# CHAPTER 23

## A Study on Dynamic Resource Allocation for Construction Projects

*Nikita Nimbalkar*, Manali Dhakate**, Vaishnavi Rane** and Avinash Bagul****

**ABSTRACT**

The construction industry is one of the backbones of national infrastructure that faces major challenges such as labor allocation, fragmented planning, and poor utilization of resources. The study aims at improving resource planning for complex residential projects by identifying bottlenecks in operations to minimise schedule delays and cost overruns. Initially, current resource allocation practices were reviewed to assess its impact on the project performance and avenues to improve resource allocation were identified considering technology based frameworks. The Study adopted a case study approach, which combines Primavera P6 for scheduling, resources levelling and track KPIs with Power BI to help practioners improve resource allocation. The framework combines hybrid simulation methodology using Discrete Event Simulation (DES) and System Dynamic (SD) approach, to understand workflow interdependencies and allows maintaining and monitoring of the project processes. Results indicate significant increase in the labor usage, improving on time delivery performance of the projects. The suggested model is valuable in terms of creating a replicable, data-driven project delivery mechanism.

**Keywords:** Resource allocation, Process improvement, Hybrid simulation (DES - SD), Project performance.

### 1.0 Introduction

The construction industry, known as one of the pillars of infrastructural development and economic growth, is a sector in a very uncertain environment, with high resource dependence and complicated coordination requirements. With the current growth of contemporary projects in size, technical complexity and dependencies, the call to control labour, equipment and materials with greater precision has grown.

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This is particularly important in high rise residential and mass infrastructural projects where the changing conditions of sites and the sequential nature of work processes means that nimble and data-driven decision-making is required.

However, as these demands change, numerous construction companies are still using stagnant scheduling processes, anarchic planning processes and manual control systems. The traditional methods have been notorious to react suitably to the real-time changes in the availability of labor force, productivity and the operational limitations. This leads to inefficient labour practices, workflow interruptions, schedule slippage and cost increase being common in the industry. These systemic challenges reinstate the necessity to have a more adaptive perceptive and analytically informed policy to the allocation of resources.

The new digital technologies, Building Information Modeling (BIM), artificial intelligence (AI), predictive analytics, Internet of Things (IoT) platforms and automated scheduling tools, offer significant opportunities to make the process more transparent and predictive and coordinate it more efficiently. Nonetheless, there is still a discrepancy in the practical use of these tools in the industry.

In attempts to fill these gaps, the current study utilizes an extensive digital framework involving the combination of Primavera P6 to schedule and level resources with Power BI to perform analytic visualization. Furthermore, a mixed simulation model based on Discrete Event Simulation (DES) and System Dynamics (SD) is taken to analyze the workflow dependencies and the resource long-term behavior. The study seeks to analyse the existing allocation activities, evaluate how optimization affects labour productivity and project performance, and develop evidence-based options to enhance resource management of the complex construction setting.

## 2.0 Literature Review

Construction projects are one of the key elements of the country's infrastructure development, but their implementation is often limited by poor resource allocation mechanisms, disorganized planning behaviours, and repetitive overruns. The problems become magnified in residential developments in large scale and high rise where conditions in the project environment include several stakeholders, interdependent activities and constantly shifting site conditions. The presence of multiple interests, long-term scope of the projects, and external regulation factors leads to a high level of uncertainty, thus making efficient project delivery more difficult (Caldas and Gupta, 2017; Mok et al., 2015).

The resources involved in construction such as workforce, material, machinery and time directly impact on project productivity and cost-efficiency. Out of them, labor and materials take a large portion of project spending, which in many cases amounts to more than

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half of the total project costs (Sroka, 2021). Poor distribution of such resources will lead to wastage of time, workflow delay, and wasting of productivity which spreads over the project phases. Mok et al. (2015) also stressed that one of the basic managerial duties is the capability to match the availability of resources with the need to construct something.

Resource planning is also complicated by the fact that the procurement of materials is uncertain. The fluctuation of material price, quality, and availability has been cited as a major problem in fluctuating the schedule and increasing costs (Ibrahim and Elshwadfy, 2021). Since the construction materials are usually obtained under the influence of several suppliers, strategic sourcing and supplier selection turns out to be the crucial factors of project success. The scholars have shown that informed sourcing choices might help decrease procurement risks and increase operational efficiency and competitiveness (Stanczyk et al., 2015; Ramanathan, 2017).

In order to solve the problem of supplier-related decisions, researchers first applied the deterministic model of optimization that includes linear programming and mixed-integer programming. One of the contributions that Ghodsypour and O'Brien (1998) made was to combine Analytical Hierarchy Process with linear programming to allow both qualitative and quantitative selection criteria. Later research made supplier selection into a multi-criteria decision-making issue, where cost, quality, reliability, and delivery performance should be assessed concurrently (Ho et al., 2010; Keskin et al., 2010). More recent studies have gone further to implement the methods with uncertainty using rough set theory, gray systems, evidential reasoning and multi-objective optimization models (Arabsheybani et al., 2018, 2019; Polat and Eray, 2015; Stević et al., 2017; Yazdani et al., 2019).

Similar trends in construction planning studies have also found an underlying weakness with the traditional scheduling behavior. Implementation of superior scheduling systems, including Primavera P6 has enhanced access to sequence of activities, identification of critical paths, and leveling of resources. However, there are a number of studies suggesting that the use of scheduling tools alone is not sufficient in responding to the dynamic characteristics of construction operations without the use of ancillary analytical and predictive methods.

This has led to the rise in the use of simulation-based methods in construction management as a decision support mechanism. DES is useful in reflecting variability of the processes and interaction of resources. System Dynamics is, conversely, appropriate to study the effects of workforce learning, rework cycles and policy impacts in the long term due to its emphasis on feedback and accumulative behaviour. Recent literature recommends the use of DES and SD together as it has been found to give a better insight on both the short-term performance on operations and the long-term pattern in the project. The application of key performance indicators with the help of digital analytics tools like Power BI has facilitated

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real-time tracking of the labor usage, schedule variance, and productivity patterns, which allows taking the project under control in advance.

Although a lot has been researched in the field of optimization, scheduling, simulation, and sustainability, the prevailing literature focuses on researching these aspects in isolation. There is a lack of focus on creating an integrated, technology-based structure that can accommodate both dynamic resource allocation, scheduling, simulation modeling, and performance analytics in one setting of a construction project. In addition, such integrated solutions have not been empirically validated when used in high-rise residential projects.

To this end, there is a distinct gap in the existing research on the use of systematic, evidence-based resource management models in the management of complex construction projects. Closing this gap with the help of the Primavera-based scheduling, resource leveling, hybrid DES-SD simulation and KPI-based performance monitoring is associated with a high potential of the improvement of the level of labor utilization, the decrease of schedule delays, and the overall project delivery performance.

## 3.0 Objectives

1. To study the current practices and techniques used for resource allocation in complex construction projects.
2. To analyse how optimized resource allocation influences labour productivity and project performance.
3. To identify the challenges and barriers that limit effective resource allocation in construction environments.
4. To propose strategies and technological solutions to improve resource allocation and enhance overall project outcomes.

## 4.0 Research Methodology

### 4.1 Research design and case study approach

The research design used in this study is a case-study based research in order to analyze dynamic resource allocation in a high-rise residential project. The literature review that informed the methodology demonstrates that the traditional conservative approaches to planning are not sufficient to deal with the variability in labor, workflow dependencies, and schedule uncertainty within a complicated construction setting. According to the previous research, it is important to incorporate digital scheduling, simulation and performance analytics. In this case, the study suggests a technology-based model which brings together Primavera P6, simulation, and data analytics to facilitate dynamic decisions. The chosen high-

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rise construction with its repetitive floor patterns and high labor utilization can serve as a realistic environment to prove the efficacy of the suggested model under the real conditions of the sites.

**Figure 1: The Figure Illustrates the Process of Reviewing Methodologies Adopted in Existing Research Studies to Identify Gaps in Both the Literature and Real-world Practice**


*Source: Created by authors*

**Figure 2: Construction Optimization Models and Tools**


*Source: Created by authors*

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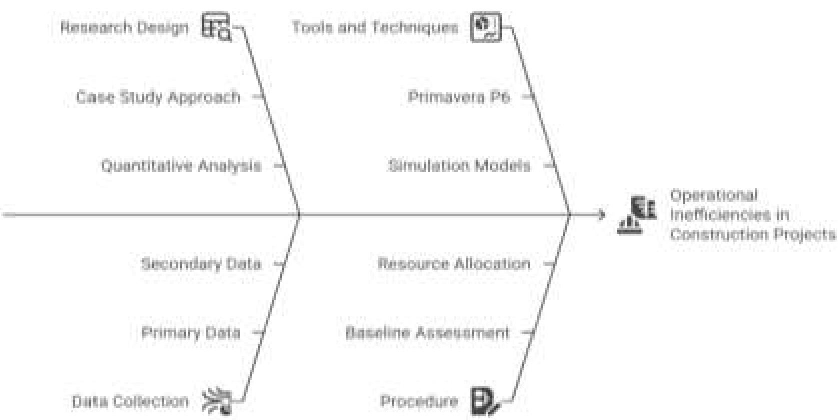
### 4.2 Literature review data analysis

Data analysis in the given study is determined by the methodologies revealed in previous studies on the optimization of the construction workforce, which focus on applying the techniques of digital scheduling and dynamic analysis. In line with that, the project schedule was developed in Primavera P6, the labor resources were allocated as well as the critical activities and the workforce imbalance were identified with the help of resource loading and levelling.

**Figure 3: Fishbone Diagram Explaining the Process of this Research Paper**




*Source: Created by authors*

### 4.3 Step-wise research framework

The research approach has been organized into four consecutive processes creating a dynamic resource allocation model that is integrated and iterative.

*Step 1: Literature-Based Approach to Method Choice and Framework.*

The initial move was to undertake a review of previous studies on construction scheduling, resource optimization, simulation, and performance measurement. The literature review has aided the determination of the gaps in the methodology, the absence of the combination of scheduling platforms and simulation and analytics tools, in particular. Through these findings, the research structure was developed such that deterministic scheduling was used together with dynamic analysis in such a manner that operational level and system level was achieved.

*Step 2: Project Scheduling and Resource Modelling with Primavera p6.*

The second step involved creation of a detailed project schedule with the help of Primavera P6. The activities were organized in a Work Breakdown Structure (WBS) that

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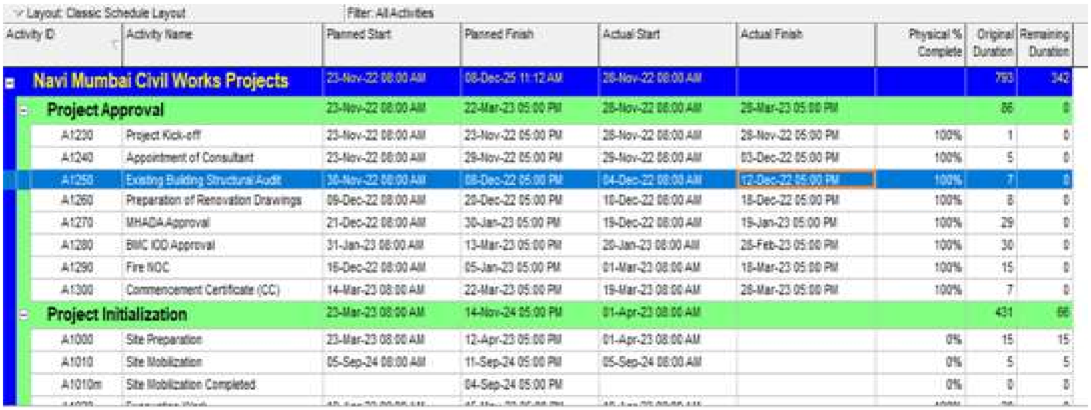
included all the key phases of the entire process of excavation to occupancy certification. The logical relationships, time durations, and milestones were stipulated depending on project documentation and site inputs. Required data fields such as planned dates, actual dates, resource assignments, costs, and progress parameters were configured.

The allocation of labor and equipment resources to activities was done using standard productivity norms. To make it possible to compare actual progress and altered scenarios, a baseline schedule was set. The resource leveling features were implemented to determine the over-allocations, idle times, and peak manpower requirements.

**Figure 4: This Template Acts as a Reusable Planning Framework, Allowing Professionals to Customise the Model for Similar Projects without Starting from Scratch**

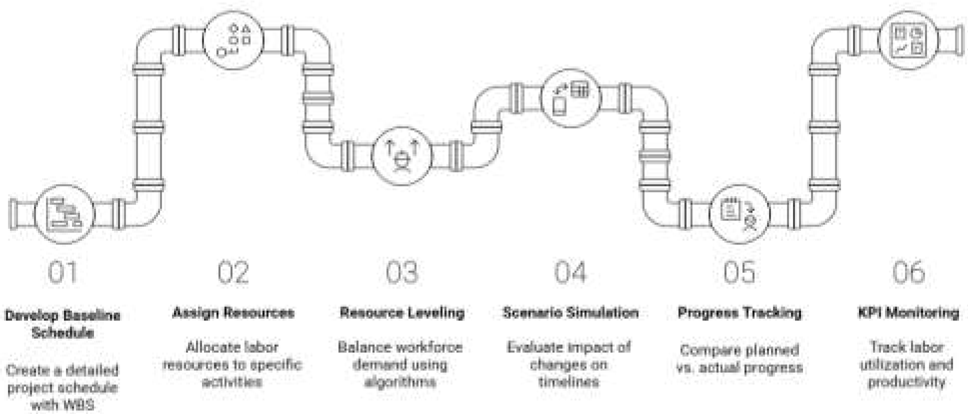


Layout: Classic Schedule Layout | Filter: All Activities

| Activity ID | Activity Name | Planned Start | Planned Finish | Actual Start | Actual Finish | Physical % Complete | Original Duration | Remaining Duration |
|---|---|---|---|---|---|---|---|---|
| | Navi Mumbai Civil Works Projects | 23-Nov-22 08:00 AM | 08-Dec-25 11:12 AM | 28-Nov-22 08:00 AM | | | 793 | 342 |
| | Project Approval | 23-Nov-22 08:00 AM | 22-Mar-23 05:00 PM | 28-Nov-22 08:00 AM | 28-Mar-23 05:00 PM | | 86 | 0 |
| A1230 | Project Kick-off | 23-Nov-22 08:00 AM | 23-Nov-22 05:00 PM | 28-Nov-22 08:00 AM | 28-Nov-22 05:00 PM | 100% | 1 | 0 |
| A1240 | Appointment of Consultant | 23-Nov-22 08:00 AM | 29-Nov-22 05:00 PM | 29-Nov-22 08:00 AM | 03-Dec-22 05:00 PM | 100% | 5 | 0 |
| A1250 | Existing Building Structural Audit | 30-Nov-22 08:00 AM | 08-Dec-22 05:00 PM | 04-Dec-22 08:00 AM | 12-Dec-22 05:00 PM | 100% | 7 | 0 |
| A1260 | Preparation of Renovation Drawings | 09-Dec-22 08:00 AM | 20-Dec-22 05:00 PM | 10-Dec-22 08:00 AM | 18-Dec-22 05:00 PM | 100% | 8 | 0 |
| A1270 | MHADA Approval | 21-Dec-22 08:00 AM | 30-Jan-23 05:00 PM | 19-Dec-22 08:00 AM | 19-Jan-23 05:00 PM | 100% | 29 | 0 |
| A1280 | BMC IOD Approval | 31-Jan-23 08:00 AM | 13-Mar-23 05:00 PM | 20-Jan-23 08:00 AM | 28-Feb-23 05:00 PM | 100% | 30 | 0 |
| A1290 | Fire NOC | 16-Dec-22 08:00 AM | 05-Jan-23 05:00 PM | 01-Mar-23 08:00 AM | 18-Mar-23 05:00 PM | 100% | 15 | 0 |
| A1300 | Commencement Certificate (CC) | 14-Mar-23 08:00 AM | 22-Mar-23 05:00 PM | 19-Mar-23 08:00 AM | 28-Mar-23 05:00 PM | 100% | 7 | 0 |
| | Project Initialization | 23-Mar-23 08:00 AM | 14-Nov-24 05:00 PM | 01-Apr-23 08:00 AM | | | 431 | 66 |
| A1000 | Site Preparation | 23-Mar-23 08:00 AM | 12-Apr-23 05:00 PM | 01-Apr-23 08:00 AM | | 0% | 15 | 15 |
| A1010 | Site Mobilization | 05-Sep-24 08:00 AM | 11-Sep-24 05:00 PM | 05-Sep-24 08:00 AM | | 0% | 5 | 5 |
| A1010m | Site Mobilization Completed | | 04-Sep-24 05:00 PM | | | 0% | 0 | 0 |

*Source: Created by authors*

**Figure 5: Primavera Project Steps Needed to Develop the P6 Model**




*Source: Created by authors*

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*Step 3: Active analysis via simulation methods.*

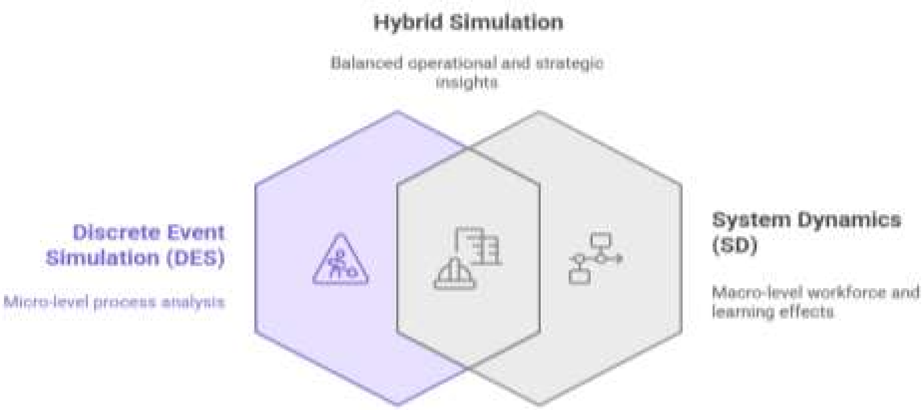
The third step to overcome the shortcomings of the static method of scheduling involved the adoption of a hybrid simulation approach.

The activity-level workflows, crew interaction and short-term disturbances including inspection delays, equipment breakdowns and productivity change were analysed using Discrete Event Simulation (DES).

System Dynamics (SD) was used to include long run feedback effects, e.g. the impact of labor shortages on productivity, rework and cumulative schedule delays.

The combination of DES and SD allowed us to obtain the full picture of both the short-term operational effects and the long-term project performance trends to make the decisions on healthy resource redistribution in the future.

**Figure 6: Visual Presentation of Planning Processes at Micro and Macro Level Eliminates Major risks that Delay the Project. Holistically Combining the Decision Making Process with Physical Activities, keeping all Stakeholders in Loop**




*Source: Created by authors*

*Step 4: Decision Support and Performance Measurement.*

The Primavera P6 data is used to identify KPIs, such as the use of labor, materials, and equipment to create a successful decision-support dashboard. The dashboard would facilitate predicting the risk, analysis of the situation, and prior mitigation as it would emphasize the possible delays and constraints. KPIs visualized enable non-technical stakeholders to interpret project status within a very short time and act on it. Constant monitoring can guarantee the flow of work, avoid any delays related to slow feedback or incorrect resource management.

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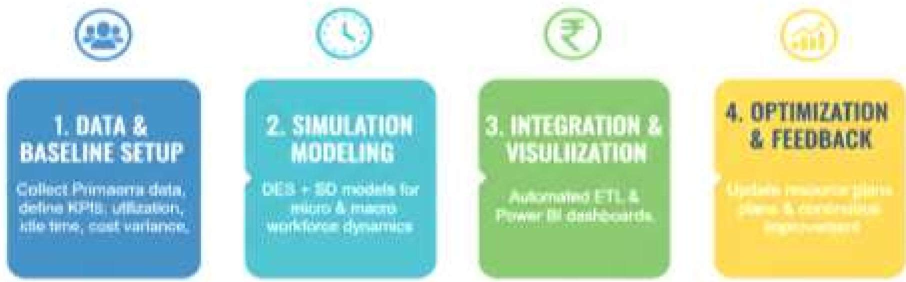
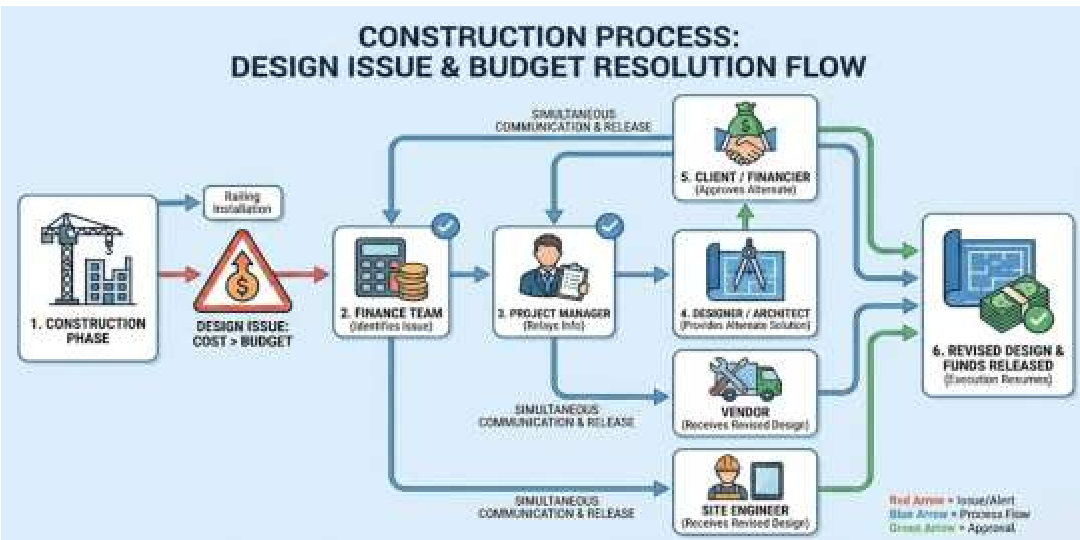
**Figure 7: KPI - Based Roadmap for Dynamic Workforce Optimization**




*Source: Created by authors*

**Figure 8: How the Model Works- e.g. While Construction Progresses, A Design Issue Arises while Installing the Railing**




*Source: Created by authors*

*Step 5: RACI Framework- Stakeholder Responsibility Alignment*

The RACI analysis shows that the PMC and Main Contractor are the main accountable and responsible parties throughout the majority of the construction phases, whereas consultants and MEP contractors are of vital importance in the coordination process during execution and completion. s

Approval-oriented stages fall under the authority of statutory bodies especially in pre-construction and OC procedures suggesting approval risks as external dependency. The RACI framework enhances role demarcation and minimizes the coordination gaps, overhangs of responsibilities and improves schedule control in a complex high-rise project.

**Table 1: RACI Framework on the Selected Case Study to Study Human Resource Allocation**

| Project Stage / Activity | Client / Developer | PMC | Main Contractor | Architect & Structural Consultants | MEP Contractors | Vendors / OEMs | Site Engineer | Statutory Authorities |
|---|---|---|---|---|---|---|---|---|
| Pre-construction approvals & mobilization | A | R | R | C | I | I | I | R |
| Excavation & dewatering | I | A | R | C | I | I | R | I |
| Piling & foundation works | I | A | R | C | I | I | R | I |
| Raft, plinth & ground floor | I | A | R | C | I | I | R | I |
| Podium, amenities & transfer slab | I | A | R | C | C | I | R | I |
| Typical floors (8th–44th, Mivan cycle) | I | A | R | C | C | I | R | I |
| Refuge floors & fire compliance | I | A | R | C | C | I | R | R |
| Terrace & above-terrace RCC works | I | A | R | C | C | I | R | I |
| Blockwork & internal plaster | I | A | R | C | C | I | R | I |
| Flooring, finishes & common areas | I | A | R | C | C | R | R | I |
| Lift installation & commissioning | I | A | I | I | C | R | R | C |
| OC documentation & NOCs | A | R | C | C | I | I | I | R |
| Final inspection & OC receipt | A | I | I | I | I | I | I | R |
| Resource planning & schedule control (Primavera) | I | A | R | C | C | I | R | I |
| Delay recovery & change management | C | A | R | C | C | I | R | I |

*Source: Created by authors*

### 4.3 Assumption of the study

The study is based on the following assumptions:

- The model is based on the selected real life case study in Indian cities environment, and made for cluster, high-rise brownfield residential development.
- This helps us make a controlled, non-generic model, which caters to this type of project.
- Activity durations are derived from standard productivity rates adjusted for site conditions.
- Labor productivity varies due to congestion, learning effects, and external disruptions.
- Resources availability is finite and constrained by organizational and contractual factors.

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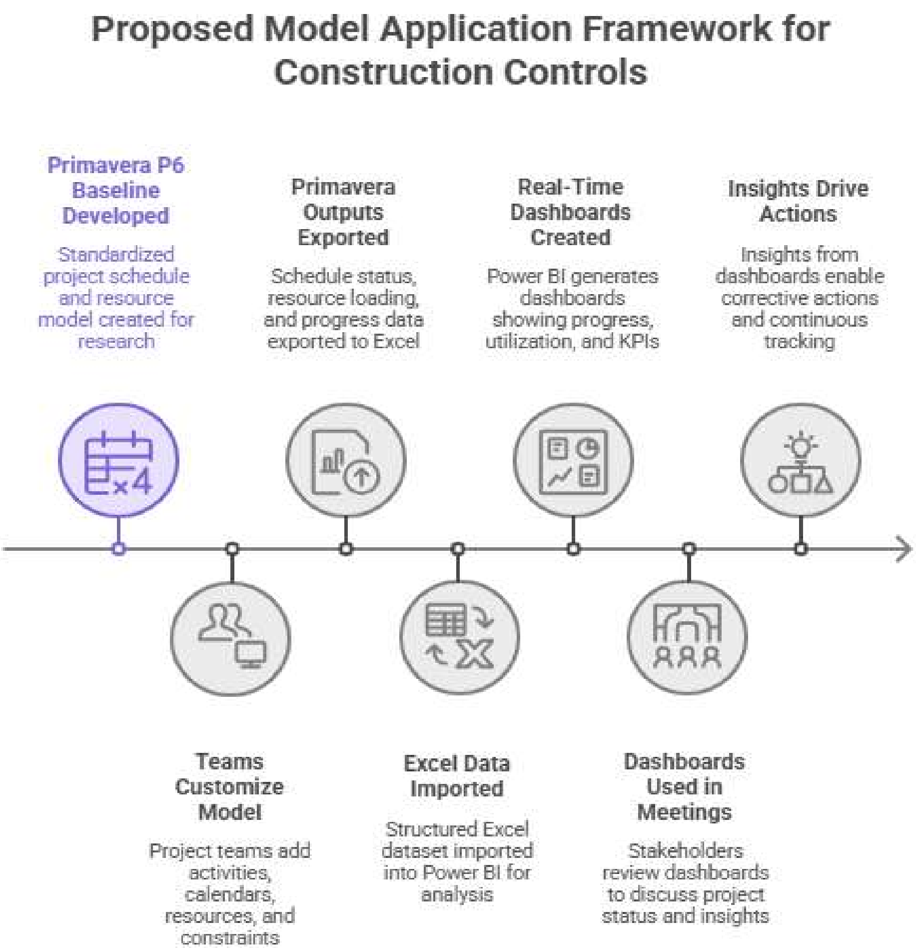
- External influences such as weather and approvals introduce variability but are manageable through dynamic planning.

**Figure 9: Steps Followed to Execute the Conceptual Idea, as per the Assumptions**




*Source: Created by authors*

## 5.0 Data Analysis

### 5.1 Case study data analysis

During model development, critical challenges influencing this category of projects were systematically assessed. In alignment with the model assumptions and functional requirements, a structured approach to data analysis was implemented.

### 5.1.1 Project overview

The case study under choice is grounded on a project in Mumbai, Maharashtra. The project will comprise several high-rise towers developed in several rehabilitation (REHAB) and sale segments, with a height of each tower between G+42 and G+48. The project is planned to be broken down into three stages:

Phase 1: REHAB + Towers 1 & 2

Phase 2: Towers 3 & 4

Phase 3: Towers 5 & 6

Considering the magnitude and intricacy of construction, resource optimization, especially concerning labor productivity, workforce allocation, etc. is vital in resolving delivery schedules without compromising on quality and cost effectiveness.

### 5.1.2 Data collection and scope

In this case study, information was gathered on the site about two key finishing activities:

- *Gypsum Work:* All data contained number of laborers assigned, their productiveness rates and completion schedule.
- *Flooring Work (Tiling):* The data consisted of the number of laborers involved, the material needed, labor productivity and efficiency in using the tile.

There were also provisional project schedules of tower stages completion. The workforce allocation, bottleneck and the influence of dynamic scheduling model are studied based on these datasets.

### 5.1.3 Workforce analysis

*Gypsum Work:* The labor team productivity variability was indicated by the data on the gypsum workforce. Mean outputs were compared to the project needs to approximate completion periods. It was noted that: Productivity was varying according to the level of skills and workforce disposition. Some of the floors had lagged behind because of the lack of fit between the manpower assigned and the work done. Optimal labor gang size was attained in balancing the speed and quality.

*Flooring WorkL:* The flooring data set was able to give information on the effectiveness of labor deployment and material use efficiency too. Others: pivotal conclusions were: The average daily/weekly productivity per worker ascertained realistic outputs. There were found cases of material wastage on the basis of erroneous tile cutting/placement, and resources inefficiency was associated with the missing gaps in workforce training. Causal relationships with other trades (e.g., waterproofing, MEP clearances) led to idle working hours, which highlighted the necessity of de facto allocation, as opposed to planned scheduling.

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**Table 2: Labour Work Tracking Sheet**

| Location | Date | Labor | | Gypsum Plaster Done | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Mason | Helper | M. Bed | Bed 1 | Bed 2 | Living | Kitchen |
| 1705 (3BHK) | 11-Jun-25 | 2 | 2 | C | | | | WIP |
| | 12-Jun-25 | 2 | 2 | C | P | Saved to this PC | WIP | WIP |
| | 13-Jun-25 | 1 | 1 | C | P | WIP | WIP | WIP |
| | 14-Jun-25 | 1 | 1 | C | WIP | WIP | WIP | WIP |
| | 15-Jun-25 | 1 | 1 | C | WIP | WIP | WIP | WIP |
| | 16-Jun-25 | 1 | 1 | C | C | WIP | WIP | WIP |
| | 17-Jun-25 | 1 | 2 | C | C | C | WIP | C |
| | 18-Jun-25 | 2 | 2 | C | C | C | C | C |
| Total | 1 week | 11 | 12 | | | | | |
| | | | | | | | | |
| 1002 (2BHK) | 21-Jun | 1 | 1 | C | WIP | NA | P | P |
| | 22-Jun | Holiday | | | | | | |
| | 23-Jun | 1 | 1 | C | C | NA | P | P |
| | 24-Jun | 1 | 1 | C | C | NA | WIP | P |
| | 25-Jun | 1 | 1 | C | C | NA | C | WIP |
| | 26-Jun | 1 | 1 | C | C | NA | C | C |
| | | | | | | | | |
| Total | 5 Days | 5 | 5 | | | | | |

*Source: Created by authors*

**Table 3: Project Timeline**

| Phase 1 | | Done | |
|---|---|---|---|
| Tower 1 | | [illegible] | |
| | Start Date | End dates | duration |
| OC Receipt- Full OC | | 26-Jan-26 | |
| Complete OC duration | | | 30 |
| OC Application- Full OC | | 27-Dec-25 | 289 |
| Lift completion | | 01-Aug-25 | 140 |
| Common area flooring completion | | 20-Sep-25 | 190 |
| Flat / Toilet Flooring/ Dado completion | | 27-Jul-25 | 135 |
| Internal Plaster completion | | 23-May-25 | 70 |
| Blockwork completion | | 23-Apr-25 | 40 |
| Above Terrace RCC | 15-Mar-25 | 19-Apr-25 | 35 |
| Terrace | 02-Mar-25 | 14-Mar-25 | 12 |
| 42nd floor_Refuge Floor | 17-Feb-25 | 01-Mar-25 | 12 |
| 41st floor | 04-Feb-25 | 16-Feb-25 | 12 |
| 40th floor | 24-Jan-25 | 03-Feb-25 | 10 |
| 39th floor | 13-Jan-25 | 23-Jan-25 | 10 |
| 38th floor | 02-Jan-25 | 12-Jan-25 | 10 |
| 37th floor | 22-Dec-24 | 01-Jan-25 | 10 |
| 36th floor | 11-Dec-24 | 21-Dec-24 | 10 |
| 35th floor_Refuge Floor | 28-Nov-24 | 10-Dec-24 | 12 |
| 34th floor | 17-Nov-24 | 27-Nov-24 | 10 |
| 33rd floor | 06-Nov-24 | 16-Nov-24 | 10 |
| 32nd floor | 26-Oct-24 | 05-Nov-24 | 10 |
| 31st floor | 15-Oct-24 | 25-Oct-24 | 10 |
| 30th floor | 06-Oct-24 | 14-Oct-24 | 8 |
| 29th floor | 27-Sep-24 | 05-Oct-24 | 8 |
| 28th floor_Refuge Floor | 14-Sep-24 | 26-Sep-24 | 12 |
| 27th floor | 05-Sep-24 | 13-Sep-24 | 8 |
| 26th floor | 27-Aug-24 | 04-Sep-24 | 8 |
| 25th floor | 18-Aug-24 | 26-Aug-24 | 8 |
| 24th floor | 09-Aug-24 | 17-Aug-24 | 8 |
| 23rd Floor | 31-Jul-24 | 08-Aug-24 | 8 |
| 22nd floor | 22-Jul-24 | 30-Jul-24 | 8 |
| 21st Floor_Refuge Floor | 13-Jul-24 | 21-Jul-24 | 8 |
| 20th floor | 04-Jul-24 | 12-Jul-24 | 8 |

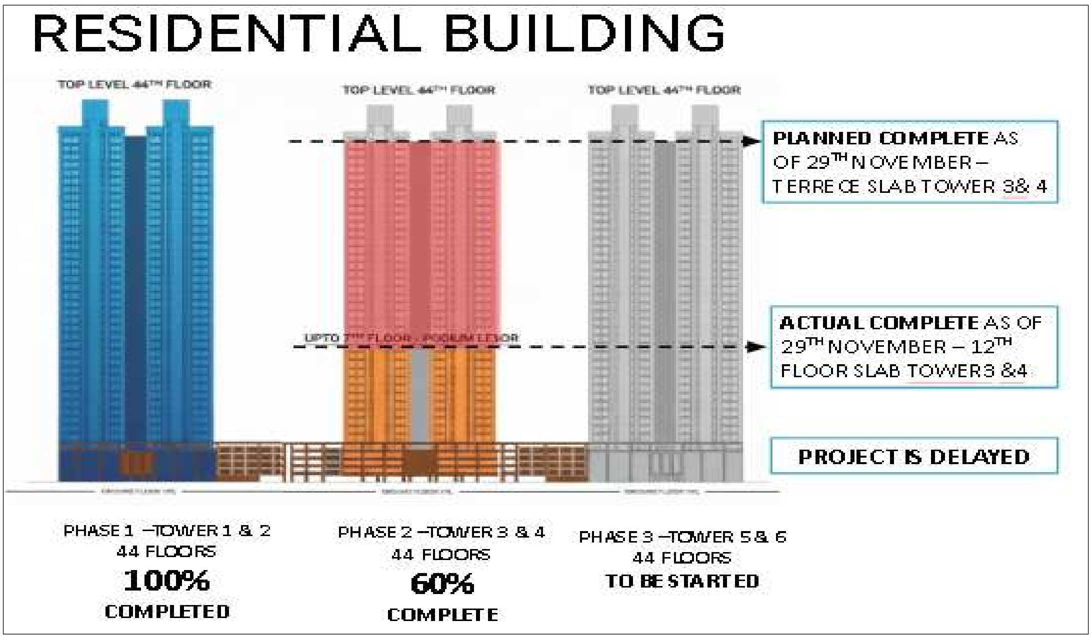
| Phase 1 | | Done | |
|---|---|---|---|
| Tower 2 | | [illegible] | |
| | Start Date | End dates | duration |
| OC Receipt- Full OC | | 19-Jun-26 | |
| Complete OC duration | | | 40 |
| OC Application- Full OC | | 20-May-26 | 289 |
| Lift completion | | 22-Dec-25 | 140 |
| Common area flooring completion | | 10-Feb-26 | 190 |
| Flat / Toilet Flooring/ Dado completion | | 17-Dec-25 | 135 |
| Internal Plaster completion | | 13-Oct-25 | 70 |
| Blockwork completion | | 13-Sep-25 | 40 |
| Above Terrace RCC | 05-Aug-25 | 09-Sep-25 | 35 |
| Terrace | 23-Jul-25 | 04-Aug-25 | 12 |
| 48th Floor | 10-Jul-25 | 22-Jul-25 | 12 |
| 47th Floor | 27-Jun-25 | 09-Jul-25 | 12 |
| 46th Floor | 14-Jun-25 | 26-Jun-25 | 12 |
| 45th Floor | 01-Jun-25 | 13-Jun-25 | 12 |
| 44th floor | 19-May-25 | 31-May-25 | 12 |
| 43rd floor | 06-May-25 | 18-May-25 | 12 |
| 42nd floor_Refuge Floor | 23-Apr-25 | 05-May-25 | 12 |
| 41st floor | 10-Apr-25 | 22-Apr-25 | 12 |
| 40th floor | 30-Mar-25 | 09-Apr-25 | 10 |
| 39th floor | 19-Mar-25 | 29-Mar-25 | 10 |
| 38th floor | 08-Mar-25 | 18-Mar-25 | 10 |
| 37th floor | 25-Feb-25 | 07-Mar-25 | 10 |
| 36th floor | 14-Feb-25 | 24-Feb-25 | 10 |
| 35th floor_Refuge Floor | 01-Feb-25 | 13-Feb-25 | 12 |
| 34th floor | 21-Jan-25 | 31-Jan-25 | 10 |
| 33rd floor | 10-Jan-25 | 20-Jan-25 | 10 |
| 32nd floor | 30-Dec-24 | 09-Jan-25 | 10 |
| 31st floor | 19-Dec-24 | 29-Dec-24 | 10 |
| 30th floor | 10-Dec-24 | 18-Dec-24 | 8 |
| 29th floor | 01-Dec-24 | 09-Dec-24 | 8 |
| 28th floor_Refuge Floor | 18-Nov-24 | 30-Nov-24 | 12 |
| 27th floor | 09-Nov-24 | 17-Nov-24 | 8 |
| 26th floor | 31-Oct-24 | 08-Nov-24 | 8 |

*Source: Created by authors*

*Tentative Timeline and Scheduling:* The completion of towers was developed into a baseline timeline using project schedules. In the conventional static approaches to planning used in MS Project (MSP) and Primavera, the durations of activities, dependencies and manpower requirements were given.

Nevertheless, these tools also exposed: Critical delays in gypsum finishing which affects other tiling works. The under-use of work force in some stages with others being overworked. In this regard, we will implement dynamic resource allocation models. To enhance project efficiency, by relocating superfluous labor in the low priority areas to the late critical path tasks.

**Figure 10: Explains the Case Study Timeline and Status**




*Source: Created by authors*

### 5.2 Primavera analysis

The figure shows a delay mitigation system in a 44 storey high-rise building, which connects key milestones with possible delay causes, and intended delay mitigation strategies. It employs levelling of resources, logic optimization, and look-ahead scheduling in order to minimize the amount of idle time and bottlenecks. Monitoring also allows identifying problems in time, which supports getting the schedule under control and completing the project in time.

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### 5.3 Development of a standardised primavera P6 project template

Following a detailed understanding of the case study, the project was translated into a primavera P6 model to develop a standardised sample template.

The P6 model can be customised and scaled by the organizations based on their requirements and needs. But the major milestones and baselines are considered as per a typical residential project of this scale.

**Figure 11: Sample P6 Project Template**

Layout: Classic Schedule Layout Filter: All Activities

| Activity ID | Activity Name | Planned Start | Planned Finish | Actual Start | Actual Finish | Physical % Complete | Original Duration | Remaining Duration |
|---|---|---|---|---|---|---|---|---|
| Navi Mumbai Civil Works Projects | | 23-Nov-22 08:00 AM | 08-Dec-25 11:12 AM | 28-Nov-22 08:00 AM | | | 793 | 342 |
| Project Approval | | 23-Nov-22 08:00 AM | 22-Mar-23 05:00 PM | 28-Nov-22 08:00 AM | 28-Mar-23 05:00 PM | | 86 | 0 |
| A1230 | Project Kick-off | 23-Nov-22 08:00 AM | 23-Nov-22 05:00 PM | 28-Nov-22 08:00 AM | 28-Nov-22 05:00 PM | 100% | 1 | 0 |
| A1240 | Appointment of Consultant | 23-Nov-22 08:00 AM | 29-Nov-22 05:00 PM | 29-Nov-22 08:00 AM | 03-Dec-22 05:00 PM | 100% | 5 | 0 |
| A1250 | Existing Building Structural Audit | 30-Nov-22 08:00 AM | 08-Dec-22 05:00 PM | 04-Dec-22 08:00 AM | 12-Dec-22 05:00 PM | 100% | 7 | 0 |
| A1260 | Preparation of Renovation Drawings | 09-Dec-22 08:00 AM | 20-Dec-22 05:00 PM | 10-Dec-22 08:00 AM | 18-Dec-22 05:00 PM | 100% | 8 | 0 |
| A1270 | MHADA Approval | 21-Dec-22 08:00 AM | 30-Jan-23 05:00 PM | 19-Dec-22 08:00 AM | 19-Jan-23 05:00 PM | 100% | 29 | 0 |
| A1280 | BMC IOD Approval | 31-Jan-23 08:00 AM | 13-Mar-23 05:00 PM | 20-Jan-23 08:00 AM | 28-Feb-23 05:00 PM | 100% | 30 | 0 |
| A1290 | Fire NOC | 16-Dec-22 08:00 AM | 05-Jan-23 05:00 PM | 01-Mar-23 08:00 AM | 18-Mar-23 05:00 PM | 100% | 15 | 0 |
| A1300 | Commencement Certificate (CC) | 14-Mar-23 08:00 AM | 22-Mar-23 05:00 PM | 19-Mar-23 08:00 AM | 28-Mar-23 05:00 PM | 100% | 7 | 0 |
| Project Initialization | | 23-Mar-23 08:00 AM | 14-Nov-24 05:00 PM | 01-Apr-23 08:00 AM | | | 431 | 66 |
| A1000 | Site Preparation | 23-Mar-23 08:00 AM | 12-Apr-23 05:00 PM | 01-Apr-23 08:00 AM | | 0% | 15 | 15 |
| A1010 | Site Mobilization | 05-Sep-24 08:00 AM | 11-Sep-24 05:00 PM | 05-Sep-24 08:00 AM | | 0% | 5 | 5 |
| A1010m | Site Mobilization Completed | | 04-Sep-24 05:00 PM | | | 0% | 0 | 0 |

*Source: Created by authors*

#### 5.3.1 Data capture and schedule updating

In Primavera P6, the actual project progress is periodically updated in a schedule during project implementation. This includes:

- Update of activity start and finish.
- Percentage completion
- Cost and resource utilization.

Primavera P6 also guarantees a reliable and consistent way of data capture because Primavera P6 is accepted as robust in schedule control and reporting.

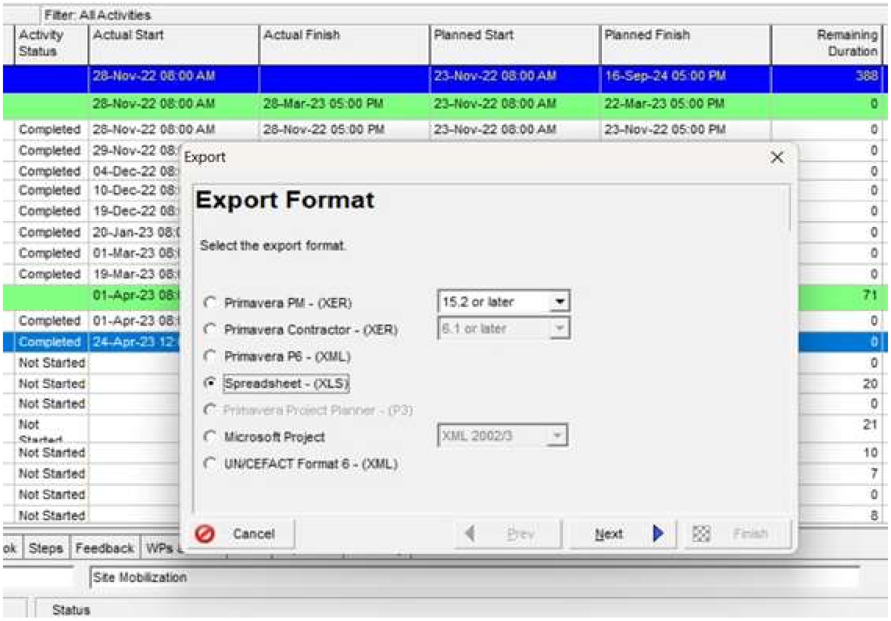
#### 5.3.2 Data export from primavera P6

The information that is exported contains only the columns needed to perform the analysis like:

- Schedule status
- Cost information
- Earned Value parameters
- Details of resources allocation.
- Risk-related indicators

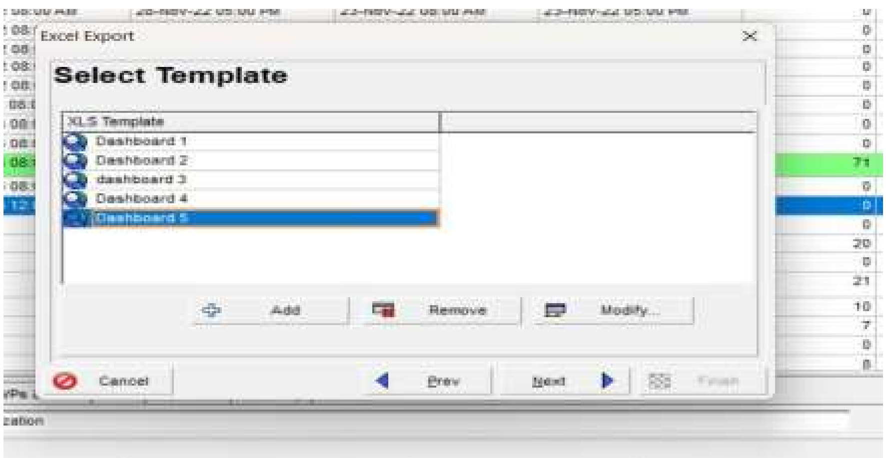
The step guarantees organized structured data to proceed with further analysis.

**Figure 12: After Updating the Schedule, the Primes Project Data is Exported in Primavera P6 to Excel (XLS) File**




*Source: Created by authors*

**Figure 13: Dashboard Templates Models Already Made as per Required KPI's and Power Bi Dashboard Requirements**




*Source: Created by authors*

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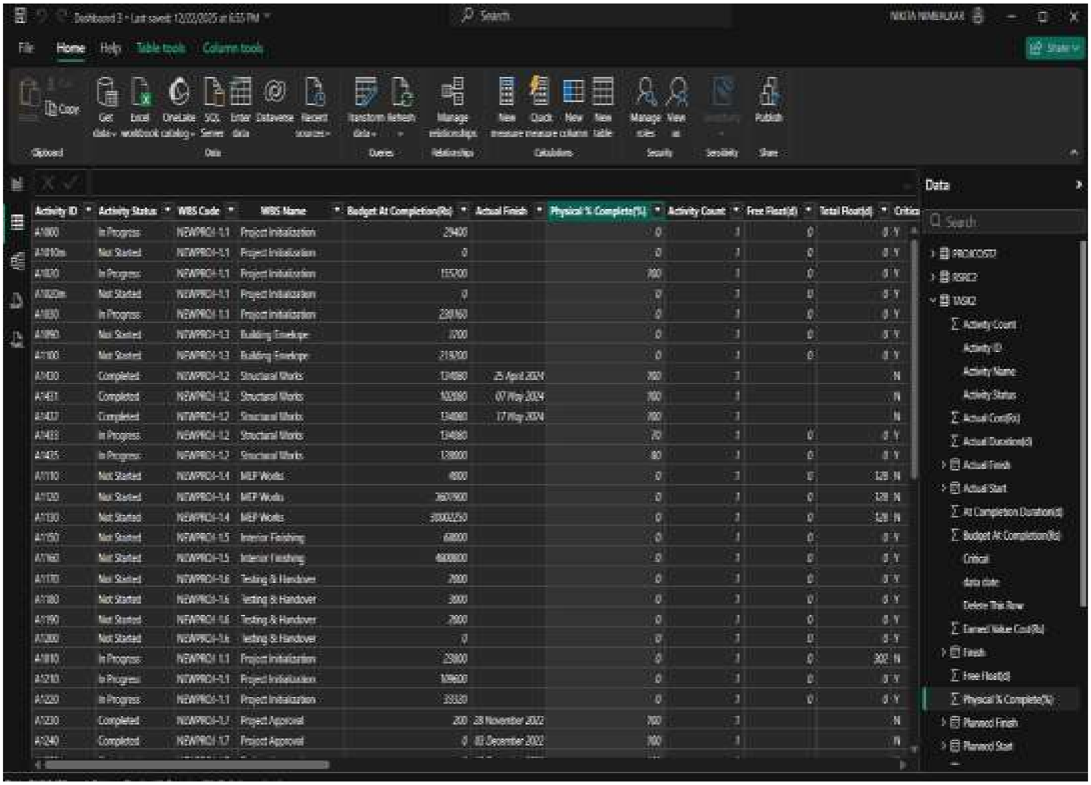
### 5.3.3: Integration with Power Bi

The xls sheet is uploaded in Power bi and transformed into filterable data and dashboards are made.

**Figure 14: Data from the xls File is Uploaded and Transformed, for Making Power Bi Dashboards**




*Source: Created by authors*

### 5.3.4 Dashboard design

- Dashboards are designed based on defined Key performance Indicators (KPI's) to ensure alignment with project objectives and performance measurement requirements.
- Each Dashboard provided focused insights into specific performance.
- Interactive visual elements such as filters ( based on WBS), drill downs ( based on days, weeks months) and trend analysis were incorporated to support real time monitoring, variance analysis and informed decision making by project stakeholders.

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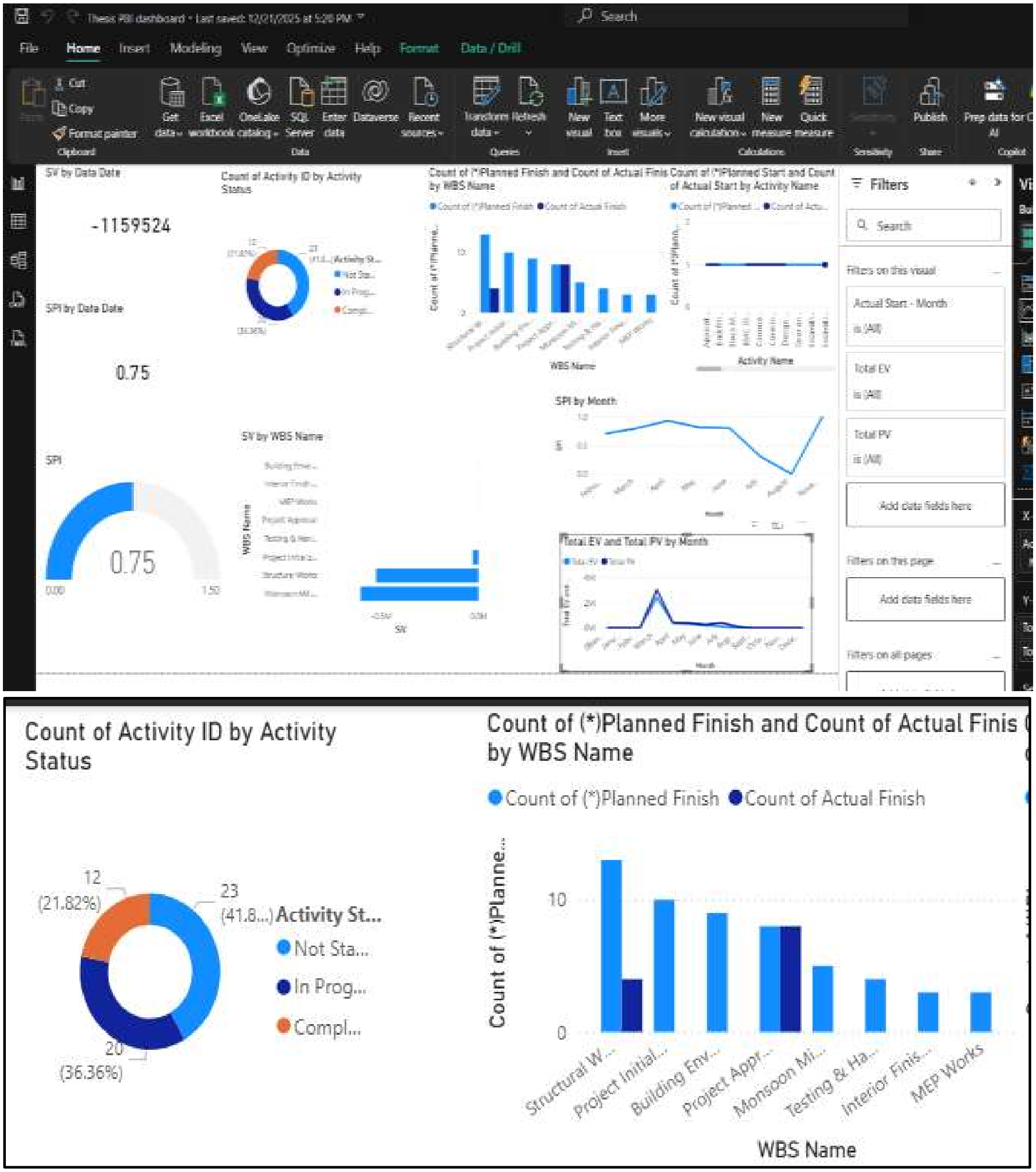
**Figure 15 & 16: Using the P6 data, The dashboard shows SPI is designed, which has KPI cards showing SPI - i.e. 0.75 which means the project is behind schedule. ( if SPi is less than 1), schedule variance based on the WBS, Activity status shows which activity is completed, in progress, or not started. Planned finish vs actual finish. Etc.**




*Source: Created by authors*

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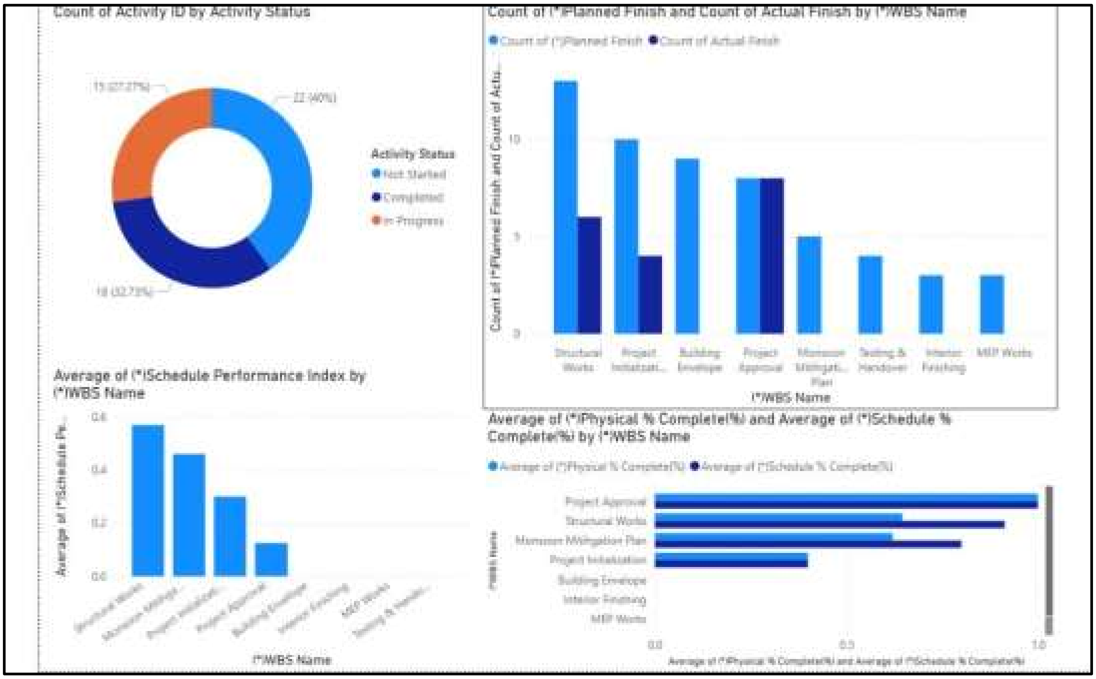
### 5.3.5 Continuous updates

The Excel files are connected to Power BI, in which the predefined data models and dashboards are already developed.

**Figure 17: Shows the Activity Status Donut Chart, Planned vs Actual Finish Clustered Chart, SPI as per each WBS Column Chart, etc.**



*Source: Created by authors*

This data derived from P6 will get updated as the manager/ in charge updated the data and over rights the XLS file. After overwriting the data in power Bi needs to be refreshed, to get an updated chart.

### 5.3.6 Stakeholder communication and reporting

The visual dashboards also translate complicated project information into understandable charts, KPI, and filters to ensure information is easily comprehended by all stakeholders.

Project managers can:

- Webcast share boards between teams and levels.
- Create updates on progress on a daily or even hourly basis.

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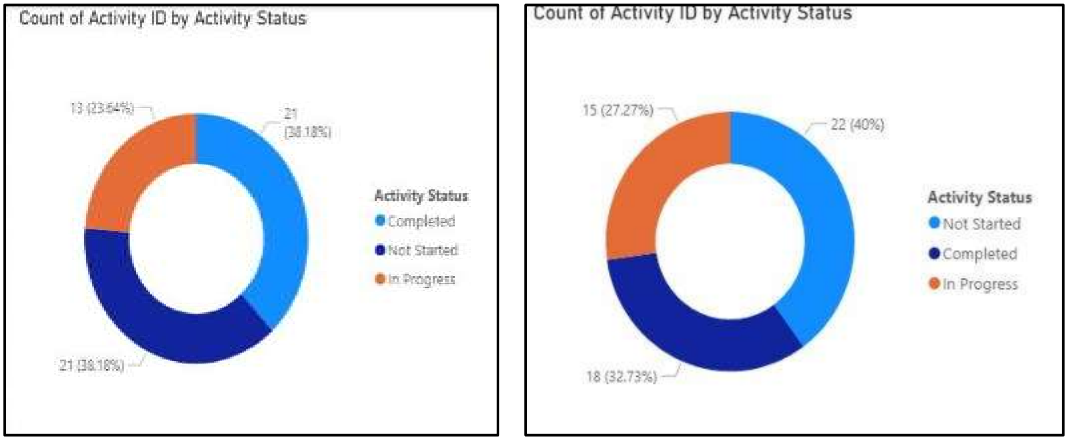
- Enhance accountability and transparency.

This greatly increases the speed and accuracy with which the information flows to assist in identifying the issues faster and taking corrective measures.

**Figure 18 and 19: Show before and after Updating the P6 Model**




*Source: Created by authors*

**5.3.7 Decision-making support and project control**

The model helps in real time monitoring of performance, whereby the project managers can:

- Early detect schedule delays.
- Determine cost overruns and resource wastage.
- Monitor variances on track.
- Be timely, informed and data-based.

This reinforces proactive project management as opposed to problem-solving.

**5.3.8 Both value and practical benefits of the model**

The proposed model will have the following benefits to project managers and planning professionals:

- Minimizes project set up and reporting time.
- Removes duplicate modelling and transformation of data.
- Enhances the efficacy and efficiency of planning as well as monitoring.
- Increases the level of coordination among the planning, execution and management teams.
- Facilitates scaling to different projects.

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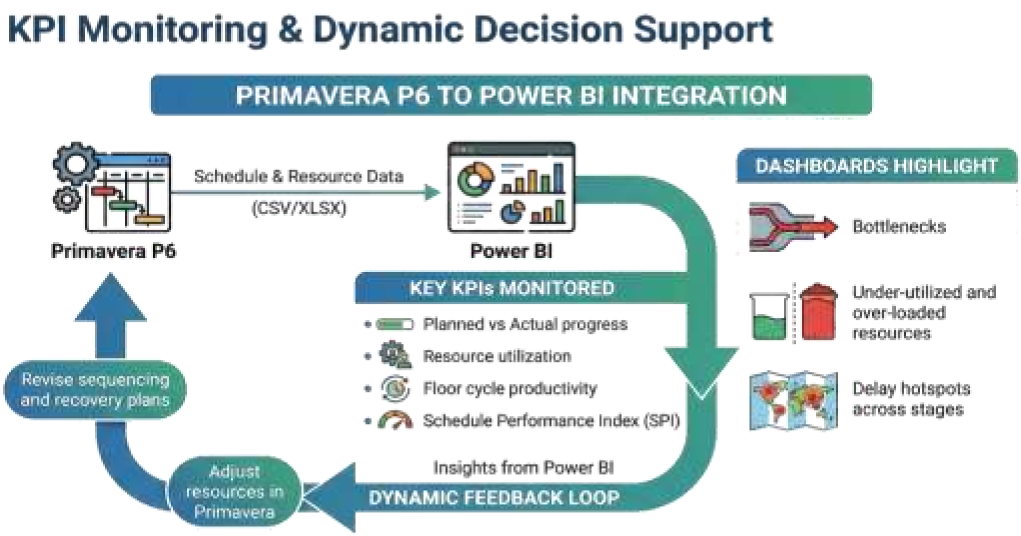
## 6.0 Key Finding

This study demonstrates that the combination of Primavera P6 and Power BI offers a scalable and data-driven planning and controlling Primavera P6 model in high-rise residential projects. In comparison to traditional systems, which are based on fragmented and delayed information, the suggested framework gives an opportunity to track everything in near real-time with the help of KPI-based dashboards. The performance of the schedule, use of labor, productivity, and delay recovery are key indicators that are used to detect the bottlenecks at an early stage. Also facilitating using the interactive dashboards is the scenario based decision making which enhances efficiency, saves planning time and increases control in the project lifecycle.

**Figure 20: Primavera P6 to Power BI Integration**




*Source: Created by authors*

The model assists organisations to gain improved control over complicated construction projects by offering a ready-to-use, versatile, and automated planning and reporting system and conserving a lot of time and effort.

## 6.2 Stage-wise delay drivers and primavera P6 based mitigation strategies

The stage-by-stage analysis of the high-rise project reveals that the project delays are interrelated due to the approval, resource, and coordination problems instead of sing-song activities. Statutory approvals and site preparations led to early delays as these factors were easier controlled by following the progress of approval milestones in Primavera P6.

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Delay in substructure and podium was attributed to equipment, new construction processes and reinforcement planning, which was enhanced by the comprehensive WBS and levelling of resources. Repetitive floor cycles (Mivan) were handled through modelling crane, labor and inspection dependencies in order to identify early breaches. Delays at finishing stage (primarily caused by procuring and documentation of Occupancy Certificate) were minimized through observing statutory milestones.

**Table 4: Simulation Table reflecting DES + SD**

| Area | P6 Feature Used | Purpose | Result |
|---|---|---|---|
| **Planning & Baseline** | Create Multiple Baselines | Compare progress over time | Identify slippage instantly |
| **Critical Path Control** | Run CPM Weekly | Locate delay-causing activities | Early intervention |
| **Resource Optimization** | Resource Leveling & Histograms | Avoid over/under allocation | Balanced workforce |
| **Monitoring** | Activity Steps + Physical % Complete | Track detailed task-level progress | Real-time visibility |
| **Forecasting** | Predictive Analysis | Predict impact of delay | Adjust sequencing |
| **Risk Management** | Risk Register & Float Tracking | Identify and quantify potential delays | Plan contingency |
| **Performance Evaluation** | SPI/CPI (Earned Value) | Quantify schedule efficiency | Data-driven control |
| **Reporting** | S-Curve & Layout Reports | Visual management updates | Transparent communication |

| Sr.No. | Stages | Delay Factors | Solutions | Effect |
|---|---|---|---|---|
| 1 | Start of Construction | Delay in statutory approvals (Commencement Certificate, RERA registration, NOCs).<br>Funding delays from promoters or investors.<br>Mobilization of contractors, machinery, and labor.<br>Delay in site handover from client/owner.<br>Site access issues, encroachments, or land disputes. | Define **pre-construction WBS** (approvals, mobilization, procurement).<br>Use **baseline start** date to monitor slippage in statutory approvals.<br>Apply **constraints** (Finish on or Before) for key approvals.<br>Add **activity codes** for responsibility (Client/Contractor).<br>Include **early warning milestones** like "Mobilization Complete". | visually see which approval is blocking construction start and manage float accordingly. |
| 2 | Excavation | Delay in approval for excavation from authorities.<br>Equipment breakdown (excavators, dumpers).<br>Hard strata or unforeseen soil conditions.<br>Monsoon interruptions or dewatering issues.<br>Safety non-compliance halting work.<br>Delay in muck disposal or dumping permissions. | Link excavation sequence with **logical dependencies** to avoid idle time.<br>Add **lag durations** for dewatering during monsoon.<br>Maintain **equipment resource calendars** to track downtime.<br>Use **activity steps** for layer-wise excavation progress tracking.<br>Monitor productivity using **earned value analysis (EVA)**. | Prevents idle time for downstream activities (e.g., raft foundation). |
| 3 | Foundation Pile (Piling Works) | Machine availability and mobilization delays.<br>Pile load testing delays.<br>Design changes due to unexpected strata.<br>Cement, steel, or bentonite shortage.<br>Safety inspection delays.<br>Poor productivity due to congestion or restricted working hours. | Assign **critical resources** (pile rigs, crane) and apply resource leveling.<br>Add **activity codes** for test piles vs production piles.<br>Set **milestones** for test approval before full mobilization.<br>Create **lookahead schedules** (weekly) for pile installation to monitor output. | Improves sequencing, ensures pile productivity meets planned cycle. |
| 4 | Foundation Raft | Reinforcement bending/fixing delays.<br>Shuttering and formwork shortages.<br>Delay in raft concrete pour sequence and curing.<br>Equipment breakdown (pumps, vibrators).<br>Concrete batching plant supply interruptions. | Use **sub-activities** (rebar, shutter, pour, curing) under a parent activity.<br>Apply **crew resource tracking** to ensure continuous labor flow.<br>Set **activity relationships** (FS + lag) for each pour sequence.<br>Use **resource histogram** to plan rebar & concrete needs. | Accurate tracking of cycle time, early identification of poor performance. |

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| | | | | |
|---|---|---|---|---|
| 5 | Foundation to Plinth (Backfilling) | Poor compaction or soil quality issues.<br>Rainwater stagnation delaying compaction.<br>Delay in retaining wall construction.<br>Testing and inspection hold points. | Assign **weather calendars** to simulate monsoon delays.<br>Define **inspection milestone** (e.g., "Plinth Inspection Clearance").<br>Link **testing labs** as resources to check availability. | Prevents further structural works from being delayed by paperwork. |
| 6 | Plinth Approval | Delay in submission of documents to consultants/local authorities.<br>Non-conformance observations during inspection.<br>Rework for structural or service alignment. | Add **document submission activity** linked to plinth completion.<br>Maintain **document approval log** in P6 under deliverables.<br>Use **flag milestones** for "Approval Received" before next stage. | |
| 7 | Ground Floor (Conventional) | Delay in material delivery (formwork, concrete, steel).<br>Labor shortage or crew underutilization.<br>Coordination delays between civil and MEP services.<br>Design revision or mismatch with foundation layout. | Define **procurement activities** (steel, formwork) with lead time.<br>Apply **resource assignment** for each trade (civil, MEP).<br>Use **"activity steps"** for detailed tracking of slab, column, beam.<br>Add **lookahead filter** for the next 2 weeks to plan dependencies. | Overlapping activities ensures no idle time between trades. |
| 8 | 1st Level to 7th Level (Podium + Amenities + Refuge) | Complex formwork systems at podium level.<br>Integration of MEP, firefighting, and waterproofing.<br>Heavy reinforcement congestion.<br>Delay in PT (Post-tensioning) work for slabs.<br>Waterproofing and podium landscaping coordination.<br>Amenity block design changes. | Link **civil + MEP + waterproofing** activities using FS and SS logic.<br>Assign **Activity Codes** for multi-discipline tracking.<br>Run **Critical Path Analysis (CPA)** weekly to see bottlenecks.<br>Add **resource curves** to match manpower peaks. | |
| 9 | Transfer Slab (2nd Level & 3rd Level) | Complex shuttering and staging design.<br>Delays in rebar detailing and PT cable installation.<br>Long curing time and strength gain delays.<br>Quality check hold points from consultants. | Use **"Resource Loading"** for formwork and reinforcement gangs.<br>Include **lag time** for curing (minimum 7 days).<br>Add **inspection milestone** for consultant clearance before next cycle.<br>Use **baseline comparison** to measure cycle variance. | Enables precise monitoring of heavy structural tasks and shift coordination. |
| 10 | 8th Floor – 44th Floor (Typical Mivan Floors) | Delay in Mivan formwork cycle (ideally 7-day or 10-day cycle).<br>Inadequate number of Mivan sets.<br>Concrete supply disruptions.<br>Rebar congestion and alignment issues.<br>Lifting and crane breakdowns.<br>Safety stoppages.<br>Delay in inspection and approval for next pour.<br>Poor coordination between civil and service sleeves.<br>Labor productivity variations. | Create **repetitive activities** using "Copy Activity + Increment Logic" for each floor.<br>Set **resource calendar** to maintain 7-day Mivan cycle.<br>Link **precedence** as FS between consecutive floors.<br>Use **Global Change function** to update multiple floor sequences quickly.<br>Track **productivity variance** through earned value metrics (SPI, CPI).<br>Add **crane and hoist resources** with limits to avoid double booking. | Allows predictive control of high-rise cycle time; one floor delay triggers early corrective action. |
| 11 | Refuge Floors (14th, 21st, 28th, 35th, 42nd) | Change in design due to fire compliance.<br>Delay in finishing works and waterproofing.<br>Special fireproof materials lead time.<br>Extra inspection from fire and structural consultants. | Create **inspection milestones** for each refuge level.<br>Maintain **approval logs** as separate WBS.<br>Assign **float monitoring** to track potential delay absorption. | Keeps tower progress aligned with statutory safety checks. |

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| | | | | |
|---|---|---|---|---|
| 12 | Above Terrace RCC & Terrace Works | Delay in parapet wall, machine room, and waterproofing. Solar panel or mechanical equipment coordination. Delay in finishing and service installations. | Add **sub-activities:** parapet, waterproofing, solar, MEP plant room. Apply **SS relationships** where trades can overlap. Assign **calendar exceptions** to track night shift work if needed. | Controls last structural stages that often impact finishing and handover. |
| 13 | Blockwork Completion | Shortage of AAC blocks or sand. Slow productivity due to vertical working heights. Delay in layout approval. Rework due to mismatch with MEP sleeves. Weather impact on curing. | Link **blockwork start** after Mivan de-shuttering + curing lag. Assign **blockwork teams** as resources with productivity norms. Use **progress update fields (% Complete Type: Physical)** for accurate tracking. | Prevents rework and ensures material flow continuity. |
| 14 | Internal Plaster Completion | Delay in material supply (sand, cement, plaster mesh). Dependency on electrical and plumbing chasing completion. Labor shortage. Quality rework due to cracks or poor surface. | Add **logic ties** with plumbing and electrical chasing completion. Use **WBS-level filters** to monitor delay in finishing sequence. Assign **crew productivity rates** to calculate accurate duration. | Reduces rework and plaster-to-finishing conflicts. |
| 15 | Flat/Toilet Flooring & Dado Completion | Tile procurement delays (imported tiles lead time). Improper leveling and waterproofing issues. Rework due to cracked or uneven tiles. Plumbing or sanitary fixture delay. | Link **procurement** with construction activities (FS + lag for delivery). Define **float limit** to identify near-critical delays. Track progress using **activity steps** (Waterproofing > Screed > Tile). | Smooth workflow coordination between procurement and execution. |
| 16 | Common Area Flooring Completion | Delay in marble/granite supply. Coordination with railing, lighting, and facade works. High workmanship rework due to aesthetic issues. | Use **inter-discipline linking** between finishing, façade, and railing. Create **constraint milestones** like "Façade Completion Before Flooring Start". Regular **baseline updates** to analyze rework impact. | Ensures coordination of aesthetic and structural finishes. |
| 17 | Lift Completion | Delay in shaft readiness and alignment. Late delivery from OEM (KONE, Schindler, etc.). Power supply availability for testing. Inspection and commissioning delays. | Link **Lift Installation FS** to "Lift Shaft Plaster Completion". Assign **OEM resource** with limited availability. Add **testing milestone** under Mechanical Completion WBS. Use **"Activity Codes"** to segregate vendor scope. | Keeps vendor work in sync with civil readiness. |
| 18 | OC Application (Full OC) | Delay in submission of completion drawings & NOCs. Pending statutory compliances (fire, STP, lift, environment). Delay in as-built documentation. Local authority inspection scheduling. | Create **WBS: Statutory Approvals** with all required NOCs as activities. Assign **responsible departments** (Fire, STP, Lift, Environment). Apply **milestones** (OC Applied, OC Inspection, OC Received). Use **progress thresholds** to track approval readiness. | Ensures readiness and avoids last-minute paperwork delays. |
| 19 | OC Receipt – Full OC | Delay in authority processing. Pending clearance certificates (Water, Drainage, Fire, Lift, Environment). Minor rectification works flagged during inspection. | | |
| 20 | Complete OC Duration | Delay in internal coordination between departments. Paperwork and audit delays. Delay in obtaining occupancy certificates for both towers simultaneously. | | |

*Source: Created by authors*

### 6.3 Stakeholder responsibility alignment

The Findings: An Online Decision Support Cycle.

This approach is able to convert the Primavera formal planning features to a dynamic, data-driven, and continuously optimized system of managing its workforce. Through the

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closed feedback loop between the planning, simulation and execution processes, project teams can have unprecedented visibility and control over the decision of resource allocation.

## 6.4 Conclusion

The proposed model offers the following advantages to project managers and planning professionals:

- Reduces time taken in project set up and reporting.
- Removes redundant data modelling and data transformation processes.
- Enhances the efficacy of planning and tracking.
- Improves the collaboration among planning, execution and management teams.

Allows scaling in use in numerous projects. By providing a ready-to-use, flexible, and automated planning and reporting framework, the model helps organisations achieve better control over complex construction projects while saving significant time and effort.

This paper finds that the model aids in making decisions based on data by converting fixed schedules into an adaptive control system, such that data presented by dashboards directly influence corrective action and recovery planning.

In general, the framework increases transparency, better coordination among the stakeholders, and allows taking control of the project, which makes it a viable and reproducible solution to high-rise and other large-scale construction projects.

## 6.5 Recommendation

Going by the results of the present study, it is advisable that construction organisations should implement a data-intensive resource and project management model that incorporates scheduling software like Primavera P6 along with data analysis tools like Power BI. Visibility of project progress, labour usage and productivity are much enhanced by the early development of standardized scheduling templates and the development of structured resource plans. Regular KPI monitoring, such as schedule performance, costs, and cycle productivity, should be institutionalised with dashboard-type reviews that allow the correction to be taken in good time and ensure proactive project control. Scenario analysis and responsibility-based planning also increase coordination among the stakeholders and as such, delays and inefficiencies in high-rise developments are minimized.

Based on this base, future developments of the model can include the use of Industry 4.0 advanced technologies like drones to track progress, an IoT-based machinery monitoring tool, and a 4D and 5D visualisation tool based on BIM. Incorporation of predictive analytics and simulation would also help to make decisions under uncertainty in a proactive manner, which would help to make project delivery more resilient and efficient.

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