REALCONS: A DIGITAL FRAMEWORK FOR CONSTRUCTION REPORTING ACCURACY AND EARLY DELAY DETECTION

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SUMMARY: *Accurate and timely reporting is essential for effective construction project management. However, existing progress tracking systems often face challenges such as delayed reporting, data inconsistencies, and inefficient documentation processes, compromising report accuracy and prolonging preparation times. This study introduces RealCONs, a digital framework for on-site project reporting management designed to enhance construction site real-time data acquisition, project tracking and reporting. The framework integrates the Rational Unified Process (RUP) methodology and Unified Modelling Language (UML) to streamline workflows. A comparative analysis was conducted using case studies from the Electrical and Instrumentation (E&I) trade dataset to evaluate RealCONs' effectiveness in 1) improving daily reports generation speed, 2) Reducing reporting errors, and 3) Improving project performance via early delay identification. A mixed-methods approach was employed to validate RealCONs' objectives, analysing daily reports and their preparation times while utilising Earned Value Management (EVM) metrics to assess the impact of early delay identification on project performance (CPI, SPI). The results demonstrate that RealCONs significantly outperforms traditional methods, increasing total report generation by 32.2%, reducing reporting errors by 84%, and enabling earlier delay notifications. Although developed for the E&I trade, the framework offers scalable applications for broader construction and infrastructure projects facing similar reporting inefficiencies.*

KEYWORDS: *Database Management, Reporting, UML, Productivity, Digital Framework.*

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1. INTRODUCTION

Project management techniques act as a critical bridge, aligning the infrastructure needs of construction projects with the practical responsibilities of project managers and site teams to ensure timely delivery and effective management (Abdelhafiz & Mostafa, 2020; Amirtash, Jalal, & Jelodar, 2021; Correa, Castañeda, Quintero, & Giraldo, 2018; Johnson, Boucher, Connors, & Robinson, 2001). A core element of this alignment is communication, which underpins project success and demands robust execution and reporting systems to keep decision-makers and stakeholders in sync (Jelodar, Yiu, & Wilkinson, 2016; Kamalirad & Kermanshachi, 2018; Safapour, Kermanshachi, Habibi, & Shane, 2018). Despite this, discrepancies between baseline plans, actual progress, and persistent schedule delays remain widespread in construction projects (Radman, Babaeian Jelodar, Ghazizadeh, & Wilkinson, 2021). Although current productivity and progress tracking systems aim to mitigate these issues by collecting site data and generating digital reports, the speed of daily report generation and reporting accuracy remain critical concerns. Existing models, such as labour output or time per unit of activity, can measure productivity, but their effectiveness is undermined by the reliability and timeliness of the underlying data (Arif & Khan, 2020; Ham, Moon, Kim, & Kim, 2020). Manual data collection still dominates the industry, often resulting in inefficient workflows, delayed reporting, and significant human error. Supervisors typically record progress manually, contributing to slow and inaccurate daily reports, which limit managers' ability to make timely decisions (H. Eliwa, Jelodar, & Poshdar, 2018; Zou et al., 2019). In contrast, real-time monitoring systems offer the potential to detect delays early, improve decision-making, and enhance overall project performance by enabling timely interventions. However, integrating effective information systems (IS) into construction management has proven challenging. Striking a balance between accuracy, reliability, and speed remains a major hurdle, particularly when digital solutions are not adequately tailored to construction-specific needs (Jelodar, Yiu, & Wilkinson, 2014; Jelodar et al., 2016).

As the construction sector continues to support national development, it faces rising pressure to deliver large-scale and complex projects. It has accelerated the adoption of advanced technologies such as Building Information Modelling (BIM), Artificial Intelligence (AI), Virtual Reality (VR), and data science to maintain competitiveness (Berdik, Otoum, Schmidt, Porter, & Jararweh, 2021; Kurbonovich, 2019). Automation and digitalisation are now widely recognised as essential for reducing manual errors, accelerating report generation, and enhancing decision-making processes (Babaeian Jelodar, Yiu, & Wilkinson, 2022; Kerzner, 2017). Nevertheless, many organisations rely on outdated systems for managing vast and interconnected project data, resulting in prolonged reporting cycles and low accuracy levels. These inefficiencies hinder real-time responsiveness and directly impact project outcomes (Berdik et al., 2021; H. K. Eliwa, Jelodar, Poshdar, & Yi, 2023; Kaur & Bhatia, 2024; Kurbonovich, 2019). This study introduces RealCONs, a digital reporting framework designed to address these issues by improving daily reporting speed, reducing reporting errors, and boosting project performance through early delay identification. This research is structured as follows: Section 1 introduces the study, followed by an overview of current digital tools and systems in Section 2. Section 3 defines the research problem, while Section 4 outlines the objectives. Section 5 details the methodology, and Section 6 examines the application of RUP/UML for efficient data handling. The proposed RealCONs framework is presented in Section 7, with the case study approach described in Section 8. Section 9 presents the results, subdivided into 9.1 (Site Data Collection Approach): Improvements in daily report generation speed and error reduction; and 9.2 (Implications of Early Delay Detection): Performance enhancements through EV-based delay identification. Finally, Section 10 concludes with key findings and recommendations for future work.

2. BACKGROUND

Project documentation and status reporting systems are fundamental components of construction management, acting as the backbone for decision-making and progress tracking (Lamptey & Fayek, 2012; Mena, López, Framiñan, Flores, & Gallego, 2010). These systems manage a wide range of interconnected data, including cost breakdown structures (CBS), work breakdown structures (WBS), schedules, and resource plans. When maintained effectively, documentation enables project managers to monitor progress accurately and make informed decisions, particularly regarding delays (Babaeian Jelodar et al., 2022). Advanced tools such as Building Information Modelling (BIM) and database management systems (DBMS) enhance documentation processes by integrating historical data and supporting life-cycle cost analysis (Kerzner, 2017, 2022; Parisi, Fanti, & Mangini, 2021). However, implementing efficient documentation and reporting systems in construction projects remains challenging. Existing methods are often manual, time-consuming, error-prone, and lack integration. This fragmented approach hinders the ability to correlate delays with key project metrics such as CBS and WBS, resulting in inefficiencies and inaccurate reporting (Radman, Jelodar, Lovreglio, Ghazizadeh, & Wilkinson, 2022a). The complexity of large-scale projects and the volume of data involved further complicate real-time decision-making. Relational databases and internet-enabled systems have been proposed to solve these issues (Goonetillake, Ren, & Li, 2023). By linking historical and real-time data, these tools provide comprehensive insights and improve project status tracking (H. Eliwa et al., 2018). However, their adoption often requires significant technical expertise and investment, which can be prohibitive for smaller firms (Likita, Jelodar, Vishnupriya, & Rotimi, 2024). Database management systems are crucial in construction and other industries because they facilitate structured data's efficient storage, retrieval, and long-term management. They support activities ranging from document control to complex data queries (Khan et al., 2023). DBMS technologies allow for creating schemas, managing large datasets, and controlling user access, typically implemented through programming languages like SQL or modelling tools like UML (Goonetillake et al., 2023).

In construction projects, documentation spans many interconnected data, including project costs, site progress reports, S-curves, resource plans, and payment records (Davis, Ledbetter, & Burati Jr, 1989). Traditionally, such datasets have been managed using fragmented methods, often leading to inefficiencies and inaccuracies. This lack of integration affects contractors' ability to assess the impact of delay events on critical project performance indicators such as CPI and SPI (Lopez & Love, 2012). Research indicates that aligning CBS and WBS through data analytics improves the ability to assess and manage delays (Radman, Jelodar, Lovreglio, Wilkinson, & Ghazizadeh, 2022). Progress curves have also been shown to support real-time tracking and improve project control (Cerezo-Narváez, Pastor-Fernández, Otero-Mateo, & Ballesteros-Pérez, 2020; Park & Cai, 2017). Moreover, combining relational databases with BIM offers the potential to resolve historical data challenges (Huang, Liu, Huang, Onstein, & Merschbrock, 2023). While this enables more accurate cost tracking and budget forecasting, access to reliable historical data remains limited (Le, Likhitruangsilp, & Yabuki, 2020; Newman et al., 2021; Solihin, Eastman, Lee, & Yang, 2017). Adu-Amankwa, Rahimian, Dawood, and Park (2023) proposed a reporting framework tailored for AECO applications, demonstrating its value in streamlining reporting processes and enhancing project efficiency. Studies on major UK construction firms further explored the opportunities and challenges associated with Industry 4.0 implementation, offering insights into the future of project management (Adu-Amankwa et al., 2023; Newman et al., 2021). The incorporation of lean construction and Industry 4.0 technologies has been refined through further research, proposing improved methods for optimising documentation (Maqbool, Saiba, & Ashfaq, 2023; Newman et al., 2021). Emerging frameworks, such as the blockchain-based digital twin model for Construction 4.0, aim to integrate sustainability goals with digital innovation in reporting systems, thereby improving tracking processes and enabling broader impact analysis (Sepasgozar et al., 2023; Tanko, Zakka, & Heng, 2024; Teisserenc & Sepasgozar, 2021). Alongside these developments, advanced DBMS continue to evolve to meet the complex data needs of modern construction reporting systems (Zou et al., 2019). Through integration with the Internet, these systems consolidate inputs from various stakeholders—including site teams, engineers, contractors, and suppliers—along with historical data and analytical models to create dynamic project dashboards and reporting platforms (Radman et al., 2021). These tools provide real-time insights, allowing contractors to monitor projects more accurately and efficiently. Relational databases, in particular, offer a structured and reliable framework for data management, enabling better access and accuracy while helping stakeholders detect delay patterns and formulate mitigation strategies (Ghosh et al., 2020; Wellings, Bollella, Dibble, & Holmes, 2004). The integration of UML with databases has further strengthened data management practices (Huang et al., 2023), reinforcing the transformative role of digital technologies in modernising construction reporting and tracking systems(Maqbool et al., 2023; Newman et al., 2021; Tanko et al., 2024).

3. PROBLEM STATEMENT

Despite advancements in construction reporting systems, a significant gap remains in implementing integrated, real-time, data-driven solutions to optimise multi-source data (e.g., engineering, planning, site operations, and contractor activities) across major projects. Existing systems often fail to leverage centralised approaches, which is critical for managing construction's dynamic complexity (Arif & Khan, 2020). Key challenges associated with current projects tracking approaches include: (1) High Costs: Prohibitive expenses limit adoption (Braun, Tuttas, Stilla, & Borrmann, 2014; Freimuth & König, 2018; Meredith, Shafer, Mantel Jr, & Sutton, 2020); (2) Inefficiency: Time-consuming implementation reduces on-site utility (Alizadehsalehi & Yitmen, 2019; Hwang, Zhao, & Ng, 2013); (3) Poor Communication: Collaboration tools inadequately support project-wide coordination (Gamil & Abd Rahman, 2023; Kerzner, 2017); (4) Data Management Challenges: Disorganised historical data impedes productivity and progress comparison (Azhar, Nadeem, Mok, & Leung, 2008; Eastman, Eastman, Teicholz, Sacks, & Liston, 2011; Jung & Kang, 2007; Kazemi, Beheshti, & Nobari, 2020; Ngcobo, Bhengu, Mudau, Thango, & Lerato, 2024; Vestin, Säfsten, & Popovic, 2023); (5) Integration Complexity: Projects struggle to address interdisciplinary requirements (Jiang & Messner, 2023; Wu, Li, & AbouRizk, 2022; Zhong et al., 2019). (6) Accuracy: Persistent reporting inaccuracies despite BIM/P6/Aconex use, exacerbated by flawed data flow among stakeholders (contractors, designers, engineers, and project teams) (Radman et al., 2021; Radman, Jelodar, Lovreglio, Ghazizadeh, & Wilkinson, 2022b). Furthermore, reliance on manual or semi-automated systems (e.g., paper-based data collection, photo documentation, and retrospective spreadsheet analysis) significantly increases the risk of delayed decision-making for critical delay events (Sanni-Anibire, Mohamad Zin, & Olatunji, 2022). These outdated approaches impair accurate time and cost forecasting, leading to compounded schedule disruptions and budget overruns (Figure 1). Standalone project management tools exacerbate these inefficiencies by creating data silos rather than enabling real-time analysis (Radman, Jelodar, et al., 2022b).

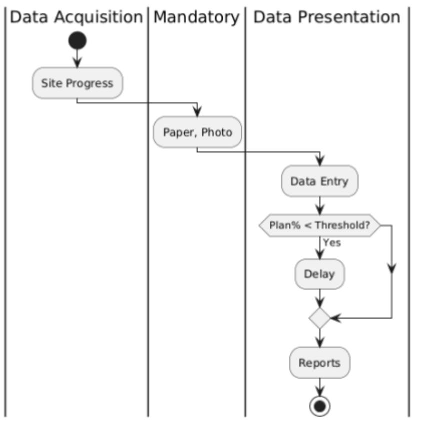


Figure 1: Overview – existing data collection process for data presentation.

This research proposes RealCONs, a digital framework for real-time construction reporting designed to address these challenges by capturing on-site data to enhance reporting accuracy, accelerate report preparation, improve data integrity, reduce reporting errors, and minimise delay-related costs and time impacts through early-stage delay management.

4. RESEARCH GOALS AND OBJECTIVES

This study aims to develop and validate RealCONs, a digital reporting framework to streamline construction site reporting. The core goals and objectives are to:

- Accelerate daily report generation through real-time data integration.
- Enhance reporting accuracy by reducing manual errors via standardised validation rules.
- Improve project performance by enabling earlier identification of delays using EVM metrics.

The research also benchmarks RealCONs against key digital tools, addressing existing inefficiencies and promoting more innovative data-driven construction practices.

5. RESEARCH METHODOLOGY

This study employs the Rational Unified Process (RUP) framework to guide the development of RealCONs, a digital construction reporting system aimed at (1) improving daily report generation speed, (2) reducing reporting errors, and (3) enhancing project performance through early delay identification. The RUP phases, such as Inception, Elaboration, Construction, and Transition, were adapted to structure RealCONs' development, from scoping and stakeholder analysis to system architecture definition, data integration, and report delivery. As seen in Figure 2, the system integrates real-time field data captured via QR codes and smartphones by site supervisors, synchronised with data from BIM (3D model), Oracle P6 (time/cost), Aconex (documents), and site databases (progress updates). A UML-based model standardises data through unification and validation workflows, minimising manual interventions and aligning reporting outputs.

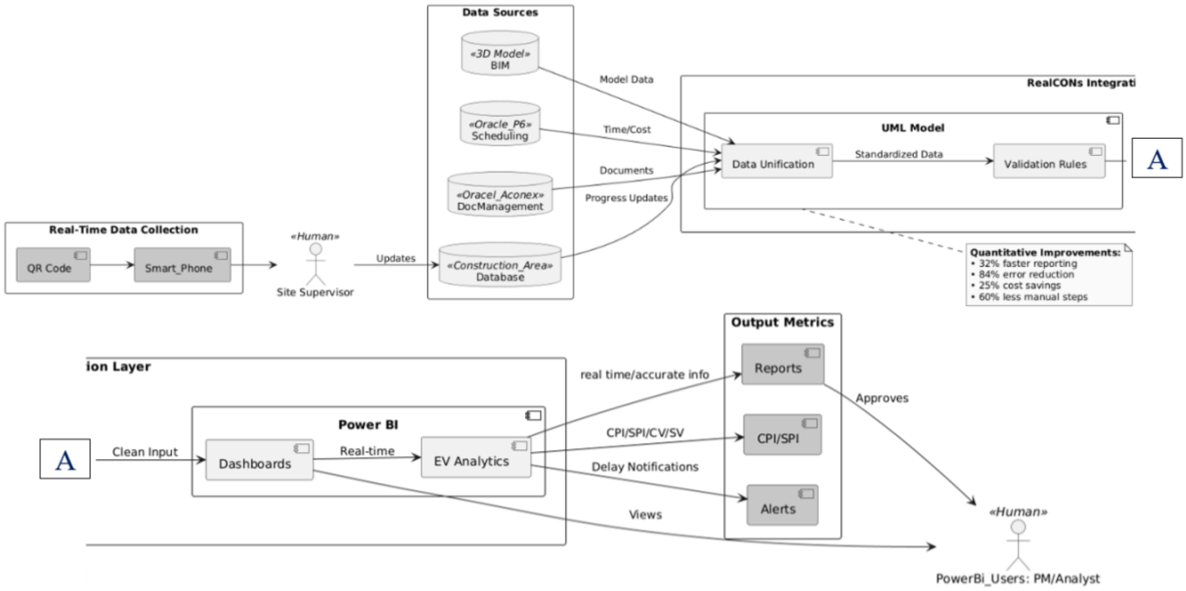


Figure 2: Research Methodology.

5.1 Research design and Data Collection

A mixed-methods approach validated the RealCONs framework. Quantitative data were sourced from an active Electrical & Instrumentation (E&I) construction project. Daily report preparation times, error frequencies, and Earned Value Management (EVM) indicators were collected and analysed.

5.2 Evaluation Metrics

RealCONs' performance was assessed using the following metrics:

- Report Generation Speed: Average daily report preparation times before and after implementation.
- Reporting Accuracy: Frequency and errors recorded in error logs.
- Project Performance Impact: Impact of early delay identification measured using CPI and SPI.

6. MODELLING: RATIONAL UNIFIED PROCESS (RUP)

Designing a real-time progress tracking and reporting system requires seamless hardware and software components integration. The Rational Unified Process (RUP), an iterative development methodology, and the Unified Modelling Language (UML), a widely used graphical language for data modelling, provide a structured approach to simplifying this task. In other words, UML is a static diagram defining a system's structure and how its components interact. Data modelling is fundamental in visualising and organising collaboration among system components, ensuring efficient tracking and reporting. This process involves three key stages: (i) Requirement Identification, where project needs are defined; (ii) Conceptual Modelling, which establishes the relationships between stakeholders and system components; and (iii) Implementation, where suitable technologies are selected and integrated into a cohesive system. This approach is illustrated by examining a dynamic on-site tracking and reporting system for railcar monitoring, which highlights the nonlinear and intricate nature of project tracking. RUP is a standard methodology that simplifies the modelling process by focusing on system architecture and relevant use cases, ensuring that only essential elements are included. RUP consists of four iterative phases:

Inception, Elaboration, Construction, and Transition, each with clearly defined disciplines, activities, roles, and outputs such as documentation, models, and system components. Therefore, Figure 3 presents the RUP view as follows:

- Phase 1- Inception Phase: It establishes project feasibility by identifying the project scope, defining stakeholders, assessing data collection needs, developing a business case, and drafting an initial reporting framework.
- Phase 2- Elaboration Phase: It refines the system architecture, establishes data processing workflows, and enhances approval and delay assessment rules, laying the groundwork for subsequent phases.
- Phase 3- Construction Phase: It involves data collection by supervisors, project administrators, and analysts, with project administrators entering data into the system. The project analyst then cleans and analyses the data, generating comprehensive reports.
- Phase 4- Transition Phase: It focuses on finalising reports, delivering them to stakeholders, improving workflow efficiency, ensuring enhanced decision-making and streamlined project execution.

UML is applied to support this structured approach due to its versatility in graphical data modelling. UML comprehensively represents the four RUP phases through class and use-case diagrams, enabling effective process monitoring and optimisation. The proposed framework ensures dynamic project tracking and reporting, with experimental results validating its effectiveness in improving accuracy, efficiency, and decision-making in project management.

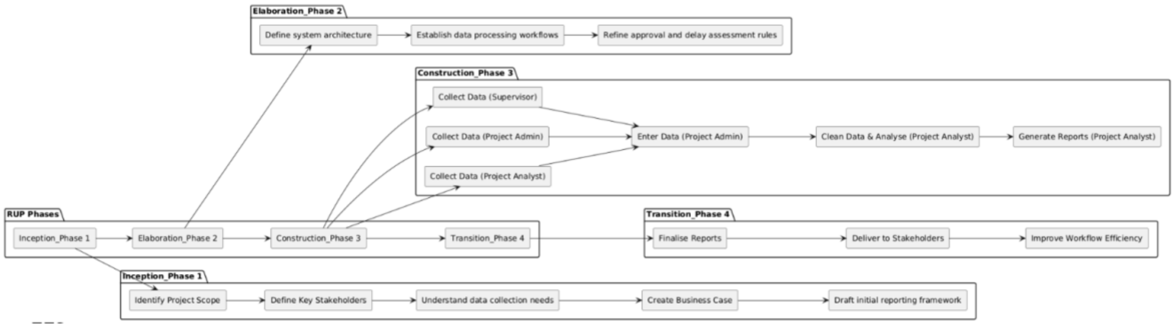


Figure 3: Research RUP Structure.

7. REALCONS FRAMEWORK IN DETAIL

This work presents a new process-based digital framework for on-site project reporting management (RealCONs) designed to address the limitations identified in the problem statements. The RealCONs framework integrates various tools and systems to improve project management, tracking, and reporting in large-scale construction projects. It connects essential tools such as Building Information Modelling (BIM), Aconex (a document management system), Primavera (P6) (planning and scheduling software), Power BI (an analytical dashboard), and SQL (a server that stores real-time construction site data) to enable seamless data flow and support real-time decision-making. The RealCONs framework employs security rules and protocols using Application Programming Interfaces (APIs), which allow multiple resources to communicate securely. Technically, APIs facilitate system integration by enabling applications to exchange data and perform tasks without requiring detailed knowledge of each application's internal workings. Within the RealCONs framework, APIs ensure efficient data exchange between BIM, Aconex, P6, and Power BI, allowing real-time data to be updated and analysed. Additionally, the Construction Site component collects real-time data using smartphones to scan QR codes. The collected data is stored in an SQL database, which connects to Power BI for advanced reporting and visualisation.

This integrated structure centralises data from multiple sources, providing a comprehensive solution for managing and reporting processes throughout major construction projects. Figure 4 depicts a use case diagram outlining the operational workflow. Authorised site supervisors employ smartphones to scan QR codes, with captured data transmitted to a centralised SQL Server repository. Concurrently, integrated tools such as BIM software, Oracle Primavera P6, and Oracle Aconex interface with Power BI via API connections, enabling cross-platform data interoperability. The analytical dashboard (Power BI) subsequently processes this aggregated data, generating visualised reports for stakeholder review.

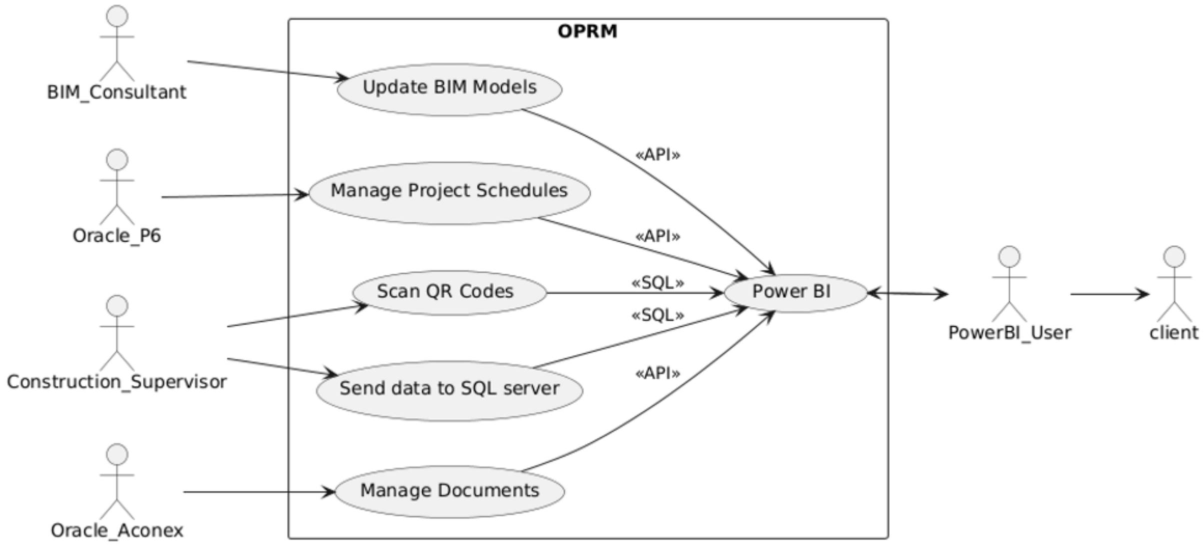


Figure 4: RealCONs framework's use case diagram between different users.

Structurally, Figure 4 encompasses five defined actors (A1–A5) and two core components (C1 and C2), as detailed in the preceding sections. This diagrammatically encapsulates the systemic integration of data collection, storage, and analytical visualisation within the project framework, as described below:

Table 1: Project framework.

Actors	A1. **Construction_Supervisor**: Authorised site supervisors can employ smartphones for on-site data collection. These devices scan QR codes, systematically gathering real-time operational data directly from construction sites.
	A2. **BIM_Consultant**: Members of the engineering and design team, including BIM consultants, utilise specialised software (e.g., Revit, Navisworks) to access, review, and collaborate on BIM. It facilitates the integration of technical designs and project documentation.
	A3. **Project Scheduler (Oracle_P6)**: Project planners, schedulers or analysts oversee the development, management, and monitoring of project timelines using Oracle Primavera (P6). This role involves critical path analysis, resource allocation, and progress tracking to ensure adherence to scheduled milestones.
	A4. **Document Manager (Oracle_Aconex)**: The head contractor grants subcontractors access to a centralised platform (Oracle Aconex) for document submission. The document manager oversees the coordination, storage, and maintenance of all project-related documentation to ensure compliance and accessibility.
	A5. **Power BI_User**: Authorised stakeholders, such as project managers and senior decision-makers, are granted read-only access to visual dashboards displaying analytical reports. For security purposes, editing privileges are restricted to designated project schedulers and analysts, who may develop, modify, and disseminate reports via Power BI.
System Components	**C1) SQL Server**: Microsoft SQL Server functions as a centralised data repository, aggregating operational information captured via QR code scans conducted on-site. This data is subsequently channelled to Power BI to support real-time analytical processing, ensuring stakeholders can access up-to-date insights for informed decision-making.
	C2) API Connections: Application Programming Interfaces (APIs) facilitate bidirectional data integration between Power BI and external third-party platforms, such as Oracle Primavera P6, Oracle Aconex, and BIM software. These connections ensure interoperability, enabling automated data synchronisation across systems while maintaining consistency and operational coherence.

Figure 5 presents a cross-sectional view of the RealCONs framework's sequence diagram, methodically delineating the chronological interactions and systemic data flow from initial on-site data collection (via QR code scanning) to the final presentation of analytical reports. In this process, construction supervisors use smartphones to scan on-site QR codes, collecting data on tasks to be completed, ongoing tasks, delays encountered, and resource utilisation. The collected data is simultaneously sent to a cloud-based central SQL Server (called construction_area as a virtual actor). The SQL Server then transfers this real-time data to Power BI for analysis and reporting. As a result, project managers, analysts, planners, and key stakeholders can monitor real-time project status and progress through Power BI dashboards. Additionally, in Figure 5, API_Systmes is representative of other actors contribute updates to Power BI via APIs as follows:

1. **BIM (Consultant)**: Provides 3D model data, which is transmitted through an API for visualisation in Power BI.
2. **Oracle_P6**: Sends scheduling information, such as actual progress compared to planned timelines, via API for comparative analysis.
3. **Oracle_Aconex**: Delivers document management data (e.g., version history and approvals) to Power BI through API integration, enabling efficient document tracking.

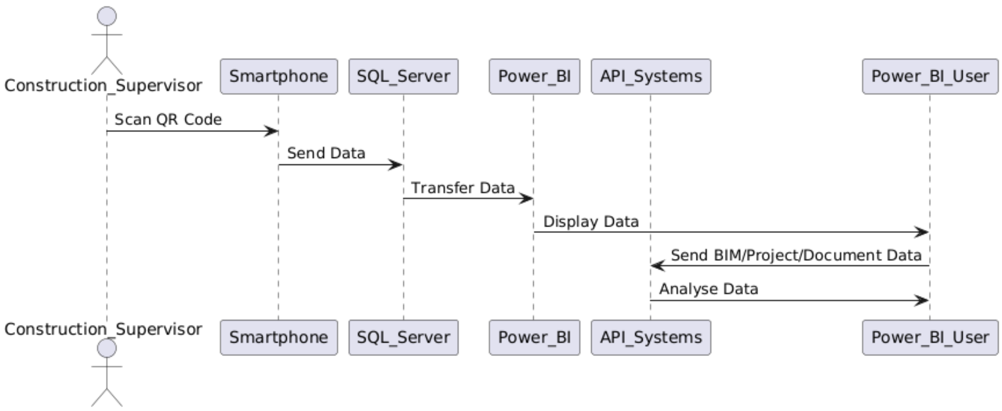


Figure 5: ReaLCONs framework' sequence diagram: Collected site data stage to reporting stage.

By integrating multiple data sources such as SQL Server, BIM, Oracle P6, and Oracle Aconex, Power BI creates a holistic view of the project, enabling stakeholders i) To visualise project status through interactive dashboards that display real-time reports; ii) To identify delays and analysis their impacts using EV metrics (Table 2); and iii) To make Data-Driven Decisions. Figure 6 illustrates the RealCONs integrated mapping approach.

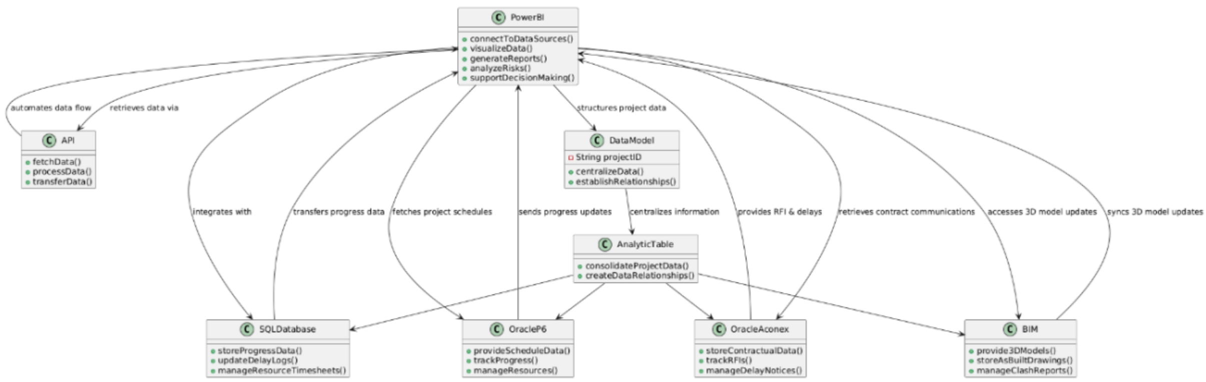


Figure 6: RealCONs integrated mapping approach.

The class diagram explains the data flow within each component and actor in Figure 5. Consequently, Figure 7 (a–e) presents individual class diagrams of the RealCONs framework components, illustrating data transfer from Oracle P6, Oracle Aconex, the construction area, and BIM to Power BI via APIs and SQL. The process starts when a smartphone scans a QR code, connects to the SQL Server, and transmits data to the construction site. A key advantage of the RealCONs system is its ability to provide early delay notifications. By continuously comparing actual progress with planned schedules (using tools such as Oracle P6), the system alerts project managers to potential delays as they arise. This early warning mechanism helps mitigate risks, enhances decision-making, and improves overall project efficiency. The following sections of this article will examine how the RealCONs system achieves its research objectives through comparative case studies.

Table 2: Earned Value Metrics (PMI, 2021).

Parameters	**Formula**	**Warning Indexes**
Schedule Variance (SV): The difference between planned and actual progress in time units.	SV = EV - PV	If SV<0 means PV > EV
Cost Variance (CV): Deviation between actual and planned costs.	CV = EV - AC	If CV<0 means AC > PV
Cost Performance Index (CPI): The ratio of EV to actual cost, measuring cost efficiency.	CPI = EV / AC	CPI =1: on budget CPI >1: Under budget CPI <1: Over budget
Schedule Performance Index (SPI): Estimated the projected time to complete the project	SPI = EV / PV	SPI =1: on schedule SPI >1: ahead of schedule SPI <1: Behind schedule
Estimate At Completion (EAC): PV of whole project/CPI	EAC=PV/CPI	
Estimated time To Complete (ETC)	ETC= Original time/SPI	

Planned Value (PV) is Budgeted Cost of Work Scheduled (called BCWS)

Actual Cost (AC) is Actual Cost of Work Performed (called ACWP)

Earned Value (EV) is Budgeted Cost of Work Performed (called BCWP)

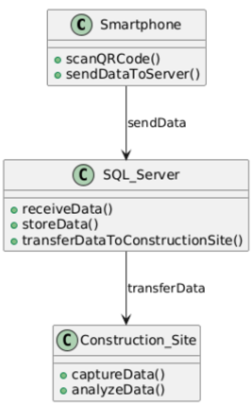


Figure 7 (a): Site Actual Data from Smartphone to Construction_Area.

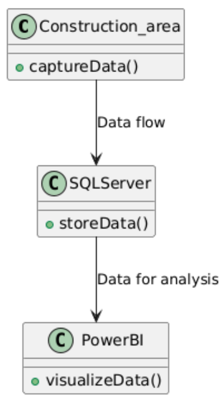


Figure 7 (b): Construction_Area (captured data) to Power BI.

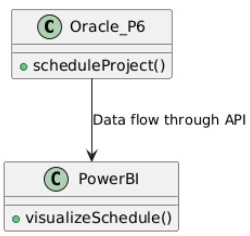


Figure 7 (c): Oracle_P6 (Scheduling) to Power BI.

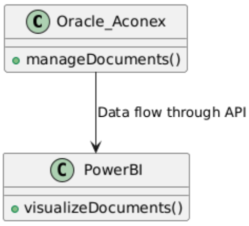


Figure 7 (d): Oracle_Aconex (Document Management) to Power BI.

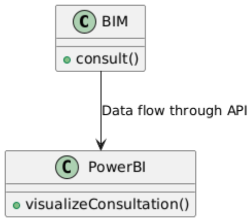


Figure 7 (e): BIM (Consultant) to Power BI.

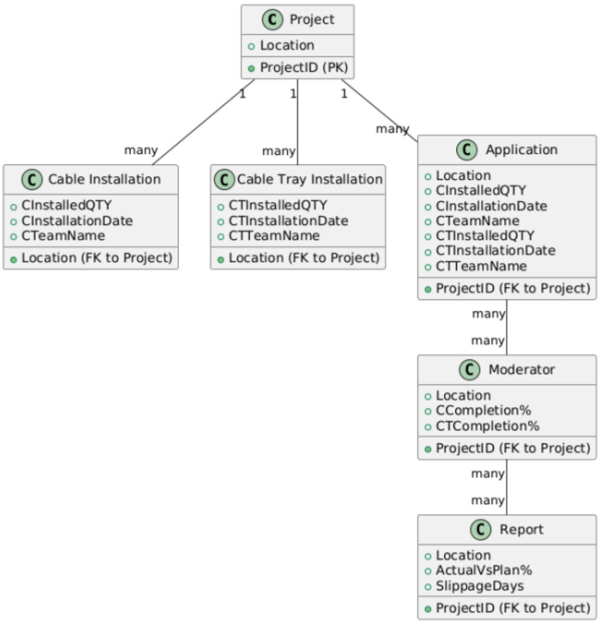


Figure 8: UML's classes and attributes.

Figure 5 illustrates the SQL Server component's role as a critical mechanism for collecting real-time site data, processing it, and transferring it to Power BI. While this workflow appears streamlined, it incorporates layered technologies and applications to facilitate efficient data acquisition, analysis, and visualisation. An object-oriented model, depicted in Figure 8 through UML class and use-case diagrams, is developed to formalise this structure. The class diagram acts as a foundational blueprint, defining system components, their attributes, and interrelationships. This abstract framework clarifies the responsibilities and services of each object within the system. For example, the "data acquisition" application class specifies parameters such as measurable items, data recording locations (e.g., building ID), timings, and personnel involved (e.g., on-site supervisors). Subsequent processing is managed through interconnected classes, including the project, cable installation, and cable tray installation classes, ensuring structured data flow and operational coherence. From a database management perspective, the processes illustrated in Figure 8 are implemented into a project database. It involves developing SQL scripts to create six relational tables: Project, Cable_Installation, Cable_Tray_Installation, Application, Moderator, and Report. The SQL script used to build this relational database is detailed in Table 3.

Table 3: Research database SQL script.

Create the Project table

```
CREATE TABLE Project (
ProjectID INT PRIMARY KEY,
Location VARCHAR(255) NOT NULL
);
```

Create the Cable Installation table

```
CREATE TABLE CableInstallation (
CableInstallationID INT PRIMARY KEY AUTO_INCREMENT,
ProjectID INT NOT NULL,
Location VARCHAR(255) NOT NULL,
CInstalledQTY INT NOT NULL,
CInstallationDate DATE NOT NULL,
CTeamName VARCHAR(255),
FOREIGN KEY (ProjectID) REFERENCES Project(ProjectID)
);
```

Create the Cable Tray Installation table

```
CREATE TABLE CableTrayInstallation (
CableTrayInstallationID INT PRIMARY KEY AUTO_INCREMENT,
ProjectID INT NOT NULL,
Location VARCHAR(255) NOT NULL,
CTInstalledQTY INT NOT NULL,
CTInstallationDate DATE NOT NULL,
CTTeamName VARCHAR(255),
FOREIGN KEY (ProjectID) REFERENCES Project(ProjectID)
);
```

Create the Application table

```
CREATE TABLE Application (
ApplicationID INT PRIMARY KEY AUTO_INCREMENT,
ProjectID INT NOT NULL,
Location VARCHAR(255) NOT NULL,
CInstalledQTY INT NOT NULL,
CInstallationDate DATE NOT NULL,
CTeamName VARCHAR(255),
CTInstalledQTY INT NOT NULL,
CTInstallationDate DATE NOT NULL,
CTTeamName VARCHAR(255),
FOREIGN KEY (ProjectID) REFERENCES Project(ProjectID)
);
```

Create the Moderator table

```
CREATE TABLE Moderator (
ModeratorID INT PRIMARY KEY AUTO_INCREMENT,
ProjectID INT NOT NULL,
Location VARCHAR(255) NOT NULL,
CCompletion DECIMAL(5, 2) NOT NULL,
CTCompletion DECIMAL(5, 2) NOT NULL,
FOREIGN KEY (ProjectID) REFERENCES Project(ProjectID)
);
```

```
Create the Report table
CREATE TABLE Report (
ReportID INT PRIMARY KEY AUTO_INCREMENT,
ProjectID INT NOT NULL,
Location VARCHAR(255) NOT NULL,
ActualVsPlanPercentage DECIMAL(5, 2) NOT NULL,
SlippageDays INT NOT NULL,
FOREIGN KEY (ProjectID) REFERENCES Project(ProjectID)
);
```

This database system enables project managers to process construction documents more effectively using the six tables. Figure 8 illustrates that the relationships between the Application, Moderator, and Report are many-to-many (m:n). Thus, links between the Application and Moderator and the Report are essential to the database structure.

Table 4: Database structure.

Link Application and Moderator	Link Moderator and Report
CREATE TABLE ApplicationModerator (	CREATE TABLE ModeratorReport (
ApplicationID INT NOT NULL,	ModeratorID INT NOT NULL,
ModeratorID INT NOT NULL,	ReportID INT NOT NULL,
PRIMARY KEY (ApplicationID, ModeratorID),	PRIMARY KEY (ModeratorID, ReportID),
FOREIGN KEY (ApplicationID) REFERENCES Application(ApplicationID),	FOREIGN KEY (ModeratorID) REFERENCES Moderator(ModeratorID),
FOREIGN KEY (ModeratorID) REFERENCES Moderator(ModeratorID)	FOREIGN KEY (ReportID) REFERENCES Report(ReportID)
);	);

In Table 3, the key points are as follows:

- Auto-Increment IDs: Auto-incrementing IDs (CableInstallationID, CableTrayInstallationID, etc.) ensure unique entries for each table.
- Foreign Keys: Maintain relationships between tables (e.g., ProjectID is a foreign key in dependent tables).
- Many-to-Many (m:n) Relationships: The ApplicationModerator and ModeratorReport junction tables manage the many-to-many relationships.

8. CASE STUDY

The case study methodology provides an in-depth understanding of specific contexts, processes, or issues within real-life settings, offering practical insights and actionable outcomes (Fellows & Liu, 2021). To establish RealCONs, two major construction projects, P-A and P-B, in double-storey buildings with a floor plan of approximately 900 m² are selected. These buildings are designed for healthcare purposes, necessitating close monitoring and reporting time, cost, and quality throughout the project life-cycle. Therefore, daily tracking of the project's productivity is essential to maintain efficiency and ensure the project stays on budget and schedule. The selection of case studies was based on several key criteria to ensure that the projects effectively represent the challenges that the RealCONs framework aims to address, such as 1) **Project Scale and Value** – the project value averages $120M, but E&I value between $20M and $35M; (i) **Similarity**- each project (building) having reached at least 85% structural completion before E&I access was granted to the site. It means buildings' roofs and walls have to be completed; (ii) **Availability of data and reporting system**- for example, the E&I team should report cabling (metre) and cable tray (meter) installation for all case studies. However, The projects use the exact reporting mechanism using Excel, photos, paper and MS Project; and (iii) **Stakeholder Diversity**- involvement of multidisciplinary trades, including Builders, E&I, Mechanical, Piping, and Structural involved multiple contractors, subcontractors, and consultants. However, the main reason for prioritising the Electrical and Instrumentation (E&I) trade is that E&I tasks must be completed earlier than other service trades, such as mechanical and security activities. This is because other trades require power for their equipment during commissioning and testing. Some overlapping tasks may be acceptable, but E&I work remains a high priority. As a result, progress is closely monitored, and early identification of issues is actively managed. The project brief specification expects the total metre of cabling and cable trays to be installed in each project, as seen in Table 5.

Table 5: Cabling and Cable Tray total quantity (must be installed).

Project	P-A	P-B	E&I Value $
Cabling (m)	12,000	11,320	$35 Million
Cable Tray(m)	12,800	12,800	$ 21 Million

For more visibility, Figure 9 provides a use case diagram that illustrates the interactions among key roles within the project management process, particularly in data-driven decision-making and reporting approaches. The primary roles include the Supervisor, Project Admin, Project Analyst, and Project Manager, each with distinct responsibilities to ensure an efficient workflow.

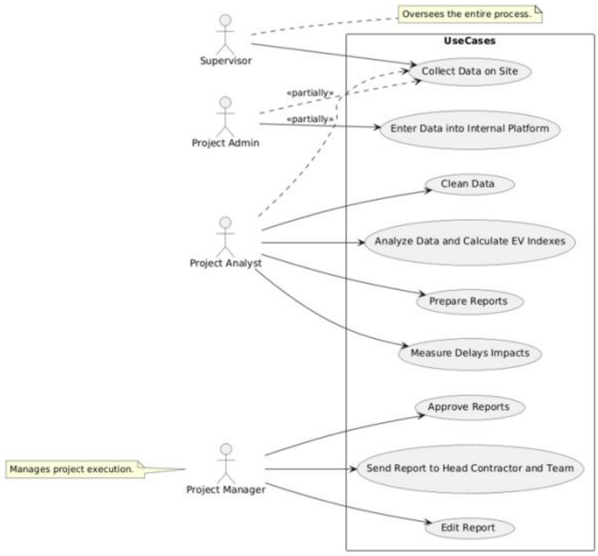


Figure 9: Use case – existing reporting approach.

The Supervisor oversees the entire process, while the Project Admin supports data entry into the internal platform, albeit partially. The Project Analyst assumes a pivotal role, engaging in critical activities such as partially collecting site data, cleaning and analysing data, and calculating Earned Value (EV) indices. The Project Analyst is also responsible for preparing reports and assessing delay impacts. The Project Manager oversees project execution, including reviewing, editing, and approving reports before disseminating them to the head contractor and the wider project team. The collaborative nature of the process is reinforced by partial contributions from the Project Admin, ensuring data integrity and completeness. This use case diagram underscores the structured approach to project management, where systematic data collection, rigorous analysis, and effective communication among stakeholders contribute to the successful execution of projects. Integrating these roles ensures that all critical aspects, from data acquisition to final reporting, are meticulously addressed, enhancing project performance and decision-making accuracy. Moreover, the existing reporting approach is examined through the reporting system structure of Project A.

For this purpose, a UML diagram is designed, as illustrated in Figure 3 – Research RUP Structure. In Project A, key stakeholders such as project managers, planners, and supervisors are represented as actors, with their relationships depicted as connections. UML is used as a tool to improve communication among these actors and to clarify project requirements. Additionally, the SIPOC (Suppliers, Inputs, Processes, Outputs, and Customers) model is applied to identify and analyse internal and external relationships within the project process, providing a structured understanding of the system. (Mishra & Kumar Sharma, 2014; Nshirim & Nwagwu, 2023). The SIPOC model is a structured framework for delineating key components within a construction project, facilitating stakeholder clarity and alignment. Suppliers encompass material providers, subcontractors, and regulatory authorities, who contribute resources or approvals essential to project initiation. Inputs include tangible and intangible elements, from construction materials, permits, and labour to technical specifications and financial capital. Processes, such as design development, site preparation, structural assembly, and quality inspections that constitute the activities Outputs are the resultant deliverables, such as completed infrastructure, compliance certifications, and project documentation, which fulfil contractual and regulatory requirements. Customers extend beyond the primary client to encompass end-users, local communities, and governing bodies, each with distinct expectations and criteria for project success. By mapping these interlinked elements, the SIPOC model enhances transparency, mitigates risks of miscommunication, and supports efficient resource allocation, thereby underpinning robust project governance in the inherently complex construction sector. Its systematic approach ensures stakeholders maintain a shared understanding of the project scope, fostering collaborative decision-making and adherence to predefined objectives.

Furthermore, SIPOC supports the Unified Modelling Language (UML) application by providing a high-level conceptual foundation for visualising system interactions. The identified Suppliers, Inputs, and Customers within SIPOC align with UML's actor and stakeholder definitions in use case diagrams. At the same time, Processes and Outputs inform activity or sequence diagrams, enabling granular mapping of workflows and dependencies. This integration ensures UML models remain contextually anchored to real-world project parameters, enhancing their utility in analysing process efficiency, stakeholder roles, and system boundaries during construction planning and execution. Figure 10 illustrates the SIPOC model diagram for the P-A project.

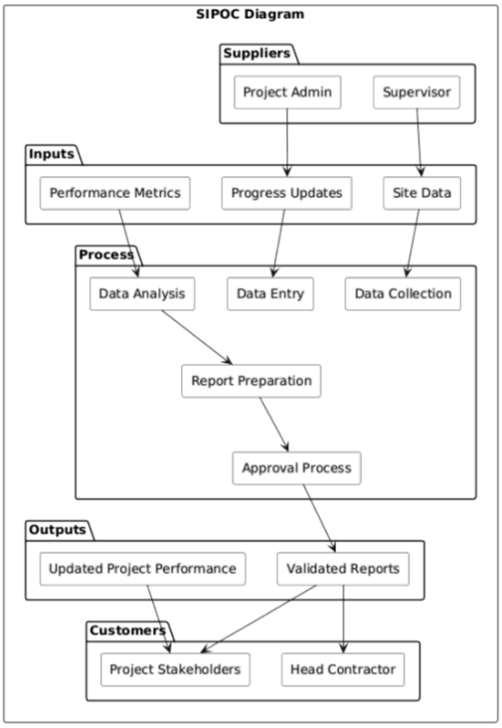


Figure 10: SIPOC model diagram for P-A Project.

From Figure 10, the SIPOC breakdown aligned with the UML activity diagram (Figure 11) as follows:

- **Suppliers (S):** The **Supervisor** is the primary data supplier, collecting on-site information and forwarding it to the **Project Admin**. So, the **Project Admin** enters the collected data into an internal platform before sending it for further analysis.

-**Inputs (I):** The primary inputs include site data, project progress updates, and performance metrics. These inputs are transferred through a structured data collection and submission process.
-**Process (P):** it is followed by six steps:

- **Data Processing & Cleansing:** The **Project Analyst** receives the data, cleans it, and ensures accuracy.
- **Data Analysis & EV Index Calculation:** Earned Value (EV) metrics are calculated to assess performance.
- **Report Preparation:** Findings are compiled into a structured report.
- **Approval Process:** The report is forwarded to the **Project Manager** for validation.
- **Conditional Assessment (Alternative Flow):** If delays are detected, their impact is measured, and an updated report is sent for review.
- **Final Approval & Submission:** The **Project Manager** edits, approves, and shares the final report with the Head Contractor and project team.

-**Outputs (O):** The final output is a validated project performance report incorporating potential delay impacts. Additionally, updated reports ensure real-time monitoring and proactive decision-making.
-**Customers (C):** The Head Contractor and project stakeholders utilise the report for strategic planning and execution. Finally, the report aids in mitigating risks and optimising project performance.

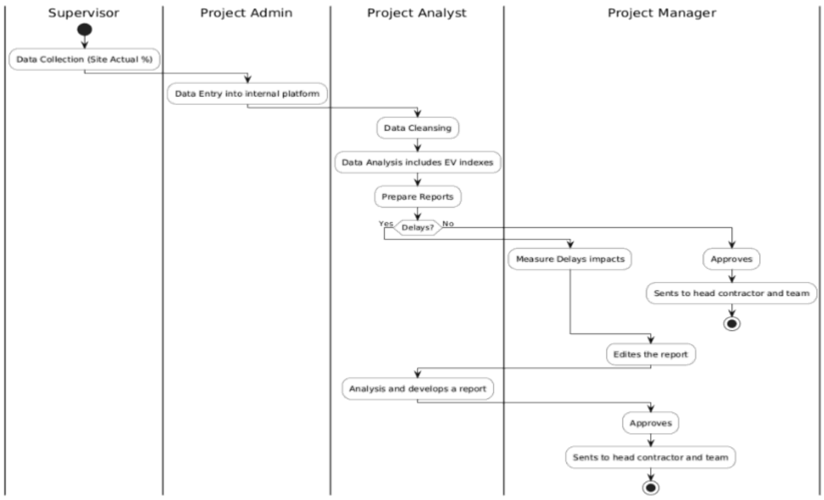


Figure 11: Project P-A (existing approach)' Activity Diagram.

In Figure 11, the activity diagram presents a structured project management process involving multiple roles and sequential steps to ensure efficient project execution. Key roles include the Supervisor, who oversees the process; the Project Admin, who is responsible for administrative tasks; the Project Analyst, who analyses data and prepares reports; and the Project Manager, who coordinates tasks and ensures timely delivery. The workflow begins with data collection from the site, followed by data entry, cleansing, and analysis, including Earned Value (EV) index calculations. Reports are then prepared and reviewed, leading to a decision point where delays are assessed. If delays are identified, their impacts are analysed before proceeding. The reports undergo approval and submission, followed by possible editing and final analysis before final approval. Once approved, the report is shared with the head contractor and team for implementation. This structured approach ensures data accuracy, timely reporting, and informed decision-making in project management.

Furthermore, the depicted sequence diagram in Figure 12 illustrates a structured workflow involving multiple roles in a project management process, focusing on data handling, analysis, and reporting. The process begins with the Project Manager collecting data on-site, which the Project Admin enters into an internal platform. This data is sent for analysis, where the Project Analyst performs data cleansing to ensure accuracy and calculates EV (Earned Value) indexes, which are critical for assessing project performance. Once the data is analysed, the Project

Analyst prepares a report and sends it to the Supervisor for approval. A decision point arises to determine if there are any delays in the project. If delays exist, their impacts are measured, and the report is updated accordingly. The Supervisor may request edits to the report before approving it. Once approved, the final report is sent to the head contractor and the team for further action. This sequence highlights the collaborative effort between roles, emphasising the importance of accurate data processing, thorough analysis, and iterative approval processes to ensure effective project management and decision-making.

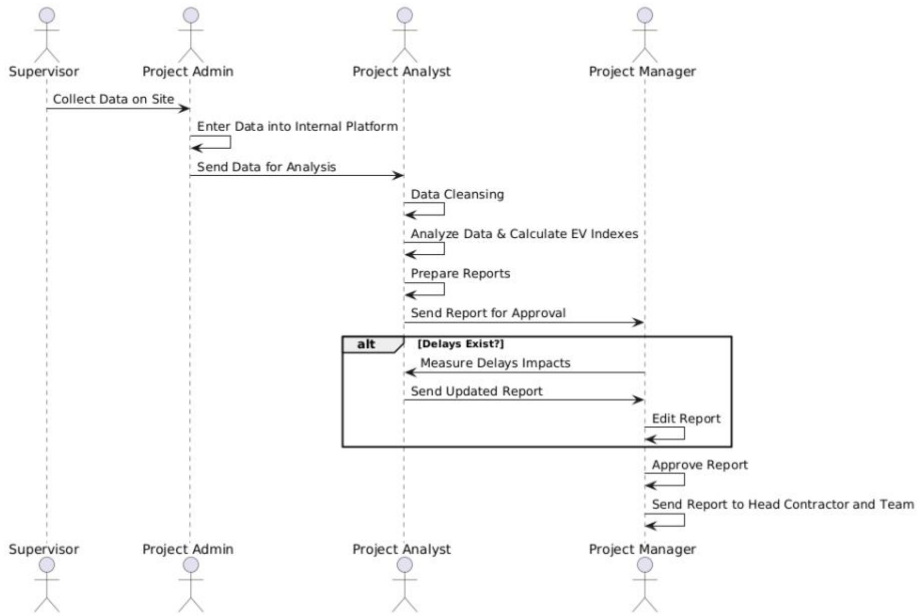


Figure 12: Project P-A (existing approach)' Sequence Diagram.

The following section will focus on assessing the research's goals: 1) improving daily report generation speed, 2) Reducing reporting errors, and 3) Implementing early delay detection and project performance analysis.

9. DISCUSSION AND RESULTS

The proposed RealCONs framework was validated through a comparative analysis between Project A (P-A), employing conventional reporting systems, and Project B (P-B), which implemented RealCONs. Two key qualitative metrics were examined: report accuracy, measured through data collection consistency rates, and report preparation time, calculated from initial data cleaning to final approval. The study further assessed RealCONs' effectiveness in early delay identification using earned value (EV) metrics and its subsequent impact on project performance. The analysis was structured into two sub_sections: Sub 9.1 (Site Data Collection Approach) focused on improving daily report generation speed and reducing reporting errors. At the same time, Sub 9.2 (Implications of Early Delay Detection) evaluated performance enhancements achieved through EV-based early delay identification.

9.1 Site Data Collection Approach

This section evaluates RealCONs' effectiveness in speeding up daily report generation and reducing errors through a three-month comparison between Project A (existing system) and Project B (RealCONs). The analysis measures report accuracy and preparation time under controlled conditions: simultaneous daily report collection, 90-report target (3 months), continuous operations, matched teams, and standardized methods (Figures 5 & 10). Project A relied on manual data collection by supervisors, requiring additional staff time for corrections, while Project B used QR code scanning. Results show Project B achieved 86/90 reports versus Project A's 65/90, with "N" indicating missing reports. Table 6 presents key performance metrics, demonstrating RealCONs' superior completion and error reduction rate efficiency. The structured comparison identifies performance gaps between the systems, validating RealCONs' advantages in operational reporting:

$$Improvement\ (\%) = \frac{(Project\ A"Existing") - (Project\ "B"OPRM")}{(Project\ A\ \text{"Existing"})} \times 100$$

For example, the total errors detected were 25 for Project A and 4 for Project B, resulting in an improvement percentage of 84%, calculated as (25-4)/25.

Table 6: Indexes analysis: Project A Vs Project B.

Performance Metric	**Project A (Existing)**	**Project B** (RealCONs)	**Improvement (%)**
Total Reports Generated	65	86	32.31%
Total Errors Detected #	25	4	84.00%
Total Errors Detected Ratio	25/90=27.78%	4/90=4.44%	84.00%
Report Preparation Time Per Report	135 minutes	50 minutes	62.96%
Total Time Saved (Across 90 Days)	-	7310 minutes	-
Daily Time Saved	-	81.22 minutes/day	-

The evaluation of time savings involved tracking actual report preparation time using a daily timesheet, which recorded the time spent by various users, including supervisors, administrators, project analysts, and project managers, from data collection to reporting approval. This process was measured across multiple reports per day to account for variations. The average time per report was calculated using the formula:

$$Actual\ Avg. Report\ Preparation\ Time = \frac{Total\ Time\ Spent\ on\ All\ Reports}{Total\ Number\ of\ Reports}$$

For example, in Project A (Existing Approach)

$$\frac{12180}{90} = 135\ minutes\ per\ report$$

To compare the performance of the two projects in report preparation time, accuracy, and efficiency, Table 6 presents key metrics. The RealCONs system (Project B) significantly improved the existing system (Project A). Over 90 days, Project B produced 86 reports compared to Project A's 65, achieving a 32.3% increase in output. Error rates declined sharply, with total errors reduced from 25 to 4 (an 84.0% improvement), while the error-to-report ratio fell from 27.8% to 4.4%. Additionally, report preparation time per submission decreased from 135 minutes to 50 minutes, yielding a 63.0% time saving and totalling 7,310 minutes saved over the 90 days as follows:

$$Total\ Time\ Saved = (Report\ Preparation\ Time\ in\ Project\ A - Report\ Preparation\ Time\ in\ Project\ B) \times TotalReports\ in\ Project\ B$$

$$Total\ Time\ Saved - Project\ B = (135 - 50) \times 86 = 7310\ minutes$$

On a daily scale, this corresponds to a time saving of 81.22 minutes per day, determined by:

$$Daily\ Time\ Saved = \frac{Total\ Time\ Saved}{Total\ Days} = \frac{7310}{90} = 81.22\ minutes/day$$

Table 7 states the Actual Average Time per Report (Minutes) for projects A and B:

Table 7: Actual Average Time per Report (Minutes).

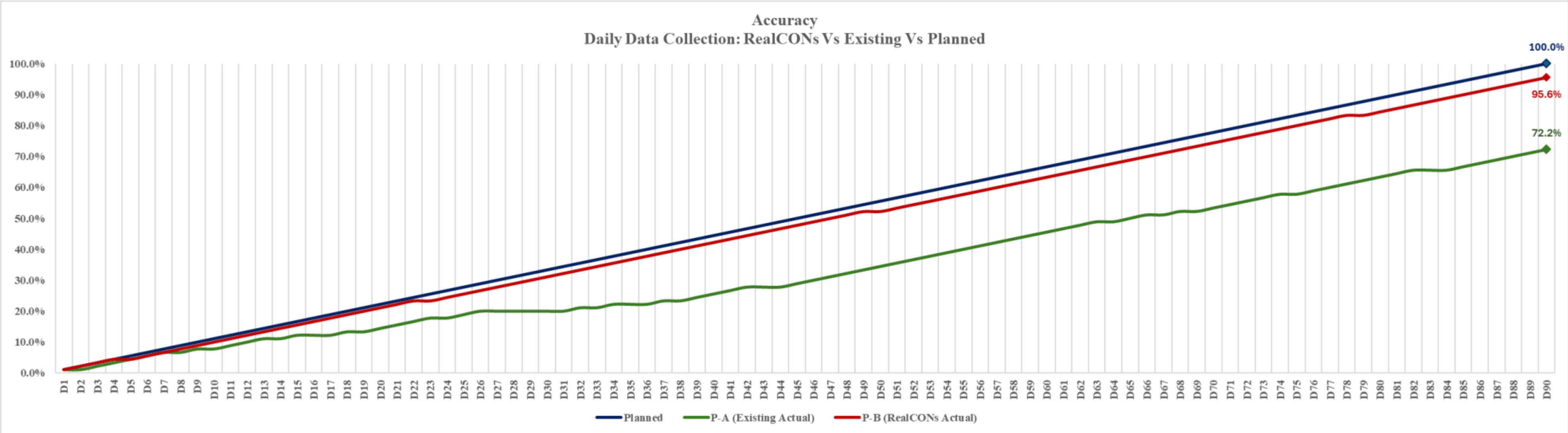
Project System	**Total Reports in 90 Days**	**Total Time Spent (Minutes)**	**Actual Average Time per Report (Minutes)**
Project A (Existing)	90 reports	12,180 min	135 min/report
Project B (RealCONs)	90 reports	4,530 min	50 min/report

The analysis showed clear improvements: (i) in reporting accuracy using RealCONs (Project B), which reached

95.6% compared to 72.2% in Project A (Figure 13), and (ii) in data slippage, which was significantly reduced from 27.8% to 4.4% (Figure 14). Table 9 outlines common reporting errors, including data entry mistakes, missing information, miscalculations, formatting issues, delays, misclassifications, and synchronisation problems. These issues often result in rework, financial discrepancies, and poor decision-making. Unlike the existing system (Project A), which depends on administrators to correct errors and fill data gaps—requiring additional time—RealCONs reduced the error rate by 84% through automated validation, real-time synchronisation, and standardised templates (Table 6). These findings demonstrate how RealCONs streamlines reporting, reduces errors, and improves operational efficiency in construction projects. While the system already outperforms manual processes, further refinement of its error detection mechanisms could enhance its reliability. Overall, this highlights the potential of digital reporting tools like RealCONs to improve accuracy and productivity in project management.

Table 8: Three-month data collection: Project A Vs Project B.

,	**90**	**65**	**86**	**Continued**			
Day	**Planned**	**P-A (Existing)**	**P-B** (RealCONs)	**Day**	**Planned**	**P-A (Existing)**	**P-B** (RealCONs)
D1	1	Y	Y	D46	1	Y	Y
D2	1	N	Y	D47	1	Y	Y
D3	1	Y	Y	D48	1	Y	Y
D4	1	Y	Y	D49	1	Y	Y
D5	1	Y	N	D50	1	Y	N
D6	1	Y	Y	D51	1	Y	Y
D7	1	Y	Y	D52	1	Y	Y
D8	1	N	Y	D53	1	Y	Y
D9	1	Y	Y	D54	1	Y	Y
D10	1	N	Y	D55	1	Y	Y
D11	1	Y	Y	D56	1	Y	Y
D12	1	Y	Y	D57	1	Y	Y
D13	1	Y	Y	D58	1	Y	Y
D14	1	N	Y	D59	1	Y	Y
D15	1	Y	Y	D60	1	Y	Y
D16	1	N	Y	D61	1	Y	Y
D17	1	N	Y	D62	1	Y	Y
D18	1	Y	Y	D63	1	Y	Y
D19	1	N	Y	D64	1	N	Y
D20	1	Y	Y	D65	1	Y	Y
D21	1	Y	Y	D66	1	Y	Y
D22	1	Y	Y	D67	1	N	Y
D23	1	Y	N	D68	1	Y	Y
D24	1	N	Y	D69	1	N	Y
D25	1	Y	Y	D70	1	Y	Y
D26	1	Y	Y	D71	1	Y	Y
D27	1	N	Y	D72	1	Y	Y
D28	1	N	Y	D73	1	Y	Y
D29	1	N	Y	D74	1	Y	Y
D30	1	N	Y	D75	1	N	Y
D31	1	N	Y	D76	1	Y	Y
D32	1	Y	Y	D77	1	Y	Y
D33	1	N	Y	D78	1	Y	Y
D34	1	Y	Y	D79	1	Y	N
D35	1	N	Y	D80	1	Y	Y
D36	1	N	Y	D81	1	Y	Y
D37	1	Y	Y	D82	1	Y	Y
D38	1	N	Y	D83	1	N	Y
D39	1	Y	Y	D84	1	N	Y
D40	1	Y	Y	D85	1	Y	Y
D41	1	Y	Y	D86	1	Y	Y
D42	1	Y	Y	D87	1	Y	Y
D43	1	N	Y	D88	1	Y	Y
D44	1	N	Y	D89	1	Y	Y
D45	1	Y	Y	D90	1	Y	Y



	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16	D17	D18	D19	D20	D21	D22	D23	D24	D25	D26	D27	D28	D29	D30
Planned	1.1%	2.2%	3.3%	4.4%	5.6%	6.7%	7.8%	8.9%	10.0%	11.1%	12.2%	13.3%	14.4%	15.6%	16.7%	17.8%	18.9%	20.0%	21.1%	22.2%	23.3%	24.4%	25.6%	26.7%	27.8%	28.9%	30.0%	31.1%	32.2%	33.3%
P-A (Existing Actual)	1.1%	1.1%	2.2%	3.3%	4.4%	5.6%	6.7%	6.7%	7.8%	7.8%	8.9%	10.0%	11.1%	11.1%	12.2%	12.2%	12.2%	13.3%	13.3%	14.4%	15.6%	16.7%	17.8%	17.8%	18.9%	20.0%	20.0%	20.0%	20.0%	20.0%
P-B (RealCONs Actual)	1.1%	2.2%	3.3%	4.4%	4.4%	5.6%	6.7%	7.8%	8.9%	10.0%	11.1%	12.2%	13.3%	14.4%	15.6%	16.7%	17.8%	18.9%	20.0%	21.1%	22.2%	23.3%	23.3%	24.4%	25.6%	26.7%	27.8%	28.9%	30.0%	31.1%

	D31	D32	D33	D34	D35	D36	D37	D38	D39	D40	D41	D42	D43	D44	D45	D46	D47	D48	D49	D50	D51	D52	D53	D54	D55	D56	D57	D58	D59	D60
Planned	34.4%	35.6%	36.7%	37.8%	38.9%	40.0%	41.1%	42.2%	43.3%	44.4%	45.6%	46.7%	47.8%	48.9%	50.0%	51.1%	52.2%	53.3%	54.4%	55.6%	56.7%	57.8%	58.9%	60.0%	61.1%	62.2%	63.3%	64.4%	65.6%	66.7%
P-A (Existing Actual)	20.0%	21.1%	21.1%	22.2%	22.2%	22.2%	23.3%	23.3%	24.4%	25.6%	26.7%	27.8%	27.8%	27.8%	28.9%	30.0%	31.1%	32.2%	33.3%	34.4%	35.6%	36.7%	37.8%	38.9%	40.0%	41.1%	42.2%	43.3%	44.4%	45.6%
P-B (RealCONs Actual)	32.2%	33.3%	34.4%	35.6%	36.7%	37.8%	38.9%	40.0%	41.1%	42.2%	43.3%	44.4%	45.6%	46.7%	47.8%	48.9%	50.0%	51.1%	52.2%	52.2%	53.3%	54.4%	55.6%	56.7%	57.8%	58.9%	60.0%	61.1%	62.2%	63.3%

	D61	D62	D63	D64	D65	D66	D67	D68	D69	D70	D71	D72	D73	D74	D75	D76	D77	D78	D79	D80	D81	D82	D83	D84	D85	D86	D87	D88	D89	D90
Planned	67.8%	68.9%	70.0%	71.1%	72.2%	73.3%	74.4%	75.6%	76.7%	77.8%	78.9%	80.0%	81.1%	82.2%	83.3%	84.4%	85.6%	86.7%	87.8%	88.9%	90.0%	91.1%	92.2%	93.3%	94.4%	95.6%	96.7%	97.8%	98.9%	100.0%
P-A (Existing Actual)	46.7%	47.8%	48.9%	48.9%	50.0%	51.1%	51.1%	52.2%	52.2%	53.3%	54.4%	55.6%	56.7%	57.8%	57.8%	58.9%	60.0%	61.1%	62.2%	63.3%	64.4%	65.6%	65.6%	65.6%	66.7%	67.8%	68.9%	70.0%	71.1%	72.2%
P-B (RealCONs Actual)	64.4%	65.6%	66.7%	67.8%	68.9%	70.0%	71.1%	72.2%	73.3%	74.4%	75.6%	76.7%	77.8%	78.9%	80.0%	81.1%	82.2%	83.3%	83.3%	84.4%	85.6%	86.7%	87.8%	88.9%	90.0%	91.1%	92.2%	93.3%	94.4%	95.6%

All items highlighted in red indicate missing daily reports.

Figure 13: *Data Accuracy:* RealCONs *Vs Existing Approach.*

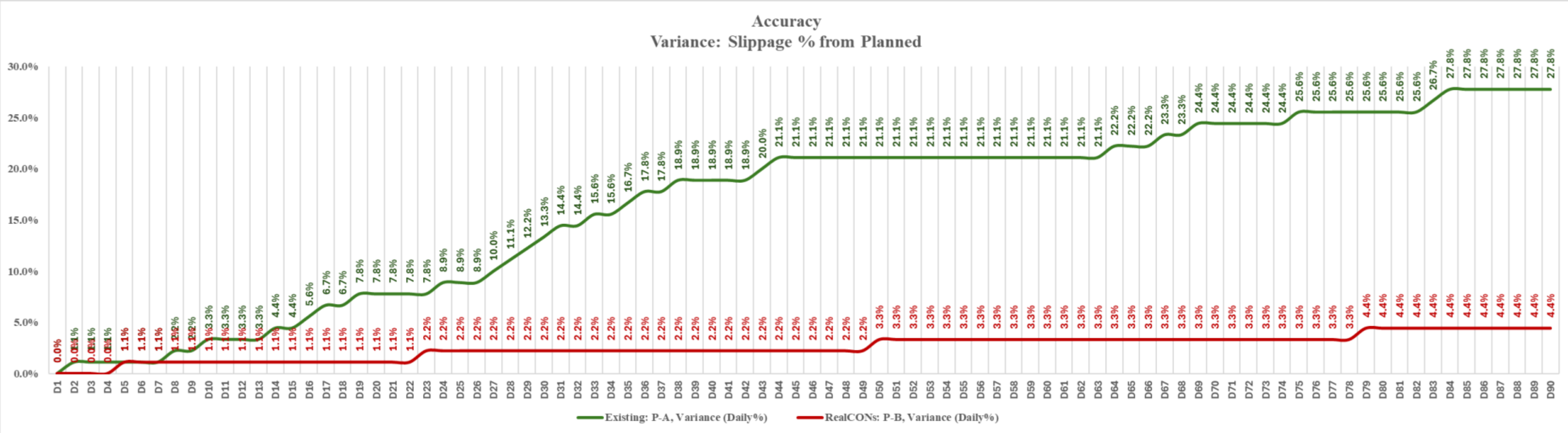


Figure 14: Data Accuracy variance: RealCONs Vs Existing approach.

Table 9: Types of Errors in Report Accuracy Analysis: RealCONs vs. Existing System.

Error Type	Common Issues	Impact on Reports	Existing System	RealCONs	Improvement
Data Entry Errors	Incorrect values, typos, misplaced decimals (e.g., 100.5 vs. 10.05).*5	Flawed decisions due to inaccurate records.	12 errors	2 errors*1	83.30%
Missing Data	Unrecorded measurements, skipped details.	Unreliable analysis, rework.	25 missing reports (65/90)	4 missing reports (86/90)	(25-4)/25= 84%
Calculation Errors	Wrong EV/CPI formulas summation mistakes.	Misrepresented project efficiency/financial status.	8 errors*2	1 error*1	(8-1)/8= 87.50%
Formatting Errors	Misaligned tables, unit inconsistencies, mismatched graphs.	Misinterpretation by stakeholders.	6 errors*3	1 error*1	83.30%
Time-Lag Errors	Delays in submission (e.g., 3-day lag).	Decisions are based on outdated data.	3-day	4-hour	88.9%*4

*1- Internet connectivity problems caused system glitches.

*2-Manual spreadsheet formulas prone to human error.

*3-Lack of standardized templates; ad-hoc report creation

*4-(3_days – 4_hours) / 3_days

*5- Project Analysis of Project A (existing) recorded data entry errors during analysis of the 90 reports

9.2 Implications of early delay detection and project performance analysis

This section explains how RealCONs enhances project performance through earned value (EV) metrics (CPI/SPI). The framework enables real-time EV analysis by integrating actual site data—captured via smartphone QR code scanning—into a structured SQL Server database (see data model). The model links project activities (e.g., cable installation, cable tray installation, applications, moderator updates, and reports) to unique ProjectIDs across locations. Automated data transfers populate SQL tables with installed quantities, team names, and dates. Power Query Editor transforms this data using M-code scripts to clean and standardise inputs (handling nulls, converting data types, filtering dates) in Power BI. Concurrently, Power BI imports planned schedule data (task start dates, durations, status) from the planning system (Figure 6), enabling baseline-vs-actual progress alignment. Earned Value metrics are dynamically calculated: PV (Planned Value), the Budgeted cost of scheduled work; EV, the Budgeted cost of completed work (based on installed quantities); and AC (Actual Cost): Site records/cost logs. Daily SPI and CPI comparisons trigger automated alerts if thresholds are breached (e.g., significant schedule/cost deviations). The system then analyses delays, identifies affected tasks, quantifies impacts (days/cost), and visualises results in dashboards. Power BI automatically generates comprehensive progress reports that include (1) task-level schedule progress tracking, (2) time and cost variance analysis, (3) delay alerts with earned value (EV) matrix insights, and (4) impact forecasts projecting revised completion dates and potential budget overruns. All reported changes and delays must be systematically updated across the relevant connected components, Oracle_P6, BIM, and Oracle_Aconex, to maintain data integrity. For instance, Figure 15 demonstrates the practical implementation of real-time monitoring, presenting an integrated technical view of Oracle_P6 components (from Figure 6) and data flow processes (from Figure 5). It illustrates how real-time site data links to and informs the project plan/schedule through systematic analysis and Oracle_P6 updates relevant changes.

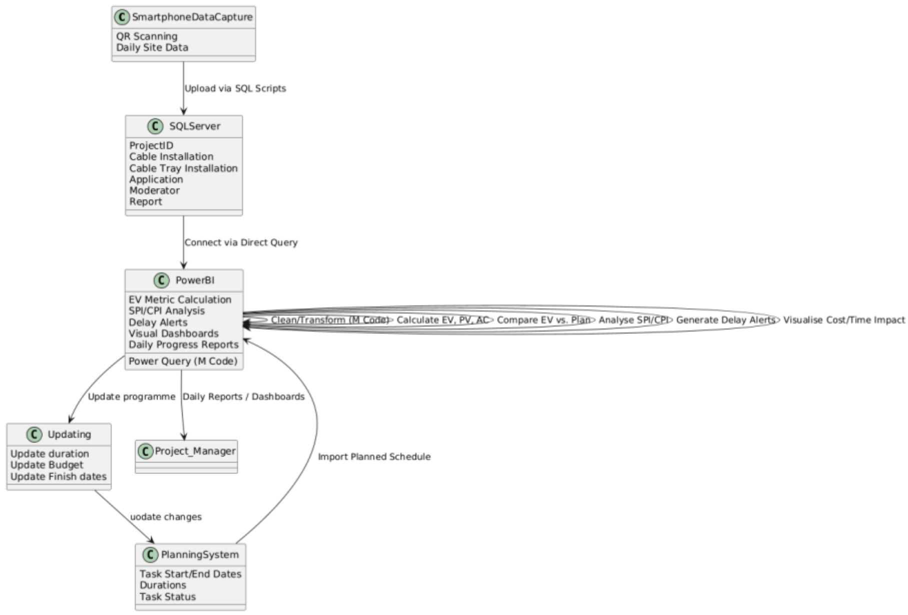


Figure 15: Technical view: earned value (EV) metrics analysis.

As illustrated in Figure 15, when a delay was reported on Day 13, RealCONs immediately updated the project schedule, enabling the schedule key milestone (contract payment) to identify affected tasks and dependencies, revealing a two-day shift in project completion (refer to SG1 as bellow). This proactive adjustment gave the project manager accurate budget forecasts for delay impacts, resulting in a $6.98M saving by Day 26 (refer to SG2 below). RealCONs achieved this through real-time integration of smartphone-captured site data (via QR codes) into SQL Server, which Power BI processed to compute Earned Value (EV) metrics, generate daily reports, and align actual progress with the planned schedule. Table 8 presents the first month of a 90-day project, quantifying the effects of the Day 13 delay. The contract included a $20k payment milestone on Day 18 and a 14-day notice response period (in this case, Day 26). Upon identifying the delay, the P-B supervisor (using RealCONs) immediately logged the disruption via smartphone, triggering an automated alert.

In contrast, the P-A supervisor (using the existing system) relied on handwritten notes, delaying the report until Day 15. As a result, P-B received real-time Power BI analysis of critical path and task dependencies, while P-A experienced a 48-hour lag, leaving the project manager unaware until Day 18. Post-analysis of P-A revealed systemic failures: missing updates, typographical errors, manual data transfer delays, and fragmented report integration—further exacerbated by poor communication regarding resource changes (e.g., sick leave). Table 10 displays the first month of the 90-day project schedule, quantifying the impact of a delay event occurring on Day 13. To evaluate the third research goal, Table 10 assesses two sub-goals: SG1) Contract Payment Milestone Impact Analysis and SG2) Project Performance Monitoring.

Table 10: *A snipped of 90 Days early delay identification via EV metrics.*

	Planned Value PV	**Earned Value EV**		**Actual Cost AC**		**Cost Variance CV=EV – AC**		**Schedule Variance SV= EV – PV**		**Cost Performance CPI=EV/AC**		**Schedule Performance SPI=EV/PV**	
Day	**P-A & P-B**	**(P-B)**	**(P-A)**	**(P-B)**	**(P-A)**	**CV (P-B)**	**CV (P-A)**	**SV (P-B)**	**SV (P-A)**	**CPI (P-B)**	**CPI (P-A)**	**SPI (P-B)**	**SPI (P-A)**
1	**$1,111.11**	$1,166.67	$1,222.22	$1,060.90	$1,164.03	$105.77	$58.19	$55.56	$111.11	1.10	1.05	1.05	1.10
2	**$2,222.22**	$2,450.20	$2,762.20	$2,334.48	$2,652.85	$115.72	$109.35	$227.98	$539.98	1.05	1.04	1.10	1.24
3	**$3,333.33**	$3,500.00	$3,166.67	$3,300.25	$3,500.00	$199.75	-$333.33	$166.67	-$166.66	1.06	0.90	1.05	0.95
4	**$4,444.44**	$4,666.67	$4,222.22	$4,222.22	$4,666.67	$444.45	-$444.45	$222.23	-$222.22	1.11	0.90	1.05	0.95
5	**$5,555.56**	$5,300.00	$4,222.22	$4,222.22	$4,666.67	$1,077.78	-$444.45	-$255.56	-$1,333.34	1.26	0.90	0.95	0.76
6	**$6,666.67**	$6,667.10	$5,277.78	$5,277.78	$5,833.33	$1,389.32	-$555.55	$0.43	-$1,388.89	1.26	0.90	1.00	0.79
7	**$7,777.78**	$7,000.00	$6,333.33	$6,333.33	$7,000.00	$666.67	-$666.67	-$777.78	-$1,444.45	1.11	0.90	0.90	0.81
8	**$8,888.89**	$9,100.00	$9,000.50	$7,388.89	$8,166.67	$1,711.11	$833.83	$211.11	$111.61	1.23	1.10	1.02	1.01
9	**$10,000.00**	$9,333.33	$8,444.44	$8,444.44	$9,333.33	$888.89	-$888.89	-$666.67	-$1,555.56	1.11	0.90	0.93	0.84
10	**$11,111.11**	$11,300.50	$9,555.56	$9,555.56	$10,500.00	$1,744.94	-$944.44	$189.39	-$1,555.55	1.18	0.91	1.02	0.86
11	**$12,222.22**	$12,200.36	$10,266.66	$10,611.11	$11,666.67	$1,589.25	-$1,400.01	-$21.86	-$1,955.56	1.15	0.88	1.00	0.84
12	**$13,333.33**	$12,833.33	$11,333.33	$11,666.67	$12,833.33	$1,166.66	-$1,500.00	-$500.00	-$2,000.00	1.10	0.88	0.96	0.85
13	**$14,444.44**	$14,000.00	$12,277.77	$12,722.22	$14,000.00	$1,277.78	-$1,722.23	-$444.44	-$2,166.67	1.10	0.88	0.97	0.85
14	**$15,555.56**	$14,666.67	$14,400.00	$15,264.37	$13,680.00	-$597.70	$720.00	-$888.89	-$1,155.56	0.96	1.05	0.94	0.93
15	**$16,666.67**	$15,833.33	$14,400.00	$16,100.30	$13,680.00	-$266.97	$720.00	-$833.34	-$2,266.67	0.98	1.05	0.95	0.86
16	**$17,777.78**	$16,833.33	$14,400.00	$16,921.35	$13,680.00	-$88.02	$720.00	-$944.45	-$3,377.78	0.99	1.05	0.95	0.81
17	**$18,888.89**	$17,833.33	$14,400.00	$18,374.03	$13,680.00	-$540.70	$720.00	-$1,055.56	-$4,488.89	0.97	1.05	0.94	0.76

18	**$20,000.00**	$18,833.33	$15,600.00	$18,998.35	$14,820.00	-$165.02	$780.00	-$1,166.67	-$4,400.00	0.99	1.05	0.94	0.78
19	**$21,111.11**	$19,833.33	$16,800.00	$20,001.36	$15,960.00	-$168.03	$840.00	-$1,277.78	-$4,311.11	0.99	1.05	0.94	0.80
20	**$22,222.22**	$20,833.33	$18,000.00	$21,523.80	$17,100.00	-$690.47	$900.00	-$1,388.89	-$4,222.22	0.97	1.05	0.94	0.81
21	**$23,333.33**	$21,833.33	$16,235.25	$21,833.40	$23,560.00	-$0.07	-$7,324.75	-$1,500.00	-$7,098.08	1.00	0.69	0.94	0.70
22	**$24,444.44**	$24,100.25	$17,268.98	$22,166.67	$24,536.35	$1,933.58	-$7,267.37	-$344.19	-$7,175.46	1.09	0.70	0.99	0.71
23	**$25,555.56**	$25,325.75	$18,021.56	$22,166.67	$22,356.30	$3,159.08	-$4,334.74	-$229.81	-$7,534.00	1.14	0.81	0.99	0.71
24	**$26,666.67**	$26,012.50	$19,125.23	$23,222.22	$21,500.00	$2,790.28	-$2,374.77	-$654.17	-$7,541.44	1.12	0.89	0.98	0.72
25	**$27,777.78**	$27,120.30	$20,156.23	$24,002.30	$22,103.20	$3,118.00	-$1,946.97	-$657.48	-$7,621.55	1.13	0.91	0.98	0.73
26	**$28,888.89**	$28,080.85	$20,831.45	$25,333.33	$24,120.32	$2,747.52	-$3,288.87	-$808.04	-$8,057.44	1.11	0.86	0.97	0.72
27	**$30,000.00**	$29,680.23	$22,365.36	$26,388.89	$25,250.65	$3,291.34	-$2,885.29	-$319.77	-$7,634.64	1.12	0.89	0.99	0.75
28	**$31,111.11**	$30,921.20	$25,270.00	$27,444.44	$27,300.00	$3,476.76	-$2,030.00	-$189.91	-$5,841.11	1.13	0.93	0.99	0.81
29	**$32,222.22**	$31,258.36	$26,410.00	$28,500.00	$30,520.36	$2,758.36	-$4,110.36	-$963.86	-$5,812.22	1.10	0.87	0.97	0.82
30	**$33,333.33**	$32,142.30	$27,550.00	$29,555.56	$31,569.65	$2,586.74	-$4,019.65	-$1,191.03	-$5,783.33	1.09	0.87	0.96	0.83

- **SG1) Contract Payment Milestone Impact Analysis:** The analysis demonstrates significant divergence in milestone achievement: Project B (RealCONs) achieved $18,833.33 EV by Day 18, nearing the $20k payment milestone (shortfall: $1,166.67) and almost reaching it by Day 20. while Project A (Existing) reached only $15,600.00 by Day 18 (4,400 short), almost attaining the milestone by Day 25 (Table 10). So, loos values and days by day 18 are:

Table 11: Loss values and days by day.

	Loss value	Loss day
P-B (RealCONs)	$20,000.00 - $18,833.33 = **$1,166.67**	20-18=**2 days**
P-A (Existing)	$20,000.00 - $15,600.00 = **$4,400.00**	25-18=**7 days**

This 5-day acceleration in Project B reflects superior schedule adherence, while Project A's delay incurred cumulative losses.

- **SG2) Project Performance Monitoring:** The performance analysis reveals stark contrasts between RealCONs and the Existing system. While projects B and A faced delays (SPI<1), Project B (RealCONs) showed improving trends: its CPI rose from 0.96 to 1.11 (Days 14-26), and SPI increased from 0.94 to 0.97, achieving cost-efficiency by Day 22. In contrast, Project A's performance deteriorated sharply, with CPI falling to 0.86 and SPI collapsing to 0.72 by Day 26, indicating severe cost overruns and schedule slippage (Figures 16 and 17):

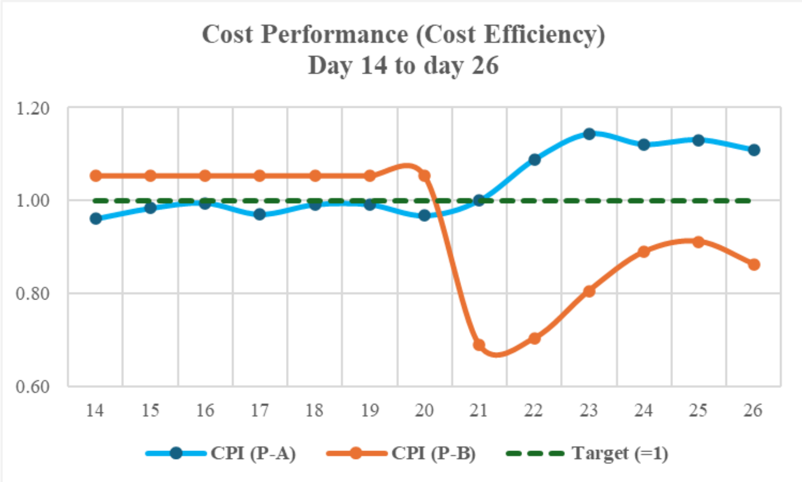


Figure 16: Cost Efficiency.

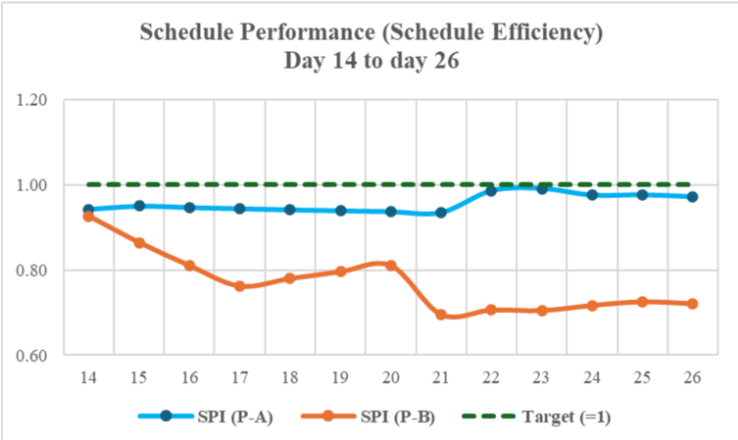


Figure 17: Schedule Efficiency.

As a result, RealCONs demonstrated superior stability, particularly after Day 20, when the existing system began to show signs of failure. This section highlights how real-time early delay alerts enabled proactive recovery actions, helping reduce cost overruns (through CPI protection) and minimise schedule slippage (via SPI stabilisation) through timely interventions. Furthermore, from the Oracle P6 (planning and scheduling) perspective, the schedule variance observed between the day after the delay was reported (Day 14) and the end of the delay notice period (Day 26) indicates that RealCONs achieved a total cost-saving of $6.98 million, as outlined below.

Tabel 12: Total cost saving.

Project	$SV_{Day\ 14}$ (Millon)	$SV_{Day\ 26}$ (Millon)	Delta (Millon)	Total Delta (Millon)
P-B (via RealCONs)	$888.89	$808.04	-$80.85 B	A-B = $6,982.73
P-A (via Existing)	$1,155.56	$8,057.44	$6,901.88 A	

Figure 18 illustrates the data flow sequence of Figure 6. It shows that regarding the reported delay (in this case, on day 13), similar to Figure 15, other components (Oracl_Aconex and BIM) are updated relevantly. For example, suppose a delay on Day 13 reported clash detection or material issue. In that case, BIM and Oracl_Aconex should be involved in updating the 3D federate model and publishing as-built drawings through oracle_Aconex for subcontractors. Otherwise, if a delay occurs because of disruption, only oracle_P6 and oracle_as should be updated.

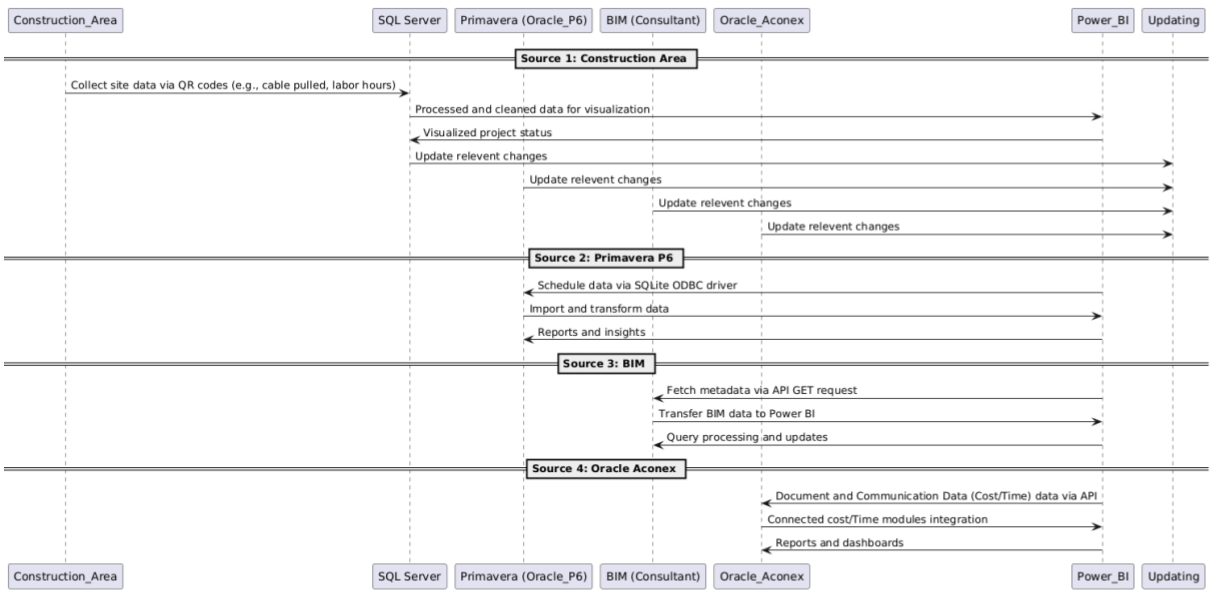


Figure 18: Data Flow Sequence of Figure 6.

To conclude this section, Figures A1-A6 present key digital and analytical reports generated by Power BI to support the research discussion. Figure 19 (the main dashboard) is an early warning system for SPI and CPI changes, triggering delay identification. Figure 20 enables project managers to review Earned Value trends by adjusting dates and building scopes. Figure 21 visualises activity breakdowns, combining cost data, actual vs. planned percentages, and cost variance for an at-a-glance project overview. Figures A4 and A5 provide dedicated views of project delays and cost trends, improving forecasting accuracy. Finally, Figure 24 displays a building sketch as a graphical progress report.

Figure 19: Project Main Dashboard (Digital Report).

Figure 20: Earned value tracking.

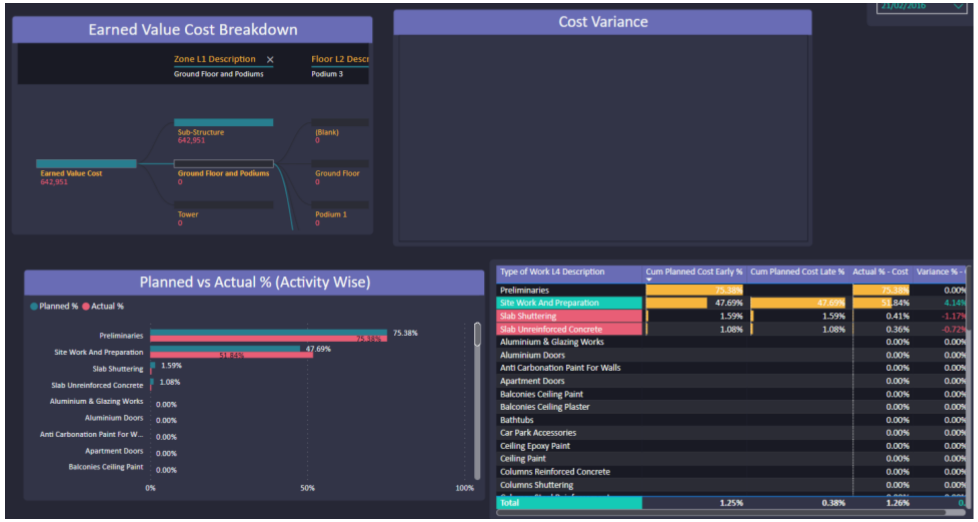


Figure 21: Breakdown Analysis.

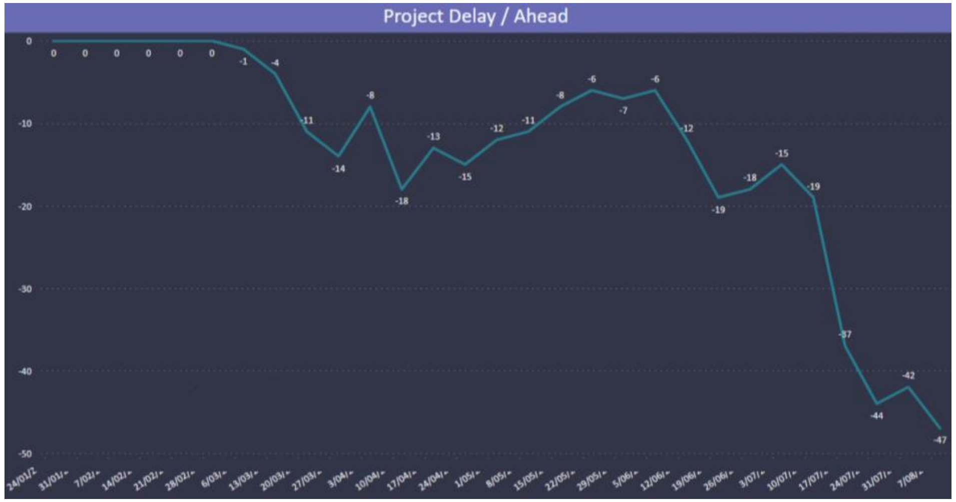


Figure 22: Delay trend.

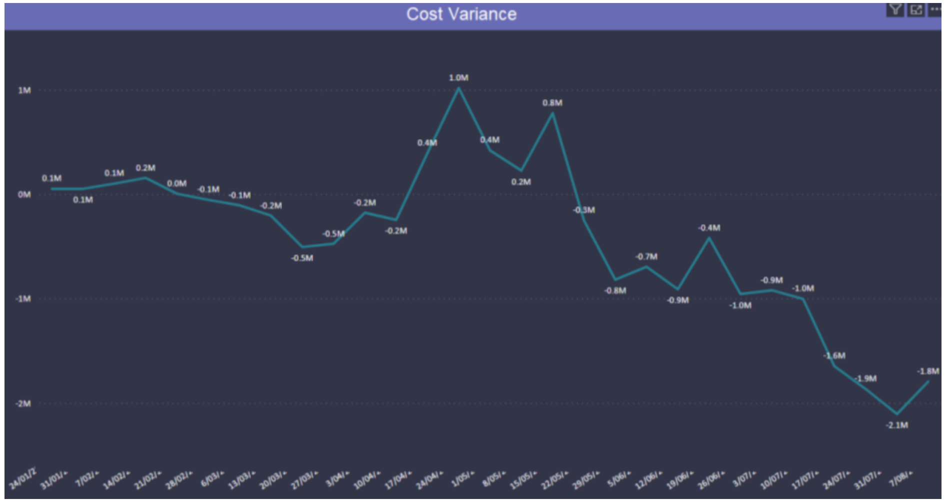


Figure 23: Cost variance trend.

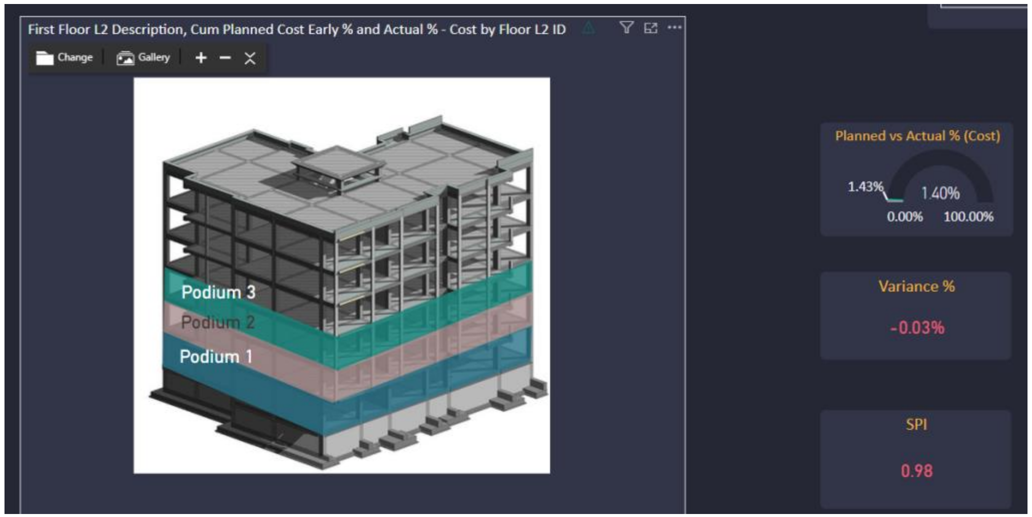


Figure 24: Building sketch monitoring.

Compared with existing digital tools/frameworks and the proposed framework, the RealCONs framework demonstrates clear advantages by enabling real-time monitoring and analysis of project status. RealCONs facilitates faster delay detection and impact analysis to make project managers make informed decisions, directly addressing fragmented communication and late delay(s) identification. These features are particularly valuable in major construction projects. While various digital tools such as Last Planner System (LPS) (C. Liu et al., 2024), 4D/5D Building Information Modelling (BIM) (Likita et al., 2024; Sun, Sun, Zhang, & Li, 2024), Digital Twin technologies (Liu, Feng, Lu, & Zhou, 2024; Xu, Feng, Jelodar, & Guo, 2024), and the project management methods like Critical Path Method (CPM) (Mostofi, Tokdemir, & Toğan, 2024; Petroutsatou, 2022), have contributed to improved planning, coordination and visualisation, they often operate in isolation or lack responsiveness to real-time changes. In contrast, RealCONs enhances project accuracy and preparation efficiency by reducing manual errors and improving early-stage reporting performance. Table 13 compares RealCONs with other digital tools, focusing on core project management attributes.

Table 13: RealCONs Vs Existing Digital Tools/Frameworks.

Digital Tool/Framework	Real-Time Monitoring	Early Delay Detection	Life-cycle Integration	Cost-Schedule Linkage	Adaptability	Limitations
RealCONs	✓ High	✓ Proactive	✓ Full life-cycle	✓ Direct, automated	✓ High	Requires connection authentications, site internet coverage
LPS	✗ Manual	✗ Reactive	✗ Execution-focused	✗ Weak	✓ Moderate	Relies on team discipline and facilitator input
4D/5D BIM	✓ Visual	✗ Limited	✓ Design–Execution	✓ Static, visual	✓ Moderate	Requires regular manual updating
Digital Twin	✓ Dynamic	✓ Conditional	✓ Strong	✓ High fidelity	✗ Low	High setup cost and technical complexity
CPM	✗ Static	✗ post-facto	✗ Planning-only	✗ Indirect	✗ Low	Inflexible, lacks adaptability to changing site conditions

Table 13 shows RealCONs utilises real-time data collection through QR code scanning on mobile devices, enabling automated deviation tracking and early warning alerts for potential delays. This functionality reduces subjectivity in performance evaluation and facilitates timely corrective actions, such as task resequencing or resource reallocation. The system also enhances reporting accuracy by decreasing preparation time and minimising human error during data capture and analysis. Importantly, it remains user-friendly and accessible to end users, including site supervisors. While integration may require adjustments to accommodate different contractual frameworks and regional practices, RealCONs consolidates predictive analytics, financial control, and delay management into a single platform. In doing so, it serves as a strategic enabler for more resilient, efficient, and data-driven construction project delivery.

10. CONCLUSION AND FUTURE RESEARCH

This research validates the RealCONs digital framework as an effective solution to six major limitations in more common construction tracking systems: high costs, inefficiency, poor communication, fragmented data handling, integration challenges, and inaccurate reporting. By aligning RealCONs with the Rational Unified Process (RUP) methodology, the system's development and deployment followed a structured, iterative approach, enhancing transparency and performance across the project life-cycle:

1) the project scope, key stakeholders, and data collection needs were clearly defined in the Inception Phase. It led to the draft of an initial reporting framework tailored for Electrical and Instrumentation (E&I) works, which was chosen due to their dependency-sensitive sequencing and cross-trade implications. To ensure meaningful comparison, both case study projects (A and B) had reached at least 85% structural completion, focusing analysis on internal trades with active dependencies rather than structural variability; 2) During the Elaboration Phase,

RealCONs system architecture was established, and data workflows were modelled, enabling real-time validation and delay detection rules; 3) This phase created the foundation for automation and synchronisation features later deployed. The Construction Phase involved operational deployment. Supervisors and project administrators collected real-time data, entered it via mobile interfaces, analysed it by project analysts, and translated it into structured reports. This end-to-end process significantly reduced data errors, accelerated report generation, and improved daily insights; 4) In the Transition Phase, finalised reports were delivered to stakeholders, driving more informed decisions. RealCONs reduced report preparation time from 135 to 50 minutes, increased reporting output by 32.31%, and improved report accuracy from 72.2% (Project A) to 95.6% (Project B). Data slippage was reduced from 27.78% to just 4.44%.

The framework also strengthened project control. Project B, supported by RealCONs, recovered from initial delays with a Cost Performance Index (CPI) improvement from 0.96 to 1.11 and Schedule Performance Index (SPI) stabilisation at 0.97 by Day 26. In contrast, the control project (A) declined to a CPI of 0.86 and SPI of 0.72. By enabling early delay alerts (as seen in UML Step: "Enter Data" to "Clean & Analyse" to "Generate Reports"), RealCONs helped avert a projected $6.98 million deviation, proving the value of the proactive intervention. Despite its success, RealCONs faces limitations for wider adoption: connectivity issues in remote areas, QR code resilience, RFID-related privacy concerns, and data source authentication. However, it also bridges the longstanding gap between planned schedules and site realities, fostering a culture of real-time responsiveness. Beyond technical improvements, RealCONs fosters a proactive and transparent project culture by bridging the gap between theoretical planning and on-site realities. Future research should focus on integrating AI and big data warehousing to enhance RealCONs' scalability and intelligence further. Priorities include improving digital connectivity, developing resilient tracking tools, and establishing robust data governance practices to manage privacy, data reliability, and regulatory compliance on construction sites.

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