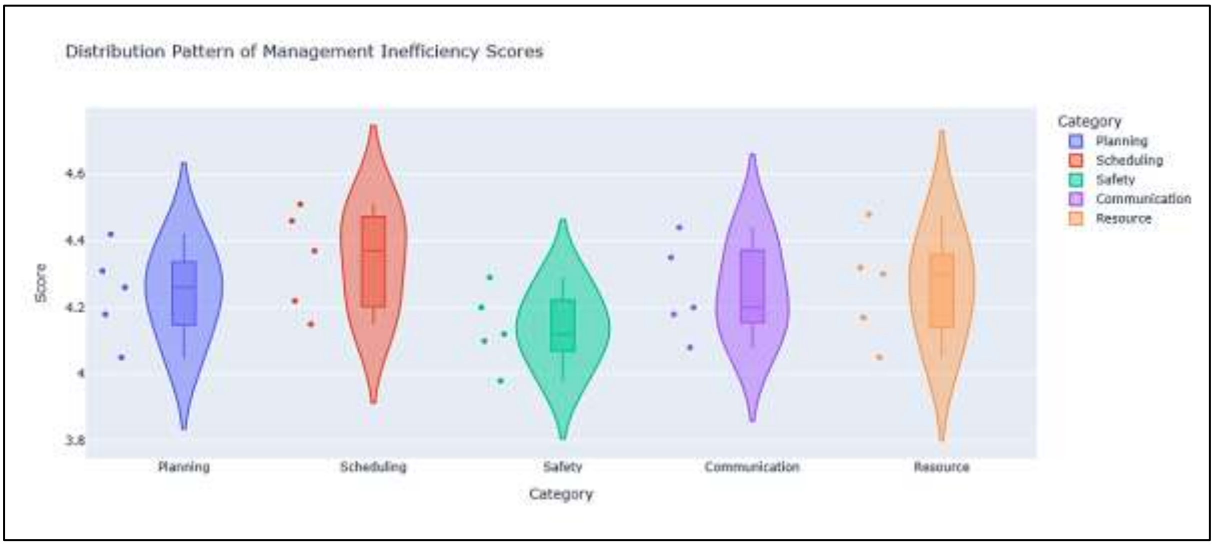


Fig .15. Distribution Pattern of Management Inefficiency Scores

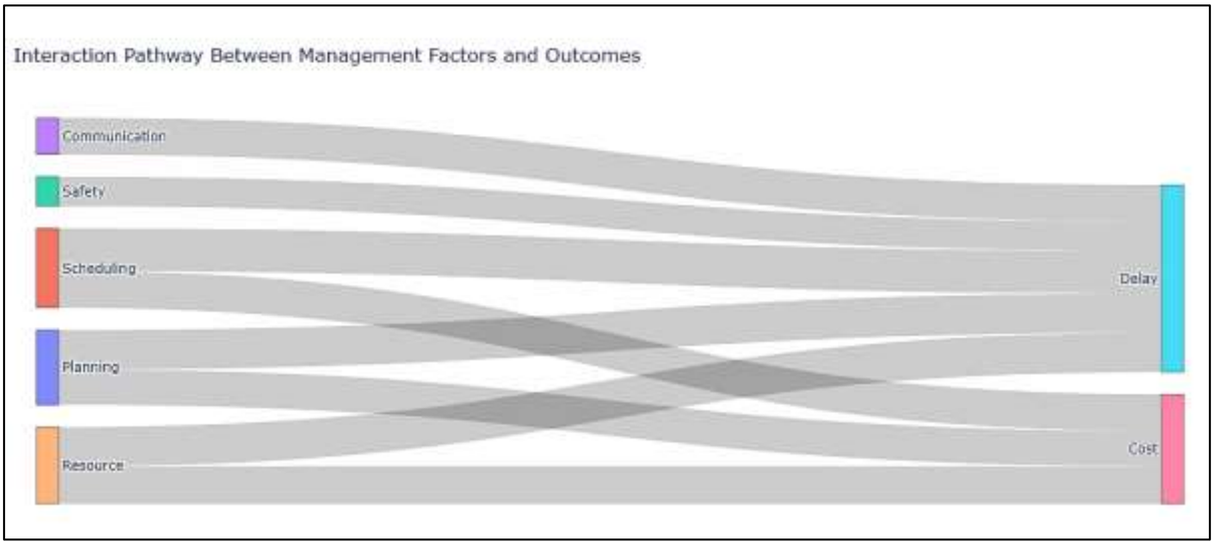


Fig .16. Interaction Pathway Between Management Factors and Outcomes

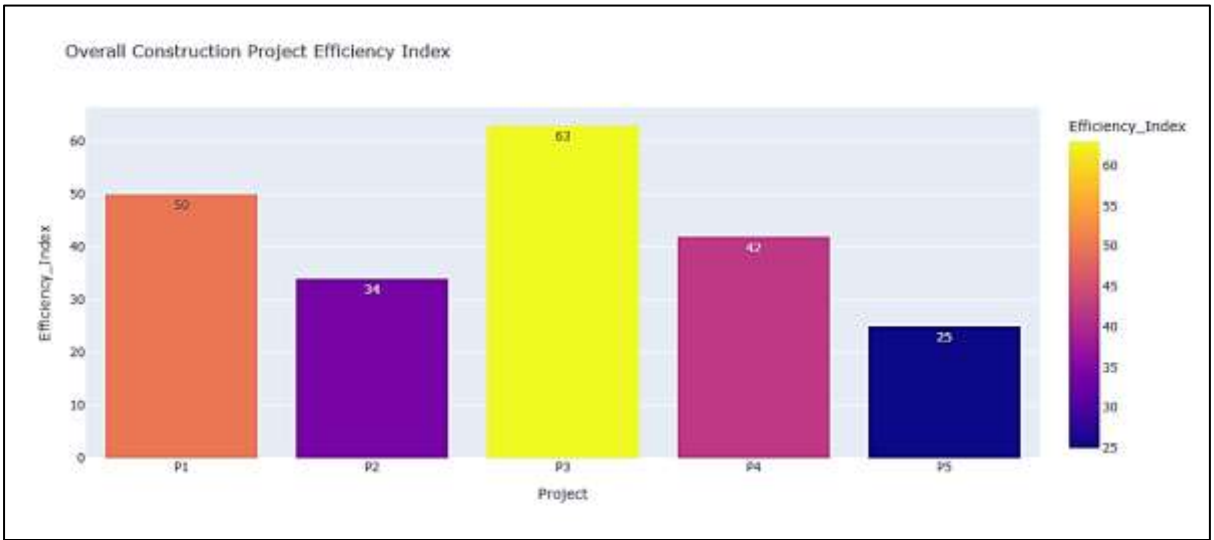


Fig .17. Overall Construction Project Efficiency Index

Relationship between Management Factors and Project Performance

A correlation relationship between construction management factors and performance indicators is presented in Fig. 5. The figure shows how the interaction between planning, scheduling, safety, communication, resource management, delays, cost, and quality occurs. The strong positive relationship between scheduling problems and delay is indicative of the significant role of poor time management in project disturbances. At the same time, there is a strong correlation between the occurrence of problems in resource management and costs because of insufficient material availability, inadequate personnel allocation, and inefficient use of equipment. The negative relationship between project management problems and quality performance indicates that higher management problems negatively impact the construction quality. It proves that construction performance depends on interrelated management factors rather than isolated factors.

Hierarchical Distribution of Management Problems

Fig. 7 shows hierarchical classification of construction management problems identified in this research. As seen in Fig. 7, the main sources of inefficiencies are divided into the categories of scheduling, planning, resource, safety, and communication, which have their specific subcategories. As seen from the figure above, the most developed areas are connected with the categories of planning and scheduling, which means that project planning and execution control are the key factors affecting the current state of traditional management. Also, problems associated with resources are important, as they involve availability of materials and labour force. On the other hand, issues of communication and safety do not have such high contributions to inefficiencies as scheduling, but they are still very important due to their impact on coordination and decisions.

Evaluation of Performance and Analysis of Efficiency of Projects

The performance evaluation of projects, which is provided in Table 9 and Fig. 9, proves that there are some differences in the performance among various construction projects. For example, project P3 received the highest performance score (87), which was primarily attributed to successful time management, costs, performance, and safety control. However, project P2 obtained a low score (68) because of high time delay and low performance rate. Fig. 17 provides information about the overall efficiency index of the construction projects under study, which indicates the performance level of the projects. From the results, it can be concluded that efficient planning and management of resources lead to high efficiency rates. The overall performance behaviour of various management dimensions is illustrated in Fig. 10 by means of the dashboard.

Development of a Data-Based Improvement Framework

An improvement framework was designed according to the problems recognized and statistical results as shown in Table 10 and Fig. 8 below. The framework transforms the recognized inefficiencies into specific actions that can be taken. The lack of proper planning and scheduling can be remedied by using digital technology for planning and scheduling. Safety constraints can be solved by installing monitoring techniques and hazard recognition methods. Problems in communication can be resolved through a platform for information exchange. Likewise, the problem regarding resources can be overcome through optimization of resource allocation. The development of this framework marks a step towards shifting from traditional experience-based construction project management to a more systematic and data-driven one.

Analysis of Project Management Performance Fingerprints

The project management performance fingerprint shown in Fig. 12 displays how projects with different behavioral performances are related to each other across various aspects of management. Through the use of parallel coordinate plots, the variations in planning, scheduling, safety, communication, resources, and quality management performances among projects can be easily seen. It was found that projects that perform better in all dimensions are more likely to have a better overall performance compared to those with imbalanced performance in various aspects. High inefficiency levels observed in scheduling and resource management imply delays in work progress and lower levels of quality performance.

Three-Dimensional Relation between Project Delay, Cost, and Quality

The relation between delay, cost overrun, and quality performance can be viewed three-dimensionally as indicated by Fig. 13 below. The diagram reveals the effects of both the temporal and financial performance of a project on its quality performance. Projects with more delay tend to have larger cost estimates because increased time taken for the completion of a project increases labor and operating costs associated with such delays. Additionally, projects that display larger delay and cost values are associated with poorer quality performance due to decreased productivity levels. The three-dimensional analysis proves that project performance dimensions are interdependent such that poor performance in one dimension may have an effect on performance in other dimensions.

Contribution of Management Failure Sources

The contribution of various management failure sources is illustrated in Fig. 14. The graph shows the relative importance of various problem areas such as planning, scheduling, resources, communication, and safety. Failures that arise from scheduling are the most significant contributors because of incorrect activity duration estimates and poor monitoring practices that have ripple effects during the whole duration of the project. Resources, on the other hand, are major contributors since there may be interruptions arising from lack of materials and poor allocation practices. The above illustration shows the importance of addressing critical issues, not all management problems.

Distributions of Management Inefficiencies

Distributions of management inefficiency scores can be seen in Fig. 15 below. This distribution uses the violin plotting method to depict variations, concentration, and dispersion in the responses provided by construction specialists across the various management parameters being analyzed. From the distributions above, it is clear that scheduling and resource management issues exhibit high concentrations of inefficiencies, thus proving their significance in lowering construction efficiency. Issues related to safety have relatively high variations, meaning that different construction projects implement different safety management practices. Issues regarding communication also exhibit significant variations owing to differences in communication channels used. These distribution analyses offer an additional dimension to response variability.

Interaction Pathway between Management Aspects and Performance Aspects of the Project

The interaction pathway between the management aspects and the project performance outcomes is shown in Fig. 16 below. In this flow chart, we understand how various inefficiencies lead to important project performance issues such as delay, increased cost, and poor performance. A number of planning, scheduling, resource and communication inefficiencies are responsible for causing the delay in a project. This, in turn, impacts the cost and affects overall project performance. This interaction-based approach helps identify preventive approaches towards managing projects successfully.

The constructed overall efficiency index based on time, cost, quality, and safety measures is shown in Fig. 17 below. The efficiency index helps in measuring the overall project efficiency using an integrated approach of considering several dimensions of project success. The analysis reveals that well-planned, scheduled, efficiently resourced, and communicated projects receive high efficiency ratings. Projects constrained by the limitations of the traditional method of project management experience low efficiency ratings due to higher delays and costs. The constructed efficiency index gives the managers an operational decision support tool to use when comparing different projects' performances and improvements needed.

Table 1. Demographic Characteristics of Survey Respondents

SI.NO	Category	Classification	Number of Respondents	Percentage (%)
1	Respondent Role	Project Manager	42	21
		Site Engineer	58	29
		Contractor	36	18
		Consultant	28	14
		Supervisor	36	18
2	Experience	< 5 Years	38	19
		5–10 Years	72	36
		10–15 Years	54	27
		>15 Years	36	18
Total Sample Size			200	100

Table 2. Characteristics of Construction Projects Considered for Evaluation

SI.NO	Parameter	Category	Number of Projects	Percentage (%)
1	Project Type	Residential	82	41
		Commercial	46	23
		Infrastructure	42	21
		Industrial	30	15
2	Project Size	Small	64	32
		Medium	88	44
		Large	48	24
3	Contract Type	Government	92	46
		Private	108	54

Table 3. Identified Traditional Construction Project Management Inefficiency Factors

S.NO	Category	Factor	Code	Mean Score
1	Planning	Poor project planning	P1	4.42
		Incomplete scope definition	P2	4.18
		Lack of risk planning	P3	4.31
		Frequent design changes	P4	4.26
		Poor decision making	P5	4.05
2	Scheduling	Unrealistic scheduling	S1	4.51
		Activity dependency problems	S2	4.22
		Delay monitoring issues	S3	4.37
		Poor time estimation	S4	4.46
		Schedule conflicts	S5	4.15
3	Safety	Lack of safety training	SA1	4.12
		Poor hazard identification	SA2	4.29
		Unsafe work practices	SA3	4.2
		Accident reporting problems	SA4	3.98
4	Communication	Information delay	C1	4.44
		Stakeholder coordination issues	C2	4.35
		Documentation problems	C3	4.08
5	Resource	Material shortage	R1	4.48
		Labour availability problems	R2	4.32
		Equipment management issues	R3	4.17
		Resource wastage	R4	4.05

Table 4. Reliability Analysis of Study Variables

SI.NO	Variable Group	Number of Items	Cronbach Alpha	Reliability Status
1	Planning Management	5	0.89	Excellent
2	Scheduling Management	5	0.91	Excellent
3	Safety Monitoring	5	0.86	Good

4	Communication Management	5	0.88	Good
5	Resource Management	5	0.9	Excellent
6	Overall Dataset	25	0.92	Highly Reliable

Table 5. Relative Importance Index (RII) Ranking of Critical Inefficiency Factors

Rank	Factor	Category	RII	Impact Level
1	Unrealistic scheduling	Scheduling	0.9	Very High
2	Material shortage	Resource	0.9	Very High
3	Poor project planning	Planning	0.88	Very High
4	Information delay	Communication	0.88	Very High
5	Lack of risk planning	Planning	0.86	High
6	Stakeholder coordination issue	Communication	0.86	High
7	Safety monitoring problems	Safety	0.84	High
8	Labour availability problems	Resource	0.83	High
9	Equipment management issues	Resource	0.81	High
10	Documentation problems	Communication	0.8	High

Table 6. Principal Component Analysis Results

SI.NO	Component	Major Factor	Variables Included	Variance Explained (%)
1	Component 1	Planning & Scheduling Failure	P1–P5, S1–S5	34.8
2	Component 2	Resource Management Inefficiency	R1–R4	21.5
3	Component 3	Communication Barrier	C1–C3	16.7
4	Component 4	Safety Management Issues	SA1–SA4	12.6
	Total Explained Variance			85.6

Table 7. Correlation Analysis Between Management Factors and Project Performance

SI.NO	Factor	Project Delay	Cost Overrun	Quality Reduction
1	Planning inefficiency	0.82	0.76	−0.71
2	Scheduling problems	0.86	0.79	−0.68
3	Safety problems	0.63	0.54	−0.59
4	Communication problems	0.79	0.72	−0.66
5	Resource problems	0.84	0.81	−0.73

Table 8. Regression Model for Project Performance Prediction

SI.NO	Variable	Coefficient (β)	p-value	Influence
1	Planning	0.28	0.001	High
2	Scheduling	0.31	0	Very High
3	Safety	0.14	0.032	Moderate
4	Communication	0.19	0.008	High
5	Resource Management	0.27	0.002	High

Table 9. Construction Project Performance Evaluation Index

SI.NO	Project ID	Time Score	Cost Score	Quality Score	Safety Score	Overall Performance
1	P1	78	82	80	75	79
2	P2	64	70	72	68	68
3	P3	88	85	90	86	87
4	P4	72	76	74	70	73

Table 10. Proposed Improvement Framework Based on Identified Inefficiencies

SI.NO	Existing Challenge	Observed Effect	Recommended Improvement
1	Poor planning	Delay and cost increase	Digital planning tools
2	Scheduling problems	Time overrun	Automated scheduling
3	Safety monitoring gaps	Accident risk	Real-time safety monitoring
4	Communication failure	Coordination loss	Integrated communication platform
5	Resource mismanagement	Waste and cost increase	Resource optimization system

As can be seen from the results of this research, there are many constraints associated with traditional construction project management frameworks due to fragmentation of project planning processes, scheduling issues, lack of effective communication channels, inefficient monitoring of health and safety measures, and ineffective allocation of resources. All identified factors have a major impact on the performance of construction projects, while scheduling, material management, and planning were found to be the most important ones.

The framework constructed in this study is based on different statistical methods and allows one to detect the key areas of inefficiency and estimate their impact on the overall performance. It has been proven that this framework could be used by construction managers to enhance their decision-making through using data-driven approaches and improve construction project management.

Conclusion

In this research, the inefficiencies that were inherent to traditional project management systems in the construction industry have been studied through statistical analysis and performance measures of projects. An analytical framework has been provided in order to assess some important problems relating to the management of the activities like planning, scheduling, monitoring safety, communication, and resource management. The analysis revealed that the traditional method is still characterized by many limitations due to inadequate coordination, improper monitoring, and experience-based decisions. The data collected from 200 construction workers have indicated that scheduling and resources are two very significant obstacles impacting project efficiency. In the Relative Importance Index analysis, unrealistic scheduling and resource shortages were observed as the two key obstacles with RII value 0.90, followed by planning inefficiency and information delay with RII value of 0.88. The findings suggest that scheduling and availability of information and resources can influence project management success.

The reliability test indicated that the proposed assessment framework was reliable as it produced an overall Cronbach's Alpha of 0.92. The Principal Component Analysis of the extracted variables resulted in four main categories of management inefficiencies accounting for 85.6% of the total variation. The first dimension of inefficiencies, planning and scheduling issues, accounted for 34.8% and reflected the greatest impact on the performance of construction projects. Resource management issues accounted for 21.5%. Communication inefficiencies and safety problems accounted for 16.7% and 12.6%, respectively. The relationship analysis showed that management inefficiencies directly influenced construction project outcomes. The scheduling problem had the greatest impact on construction project delays ($r = 0.86$). The resource problem, on the other hand, significantly influenced cost overruns ($r = 0.81$). The regression model also showed that scheduling, planning, and resource management inefficiencies were the most influential predictors of project success with regression coefficients of 0.31, 0.28, and 0.27, respectively.

The formulated framework offers a structured methodology to diagnose construction management inefficiencies and determine improvement strategies. While traditional methodologies analyze project issues independently, the framework developed herein incorporates various management aspects into a single performance assessment system. The framework enables construction practitioners to shift from the traditional reactive problem-solving approach to a proactive one through quantitative analysis. Future research will explore ways of improving construction project management through incorporation of real-time project tracking information, BIM, IoT-sensing technologies, and artificial intelligence-based forecasting methods.

Author Contributions: Conceptualization, PK and VV; **methodology,** PK and GS; **validation,** PK, MS **formal Analysis,** MS; **investigation,** MS,BK,RK GS; **resources,** PK; writing—**original draft preparation,** MS; **writing—review and editing,** MS,BK,RK]

All authors have read and agreed to the published version of the manuscript.

● Ethical approval and consent to participate

We obtained consent from the participants concerned with their technical inputs provided for developing this research, all efforts have been made by the authors to anonymize the participants information.

● Consent for publication

The Author confirms:

- that the work described has not been published before (except in the form of an abstract or as part of a published lecture, review, or thesis);
- that it is not under consideration for publication elsewhere;
- that its publication has been approved by all co-authors, if any;
- that its publication has been approved (tacitly or explicitly) by the responsible authorities at the institution where the work is carried out.

● Competing interests

- All authors are aware the given information regarding this manuscript is correct.
- All authors have agreed that there is no conflict of interest in this manuscript.

- All authors have declared that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
- **Funding:** This research received no external funding.
- **Conflicts of Interest:** The authors declare no conflict of interest.
- **Data Availability:** Data will be made available on reasonable request.

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