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Integrated Project Delivery Readiness and Schedule Risk Index (IPDRSRI): A DPMS and Primavera P6-Based Predictive Framework for Engineering, Procurement, Construction, Commissioning, and Contract Closure in IISCO Steel Plant Projects

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Abstract - Although the implementation of Industry 4.0 technologies provides new avenues to enhance project performance across industrial domains, steel plant expansion projects have no widely recognized tool to ascertain digital readiness for project implementation. This study proposes a digital project readiness index (DPRI), an aggregate index constructed using AI, BIM, digital twins, mobile field supervision, and project performance analytics. The framework assesses the level of digital readiness in five aspects: digitalized planning, BIM implementation, data connection, predictive capabilities, and digital lifecycle asset management.

Weight of index components is derived through a hierarchical structure using the Analytic Hierarchy Process (AHP).

The DPRI offers a quantitative mechanism to enable project managers in determining their project's digital transformation capabilities, benchmarks for comparing across the industry, and areas of digital improvements. The methodology adds to the literature on industry 4.0 project management and has managerial implications for the successful modernization of steel plant expansion.

Keywords: Digital Project Readiness Index, BIM, Artificial Intelligence, Digital Twin, Industry 4.0, Steel Plant Projects, Project Digitalization.

1. Introduction

The steel industry is undergoing rapid transformation as Industry 4.0 and digitization takes hold. Major project investments (like in Blast furnace plants, Steel melting shops, rolling plants, Oxygen plants, and material handling plants) require robust monitoring and control of overall project execution (1). Traditional project management practices are driven by manual reports, spreadsheets, and standalone applications, giving the project managers difficulties in terms of real-time status tracking, identifying project delays, and coordinating various disciplinary tasks (2). Digital project monitoring systems are a relatively new approach to overcoming these challenges by integrating BIM models, scheduling and mobile apps into a cohesive digital workspace that offers greater control and transparency (3). This paper develops a framework which utilizes: Oracle Primavera P6 Scheduling, Multi-dimensional BIM(3D-7D), Mobile data capture applications, Artificial Intelligence based forecasting, Digital twin for creating holistic view of the project and for prediction of project delays. AI, BIM, IoT and Digital Twins are a collection of Industry 4.0 tools that are influencing how project design and monitoring is achieved in industrial projects (18).

2. Literature Review

It is acknowledged that BIM is useful for visualization and coordination (4) and some literatures have shown that 4D BIM is beneficial to schedule visualization and stakeholder communication (5), 5D BIM can help to save time and cost in estimate and cost management by adding the financial information in BIM model (6). Nowadays studies have focus on the use of digital twins to maintain the infrastructures and industrial projects through the life cycle management and prediction of failure (7) and Primavera P6 is still the common tool in Primavera project management software for large scale industrial project (8). BIM is used for visual and informational communication, integration and coordination on the project during its life cycle (15, 16). By using the concept of digital twin, a virtual twin which can track, monitor, identify predictive and perform asset life management with ease is developed (11,13,19). These analyses, powered by AI, detect bottleneck operations and delays in project schedules can anticipate potential future risks and lead the organisation towards data informed decisions (12).

There is limited research that has explored the following integration:

1) AI Forecasting

2) Primavera Scheduling

3) 7D BIM

4) Mobile Monitoring Applications

within a project monitoring system in the steel plant expansion project scope.

3. Research Gap

Prior academic papers are cantered on an isolated application of BIM for design coordination and visualisation or using scheduling tools for the planning and construction process. Other have suggested that, digital twin is useful in the construction industry, but these systems are currently poorly implemented and siloed (10,11,13,19) and there are also few studies about combined use of AI for delay forecast; BIM; digital twins; and Primavera P6 scheduling under the context of an integrated approach (12). This paper proposes a framework for a DPMS which integrates real time monitoring, prediction of delay, cost, and sustainability control and maintenance during the whole facility life cycle (14).

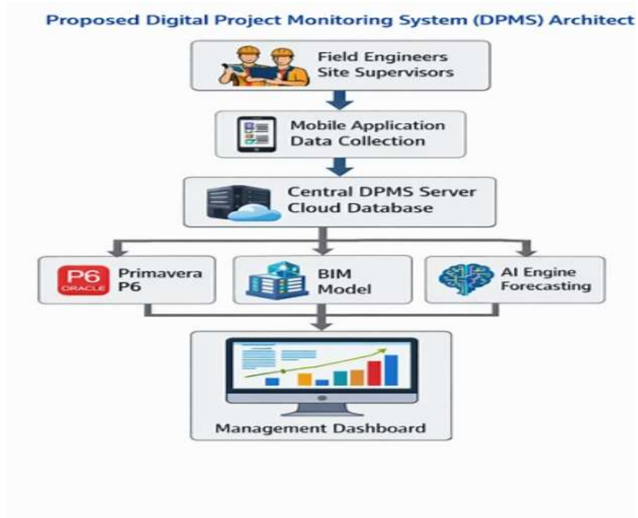
Table 1. Comparative Research Gap Analysis

Study	BIM	AI	Digital Twin	Readiness Index
Study A	Yes	No	No	No
Study B	Yes	Yes	No	No
Study C	Yes	Yes	Yes	No
Proposed DPRI	Yes	Yes	Yes	Yes

4. Methodology

The digital revolution has already brought significant changes in construction and industrial projects in the sense that digital technology has facilitated more integration, automation, data usage and better decision making (14,18). Moreover, due to use of IOT and sensor technology for collection and processing real-time project data via apps on smart phones improve project control and supervision and increase the flow of real-time project information (17). To achieve project success, with regards to project timeline, budget, and performance, good project planning, scheduling and control will remain important for large projects that are run by different stakeholders (20).

4.1 Proposed DPMS Architecture



Pic. 1

This is a suggested architecture for the Digital Project Monitoring System (DPMS). This design is a holistic digital model aimed at monitoring and controlling projects throughout its life cycle. It consists of data inputs sources, database module, analytics engine, performance evaluation module, visualization interface and a decision-support system.

Through this DPMS, we can monitor project activities on real-time basis, analyse variances in cost and schedule, predict risks, and provide valuable and actionable inputs to the project management stakeholders. This will centralize project related information on a single platform and improve transparency and effective decision-making.

General architecture of the proposed Digital Project Monitoring System.

Figure 1. DPMS System Architecture

Field Engineers
↓
Mobile Application
↓
Central DPMS Database
↓
Primavera P6
↓
BIM Model
↓
AI Forecasting Engine
↓
Management Dashboard

The structure allows information to flow between the stakeholders on a project in two directions.

4.2 Software Ecosystem

Table 2. Comparative Research Gap Analysis

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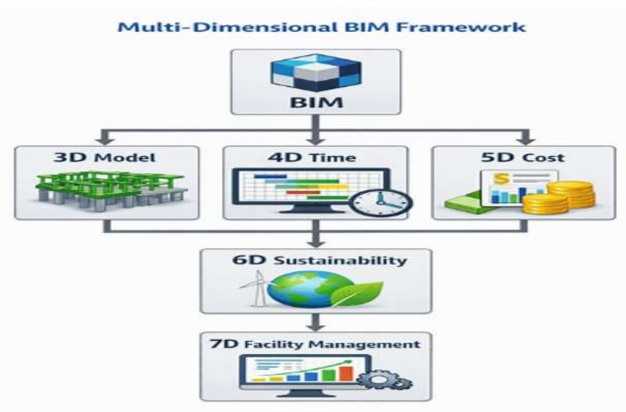
Software	Function
Oracle Primavera P6	Scheduling
Autodesk Revit	BIM Modelling
BIM 360	Collaboration
Navisworks	Clash Detection
Power BI	Dashboard Analytics
Android/iOS Apps	Field Reporting
Python AI Models	Delay Prediction

4.3 Multi-Dimensional BIM Framework



Pic. 2

Pic 2. BIM Dimensions

3D Visualization

4D Time Integration

5D Cost Integration

6D Sustainability

7D Facility Management

The 3D model(geometry): The dimension of space, that provides an opportunity to identify potential conflicts in the design. Architects, engineers and contractors use the model to find clashes before construction even starts.

The 4D time(scheduling): The project schedules construction sequences which then attach to the 3D model, so that they can simulate sequences and work out how to run the most efficient project schedule possible, often using Primavera P6 to model and simulate sequences.

The 5D cost(estimation): Integrate cost to model, comparing the cost of planned work to actual, with opportunities for value engineering and budget control.

The 6D sustainability: Sustainability requirements and data are fed in the model that will assess the materials, carbon footprint, energy consumption of the building, so the goal to achieve a sustainable project.

The 7D facility management: When construction is completed, the BIM model is converted into a digital twin of the building that will be used for management and maintenance of the facility.

BIM improves team collaboration, visualisation, clash detection and information coordination across the project lifecycle (15,16).

4.4 AI driven Delay Prediction

The AI engine constantly monitor:

- Schedule variance (SV)
- Cost variance (CV)
- Resources availability
- Weather impact
- Procurement stage

Predictive analytics, using AI techniques, can help detect project risks, identify potential project delays and recommend proactive actions (12).

4.5 Development of Digital Project Readiness Index (DPRI)

DPRI Digital Project Readiness Index is an evaluation metric to measure and quantify the progress of steel plant digital transformation on construction of expanding projects. It consolidates five key dimensions of project digitalization and Industry 4.0 implementation.

The average priority in DPRI was calculated by comparing values to respective DPRI dimension. The comparative priorities (equal to weights) in DPRI were achieved through analytic hierarchy method (AHP). Expert values from professionals of project management, BIM, digital transformation, and steel.

The DPRI is calculated as:

$$DPRI = 0.25(PD) + 0.20(BI) + 0.20(DC) + 0.20(PI) + 0.15(LM)$$

Where:

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PD = Planning Digitalization

BI = BIM Integration

DC = Data Connectivity

PI = Predictive Intelligence

LM = Lifecycle Management

The weights reflect the varying influence of individual dimensions on the successful execution of digital projects. This ultimate DPRI calculation spans from 0-100 and quantifies the overall digital readiness of a project.

Table 2. AHP Derived Weights of DPRI Dimensions

Dimension	Description	Weight
Planning Digitalization (PD)	Digital planning and scheduling systems	0.25
BIM Integration (BI)	BIM adoption and model integration	0.2
Data Connectivity (DC)	Real-time data sharing and cloud systems	0.2
Predictive Intelligence (PI)	AI and predictive analytics utilization	0.2
Lifecycle Management (LM)	Digital Twin and asset lifecycle management	0.15

4.6 DPRI Maturity Classification

Table 3. Digital Project Readiness Maturity Levels

Score	Level
0–20	Traditional
21–40	Basic Digital
41–60	Developing Digital
61–80	Advanced Digital
81–100	Intelligent Digital Project

5. Results and Discussion

5.1 Construction Stage Coordination

Pic. 3 BIM-Based Construction Coordination

Merging civil, mechanical, electrical, structural, and instrumentation disciplines under the same BIM environment alleviates conflicts and reduces rework.

Pic. 3

This above diagram shows how the physical construction is duplicated in digital form with an integrated monitoring system:

Physical Construction Site: Represents the actual physical reality where the structural, mechanical and electrical construction takes place, and information such as readings from the sensors, supervisors, and field engineers is collected on a constant basis.

BIM Digital Model: is the virtual representation of the physical world, and aggregates geometry, materials and construction progress, and helps visualizing the current situation of the construction and detecting any possible clash.

Primavera Schedule: integrates the BIM model with the construction timeline. Any activity in the BIM model is integrated in the scheduling tool in P6, and allows real-time follow-up of planned versus actual progress.

AI Analytics Layer: combines the BIM data with the scheduling and provides real-time prediction of delays, resource problems, and financial variance by machine learning and analysis of information collected.

Management Dashboard: allows the management to see and monitor the KPIs, progress charts, and predictive reports.

5.2 Design Stage Visualization

Pic. 4. 3 D BIM Design Model

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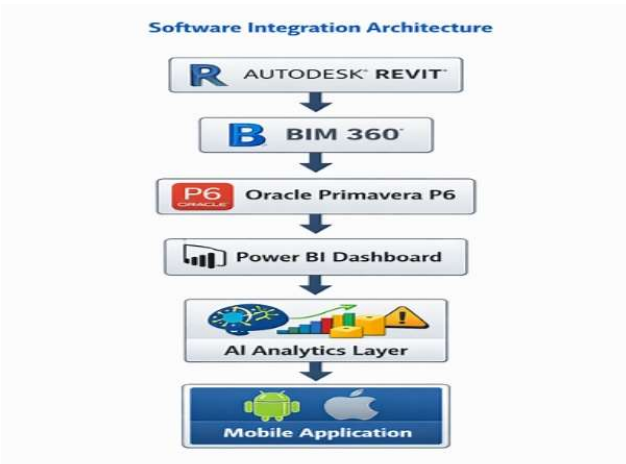
Visualisation early helps stakeholders to detect constructability problems prior to build

- Benefits
- Increased decision-making capabilities
- Enhanced communication between stakeholders
- Reduced changes to design



Pic. 4

Above diagram outlines how the primary software packages that will comprise the proposed DPMS system are interconnected for steel plant expansion purposes.

Autodesk Revit BIM 360: The base 3D/7D BIM model is built in Revit and the associated collaborative cloud platform is BIM 360 which serves for clash detection, design coordination and versioning.

BIM 360 Oracle Primavera P6: the schedule and activity information derived from the BIM model will be synced with the project schedule in Primavera P6.

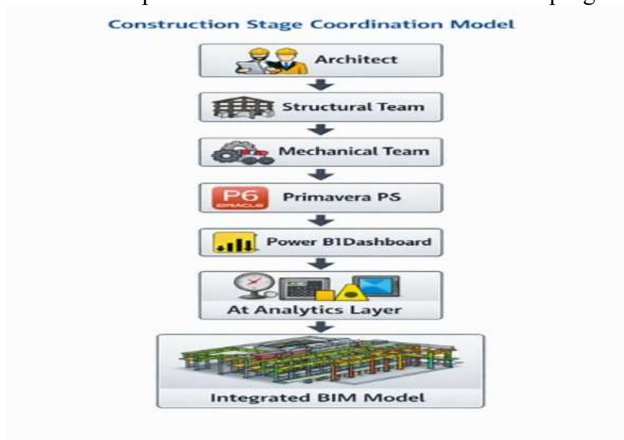
Oracle Primavera P6 Power BI Dashboard: scheduling and costing information from Primavera will be imported and visualized on interactive and dashboard supported Power BI displays to be consumed by management.

Power BI Dashboard Mobile Application: The analysis, KPIs derived from the Power BI application will be broadcast on mobile displays for use by field engineers or site managers who will enter progress report data on the field.

5.3 Progress Monitoring

Pic. 5. Tracking on Site

Daily information gathered from mobile devices is uploaded and synchronised to the Primavera schedule and BIM model. The project manager has a "look on line" to the differences between planned and real time progress



Pic. 5

Above illustrates the layered cooperation between multiple design disciplines during the construction phase of a steel plant expansion:

Architect: Begins by establishing intent and spatial arrangement. The architect's model forms the base for all other engineering disciplines to be linked and built off of.

Structural Team: Translate architectural elements into structural models and determine where to place supports and the appropriate loads they need to hold. Their model forms the "skeleton" of the facility.

Mechanical Team: Overlay all of the mechanical design work into the model such as the duct work and piping and layout of equipment. Coordination in this step is critical for avoiding spatial conflicts with the structural model.

Electrical Team: Overlay the electrical system design, including the power, lights, and controls. Their model coordinates with the mechanical and structural models.

Instrumentation Team: Add the instrumentation, control panel, and other control systems that are essential to the process operation.

Integrated BIM Model: All disciplines have their models linked together in a comprehensive environment where clashes and sequencing can occur and for progress visualization of the construction efforts.

5.4 Plan versus Actual Analysis

Pic. 6 Delay Monitoring Dashboard

The dashboard highlights:

• Critical activities

• Delayed activities

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• Resource shortages

• Schedule slippages

Pic. 6

The above illustrates the ongoing improvement process cycle adopted in DPMS for the expansion projects of a steel plant. This implies the way planning, execution and analysis continues to form an iterative cycle which ensures efficiency and timely completion.

Planning: The initiating point of the entire cycle. All project goals, timings and resource inputs required for execution are specified using software such as Primavera P6, or BIM based simulations.

Execution: All the designed activities are executed by the site teams, wherein inputs from site supervisors and mobile applications are logged in the DPMS server for a real time status monitoring.

Monitoring: Progress, cost and quality reports are constantly monitored to check the status. The actual performance is continuously compared to the planned inputs on the DPMS dashboards.

Analysis: The AI driven analytics identify the delays and cause behind them by finding out the delay patterns, predict and analyse any risks, etc and portray the same on Power BI dashboards.

Corrective Action: Targeted interventions such as rescheduling the activities, reallocating resources or re-designing certain elements of the project are executed in order to address the risks and delays.

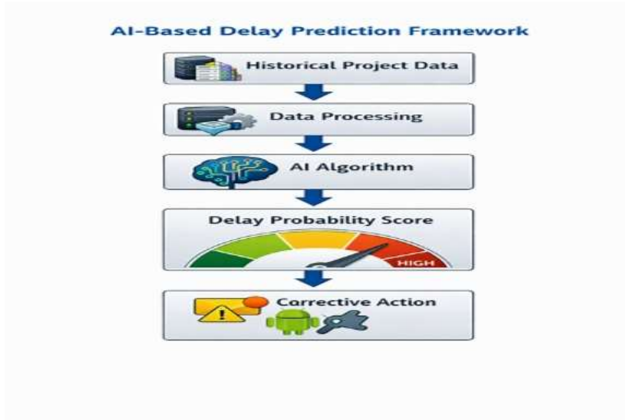
Re Planning: The whole cycle repeats in a revised way, thereby ensuring an iterative adjustment and improvement process.

5.5 Cost distribution Analysis

Estimated Project cost distribution: The bulk of costs are concentrated under civil and mechanical activities of the project

5.6 Schedule Performance Trend

Pic. 7 Monthly Schedule Performance



Pic. 7

This picture indicates how AI turns project data into insights for proactive delay management within DPMS.

Historical Project Data: The project past data (schedules, resource records, procurement, performances, etc.) were collected from Primavera P6 and BIM databases. All the data sets built predictive modelling foundation.

Data Processing: Data collected was then cleansed, normalized and structured. Inconsistent or null values were fixed to build reliable inputs for machine learning algorithms. All data were categorized by project phase, discipline, etc.

AI Algorithm: Machine learning algorithm (e.g. Regression, random forest, neural networks) were built to find relations among variables like engineering completion, vendors' performances, and weather effect, and predict risk on delay.

Delay Probability Score: AI engine calculated the probability of delay for each activity and assign score. This score was represented with colour code-Green (low risk), Yellow (medium risk) and Red (high risk) on management dashboard.

Management Alert System: When the score was over a threshold, automatically notified project managers by e-mail or cell phone message so that they could take effective action (re-planning, resource substitution, supplier monitoring etc.) to reduce risk on delay.

Pic. 8 Plan vs Actual Monitoring Concept

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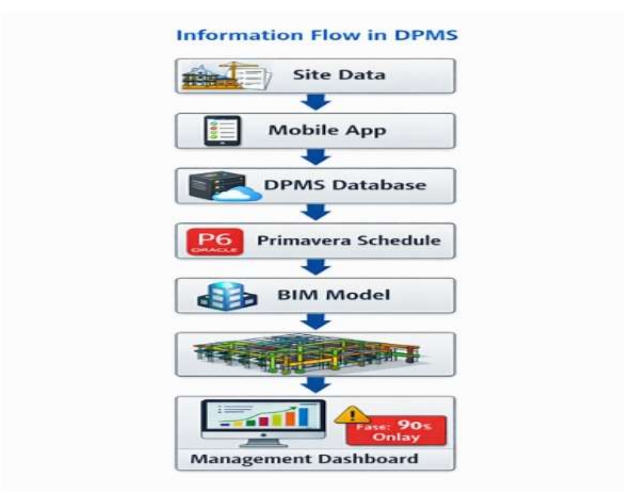
Pic. 8

This visualization plots the intended advancement with the actual advancement and the performance lag which clearly signals a project lag. Planned Progress (100%) The green bar reflects the target project advancement defined by the base schedule in Primavera P6. This bar indicates the desired progress of the project. Actual Progress (80%) The yellow bar represents the real-time progress captured by means of DPMS mobile updates and BIM tied monitoring. It signals the poor performance. Gap = 20% Lag The red bar indicates the extent of the lag between the planned and actual advancement. The 20% lag causes warnings in the AI based management dashboard which necessitates action, such as; resource diversion or schedule adjustment.

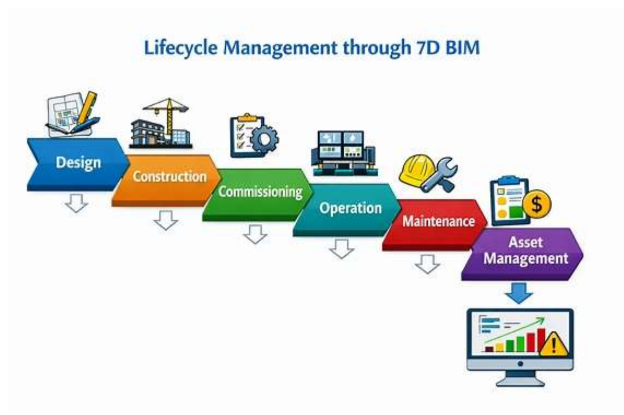
Pic. 9 Information Flow in DPMS



Pic. 9

Data pipeline the graphic shows the path data takes through the DPMS, from field collection all the way up to executive dashboards: Site data: This data comprises all real-time progress, resource, and quality indicators collected on the construction site by field engineers and supervisors. Mobile app: This is the first digital point of interaction and pushes data updates, photos, and checklist completion from the site to the DPMS server in the cloud. DPMS database: This is the central cloud repository for all data – all information collected from the field, scheduled, and tracked – and facilitates secure access and management. Primavera schedule: Scheduling data from primavera is combined with actual project progress derived from the DPMS database so that the gap between planned and actual schedules can be continuously tracked. BIM model: Geometric and schedule data are combined in the model. The building information model displays the current progress status and helps to identify design clashes. Management dashboard: The processed and aggregated data, which consists of key performance indicators, cost reports, risk alerts, and other insights on project progress, costs, resources, risks and quality, is then summarized for executive dashboards and reporting purposes.

Pic. 10 Lifecycle Management through 7D BIM



Pic. 10

- Above figure shows the whole project life cycle where 7D BIM can be used and data is passed from design phase to life time asset management phase.
- Design stage: it is the first phase, architects and engineers will generate the digital model where you will define all the geometrical, physical and operational information. This phase ensures the accuracy and consistency of the data.
- Construction stage: The model will provide guidance for real time construction and information is collected and checked on the site. The Primavera P6 integration will facilitate monitoring progress of schedule and utilization of resources.

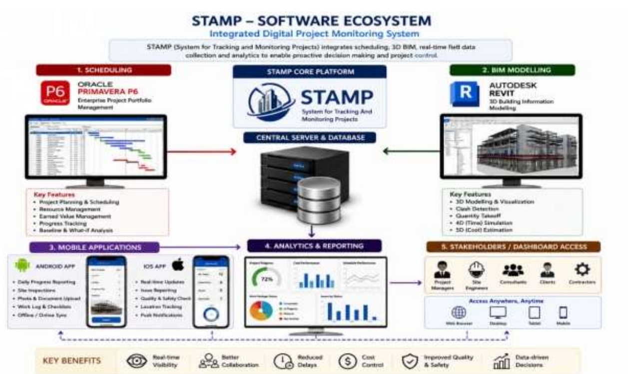
- Commissioning stage: the performance of the facility will be tested according to the design data. The BIM data can provide information about quality of installed systems and facilities.

- Operation stage: The facility has become functional. Operational data, for example, information about energy consumption, performance of machinery and spatial usage will be provided.

- Maintenance stage: Preventive maintenance is scheduled with 7D BIM integration with sensors and AI, to detect damages on components, predict failures, reduce time between maintenance procedures, and increase usage period of the facility, minimizing downtime, and to increase its usage.

- Asset management stage: at last, all data through life cycle is integrated to digital twin, which provides for life cycle planning, optimization of expenditures and tracing sustainability. Managers will use dashboards to trace all asset's performances and condition.

5.6.1 STAMP – Software Ecosystem



Pic. 11

Pic. 11 Demonstrates the integrated software architecture of the proposed System for Tracking and Monitoring Projects (STAMP) which forms the basis for the Digital Project Monitoring System (DPMS). This framework integrates Oracle Primavera P6, Autodesk Revit BIM, mobile applications, centralized database and analytics dashboards, bringing these components together into a seamless digital environment for project planning, monitoring and control.

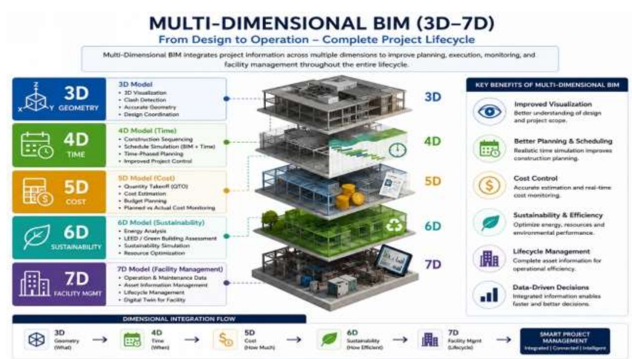
Oracle Primavera P6 is used as the scheduling engine supporting project planning, resource assignment, progress measurement and earned value reporting. Concurrently, Autodesk Revit is used as the Building Information Modelling (BIM) platform providing a 3-D visualization, clash detection, estimation and scheduling functionality. All these are linked to a centralized server and database providing real time information synchronization.

Mobile application functionality enables field engineers and site supervisors to log day to day progress, pictures, inspection reports and quality observations directly from the construction site. This real time uploading of information reduces the lag between on- site activity and reporting, thereby enabling closer cooperation between site personnel and management.

An analytics and reporting module is developed to present the project data in useful charts, reports and performance indicators. These enable project managers to evaluate progress performance, identify trends in cost and work package performance and identify project risks. Through stakeholder dashboards, consultants, contractors, clients and engineers can access this data on any location by web browser or device (desktop, table or mobile phone).

These digital technologies are integrated to form a complete project monitoring system. This fosters an environment of transparency, coordination and a robust process for effective decision making. This system ensures a proactive approach to managing projects by providing real time project performance visibility; mitigating schedule slippages, boosting work quality and facilitating informed decisions through the course of the project lifecycle.

5.6.2 Multi-Dimensional BIM (3D–7D)



Pic. 12

Pic. 12 Is a visualization of Multi-Dimensional BIM, where BIM extends from traditional three dimensions into total project lifecycle management. Geometric, scheduling, cost, sustainability, and facility management information is integrated into one digital platform, allowing stakeholders to make informed decisions throughout the lifecycle of the project.

The 3D BIM dimension is the geometric visualization of the project, serving as the backbone of the BIM environment. It enhances design coordination, clash detection, visualization, and communication between the designers (architects,

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engineers, consultants) and builders (contractors) and helps detect design conflicts before actual construction, reducing the rework of project execution.

The 4D BIM dimension integrates project schedules with the 3D models. Linking the actual activities involved in the construction of the project with specific project components provides the ability for the scheduler to visualize and monitor the construction sequence, the construction time progress, and evaluate the construction schedule performance, thus improving the planning and management of construction work and the coordination between the different team members in the construction project.

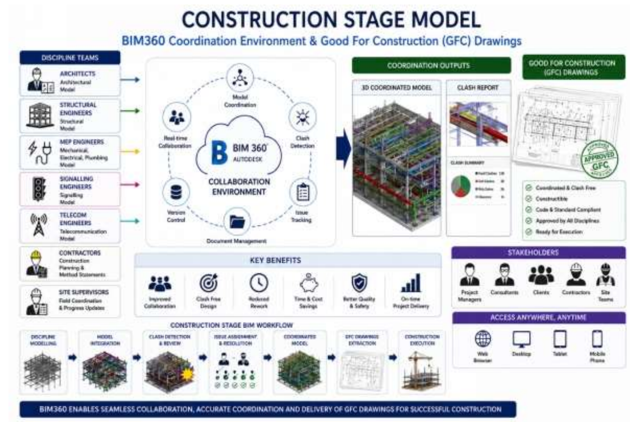
The 5D BIM dimension integrates cost data with the digital models. This dimension will allow the quantity take-off, cost estimating, cost forecasting, planned vs. Actual cost reporting and monitoring, and evaluation of project financial performance to be done efficiently, while helping project managers to maintain their budgets through effective control of budget overruns.

The 6D BIM dimension addresses sustainability and energy performance of the project. The features within this dimension are energy analysing, resource optimization, sustainability appraisal, and green building rating and certification. By having environmental performance considerations in the planning and design phase, organizations can improve the efficiency and sustainability of their operations and projects.

The 7D BIM dimension links the BIM models into facility management and lifecycle operations. It encompasses information such as assets, maintenance schedule, operational performance history, equipment specifications, life cycle performance, and will allow for the realization of the digital twin to facilitate effective facility operation, maintenance, and long-term asset management.

The illustrated dimensional flow shows the relationships and progressions between 3D geometry (What), 4D time (When), 5D cost (How Much), 6D sustainability (How Efficient) and 7D facility management (Lifecycle). The integration in the BIM model provides more comprehensive and robust information that takes BIM from being solely a design tool to a strategic project management platform that will support the complete lifecycle of industrial infrastructure projects.

5.6.3 Construction Stage Model



Pic. 13

Pic. 13 Shows the BIM-enabled construction phase coordination framework by BIM360 collaboration platform. As showed from the picture, there are many project participants including architects, structural engineers, MEP engineers, signalling engineers, telecommunication engineers, contractors, and site supervisors participate in this central digital platform in construction phase coordination and implementation.

Within BIM360 environment, it works as a common data environment (CDE) where all project information will be uploaded, reviewed and synchronized in real time. In each discipline (architectural, structural, MEP, signalling, telecommunication), the discipline's own models are built up, and later integrated into the federated BIM model. It enables multi-disciplinary coordination and project teams will be capable to find and resolve the design clash before construction activities can start.

As showed in the picture, it highlights the clash detection process where the spatial conflicts between structure, mechanical, electrical, plumbing and communication systems will be identified. Identification of clashes in the early stage will effectively reduce construction errors, minimize re-working, and enhance quality performance. Issue tracking and document management functions would ensure design changes, approvals and project communication is controlled.

Coordinated BIM model leads to the derivation of Good for Construction (GFC) Drawings. GFC Drawings are the approved construction documents used for construction activities. It's created after multi-disciplinary verification and compliance check so that all elements are buildable, clash-free and conform to the project specification and standard.

The workflow in the bottom of the picture shows the stage from disciplinary modelling to model aggregation, clash detection, issue resolution, coordinated model creation, GFC drawings creation and eventually construction execution. It provides the systematic workflow in digital form.

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This model also shows project performance improvements such as better collaboration, clash-free design, minimized rework, cost and time saving, enhanced quality & safety performance, and early project delivery as its benefit section. The accessibility feature also show that the information can be accessed by web, desktop, tablet, and mobile to monitor and make decisions for the project in real-time.

5.6.4 Design Stage Model

Pic. 14

Pic. 14 Shows an overall 3D BIM Design Stage Model which was created for architectural visualization, design validation and owner review prior to project construction. This model is an effective way to check various design options, construction viability and operational requirements.

The overall building configuration, floor arrangement, equipment layout, access systems and building external appearance are displayed through this primary building visualization, where stakeholders get to examine the project from multiple points of views. BIM visualization enables clients to ensure all requirements are met prior to building construction.

The critical building design elements included in the BIM model are the structural system, wall and cladding system, roof structure, stairs, platforms, piping system, equipment layout, doors and windows and site development. By consolidating these features in the same building information model, architects, structural, MEP engineers and planners are able to coordinate building design more effectively.

The design analysis displayed shows the ability of the BIM application to provide solutions to various planning issues such as space planning, accessibility study, circulation analysis, energy analysis, code checking and clash detection. Analyzing these requirements will allow teams to spot potential problem areas early and in turn minimize expensive change orders.

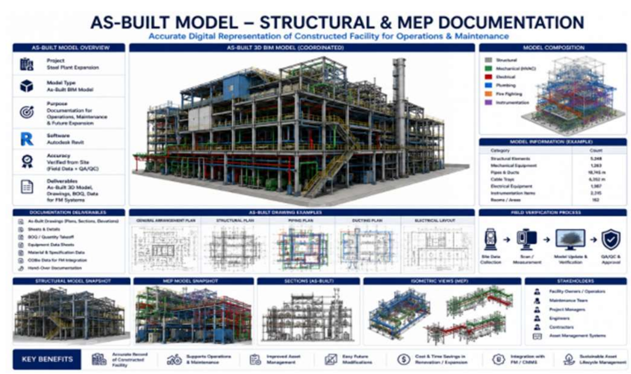
Through a variety of interior perspectives stakeholders get to explore the interior of building and view different operational areas which will be affected by building design for functionality, maintenance, safety and accessibility to equipment. Additional sectional views, site layout model gives an overview on relationships among different buildings, structural elements and building sequence.

The BIM Model Snapshot displayed above illustrates the BIM interface and platform used to develop the building model. Such BIM model serves as a central source of project information for effective team coordination. The materials and finishes palette can be viewed on the BIM model. This function can guide clients and architects in choosing suitable building materials and finishes.

Stakeholder Integration framework pictured shows the collaborative process of BIM. Clients, architects, engineers, MEP designers, contractors and regulators can collectively participate in the project design review process through the central BIM model. Communication and decision making are much more efficient.

Key Benefits of this design model include but are not limited to; Enhanced visualization; Design validation and confirmation; multidisciplinary integration; Collision and conflict detection; Optimize time and cost; Better communication between stakeholders; Reduced waste and Rework.

5.6.5 As-Built Model



Pic. 15

Pic. 15 This presents the As-Built BIM Model produced following completion of construction activities. This document represents the completed status of the facility with verified structural, architectural, MEP and utility data; Unlike models produced at the design phase, the as-built BIM model reflects what has been constructed as there have been changes to structural elements and services.

The structural documentation captures information related to the elements of construction including; columns, beams, slabs, foundations, staircases, platforms, roofs and other load-bearing construction components. Engineers and facility managers are able to view information regarding structural elements of the facility in a digital format for inspection, maintenance, upgrades and any future works.

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The MEP documentation layer is able to capture information regarding electrical distribution systems, HVAC, fire protection systems, plumbing systems, communications systems, instrumentation systems and utilities. Engineering systems are consolidated in to a single BIM model that provides information for the maintenance and operation of the facility.

The views of the completed facility provide a representation of the structure and architecture and of the facility both externally and in internal circulation areas, on platforms, staircases and service spaces. Access to information is enhanced and future decisions can be made by referencing visual data.

A significant benefit of the as-built BIM model is its use as a basis for the creation of a Digital Twin environment, where a virtual representation of the real world is linked to asset performance monitoring, preventive maintenance planning, equipment inventory, asset maintenance and the examination of lifecycle costs. The concept of Digital Twins promotes operational efficiency and supports the application of data-driven maintenance (11,13,19).

The BIM model provides a single place where all relevant project documents including equipment specifications, installation details, warranties, maintenance schedules, reports and operating manuals can be stored and accessed readily. Centralized access to such documents helps to speed up document retrieval times and improves efficiency in facility management.

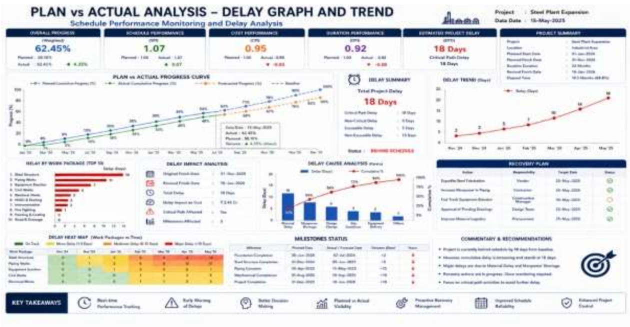
The information contained within the as-built BIM model also enables and assists with future upgrades, refits and new build projects with relevant geometrical and engineering information so engineers can assess design options, spatial constraints and evaluate potential risks and impacts before any modification or development work is undertaken

5.6.6 Site Progress Monitoring

Pic. 16

Pic. 16 The construction progress and schedule performance are monitored in Pic. 6 on Site Progress Monitoring Dashboard which is part of the DPMS designed and developed to allow monitoring of the project performance in real time. The dashboard includes information about the construction progress, schedule performance, cost performance, quality, safety, workforce and project status and it is essential for managers to monitor project health. The dashboard displays relevant Key Performance Indicators (KPI's) such as overall project progress, SPI, CPI, budget performance and safety metrics at glance that will allow them to track progress, make real-time decisions and respond quickly on new risks or other issue to the project. A section showing the Planned Vs Actual Progress Curve at site level can show graphically how the work carried out in the site differs from planned work. If a difference between the curves shows, then managers can immediately react and apply a mitigation action to control the project on schedule. The information on work package performance shows in detail the progress in all work packages of the project (civil works, structural works, equipment erection, piping, electrical, HVAC, instrumentation and finishes work) and helps the managers to easily find those ones not on time and adjust resource allocated for them. The cost performance section of the dashboard displays how the cost is monitored and controlled by tracking costs, budgets and expenditures and planning to act to avoid project cost overrun by comparing planned vs actual. Integrating cost information with planned work on a schedule provides for greater financial transparency. Safety and quality are also addressed through Quality and Safety Performance Indicators, including inspection results, non-conformance reports, safety observation reports and incident statistics and used by managers to ensure all project tasks are accomplished according to standards and regulations, as required and minimize risk of accidents at the site. Workforce and resource tracking allow the management team to see work efficiency and optimize the available resources to minimize construction and project costs by observing the man hours per work, work done per employee, resource (manpower & equipment) allocation and to keep the project on schedule by providing man-hours for each work package in the project. Weather forecast, site images, alerts and notifications about project statuses are additional information displayed on the dashboard to provide as much information as possible. Site information is sent from site to the manager via smart mobile applications. The final part is where the actual benefits of having the DPMS are summarized including, real-time progress, plan vs actual, deviation management, cost control, schedule control, risk management and project decision-making processes.

5.6.7 Plan vs Actual Analysis



Pic.17

Pic.17 displays the Plan versus Actual Performance Analysis Dashboard designed to analyse project schedule performance and predict delay. Through the trends of graphics, it displays planned progress versus actual status at site on time at a definite reporting period allowing the project manager to get information and to be able to take action to avoid delay on time.

The planned vs actual progress curve at the centre shows a baseline schedule created in planning time versus the current progress at the site. It illustrates the trend and difference between planned progress line and actual progress line so as a measure of delay or acceleration.

Delay trend graph displays a visual of the trend of project progress. If the deviation from planned progress line to actual progress line increases it means that the cumulative project delays grow. If the deviation decreases, it implies that the performance of the project at site improves due to recovery actions. By analysing a project delay trend, it is possible to judge if a project is under improved performance or not.

The dashboard indicates Schedule Variance (SV) and Schedule Performance Index (SPI). SV is a difference between plan and actual performance and SPI is a measure of progress efficiency against the schedule. SPI is under 1 indicates it lags behind plan, if is over 1 then it is over performing project. The values provide support for judgment and decision.

Delay Analysis for Activities, critical activities can be identified. Each part like Civil Work, Structural Erection, Equipment Installation, Piping, Electrical, Instrumentation and Commissioning are can be illustrated separately by the graphs. Project manager can know what critical part is suffering from delay and take necessary action.

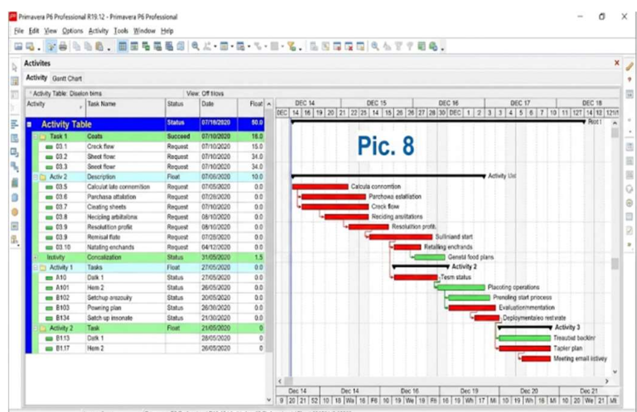
Forecasting can also be developed from past trends, by using analysis with current data to predict the estimated completion dates. By doing some calculations on the present progress and work performance productivity, it is able to determine how many delays will be resulted and make better plan to avoid them. Forecasting has a significant impact on huge industrial project where project manager is afraid of delay.

Root cause of Delay section provides the classification of delay by source such as shortage of materials, unavailable equipment's, low manpower, re-design of structure, approval lag, weather, and bad performance by contractor, etc. By investigating the reasons of delay, it is able to find out some particular plans to cure these troubles.

The graphical reporting allows effective stakeholders communication as it changes the complexity of schedule analysis to easy understand graphic. Every project stakeholder including project owner, consultant, contractor and manager are able to identify the project performance quickly by looking at project data from different view.

It ensures that site, mobile reporting system and Prima-vera P6 analysis system are integrated to provide a real-time updated performance analysis, which helps a lot in managing and accountable projects when compared with traditionally reporting system.

5.6.8 Primavera P6 Schedule View



Pic. 18

Pic. 18 shows how Oracle Primavera P6 is being employed as the scheduling engine in the proposed Digital Project Monitoring System (DPMS). In the scheduling view, the Work Breakdown Structure (WBS) is incorporated with a Gantt chart timeline in presenting activities of the project in an organized manner. This environment for digital scheduling provides a user-friendly facility for project teams to plan, monitor and control project execution throughout its lifecycle.

The Gantt chart shows activity duration, start and finish dates, milestones, and dependencies between project activities. Visual display of the schedule shows the sequence of construction activities and allows the project manager to see any possible schedule conflicts prior to its detrimental impact on project progress. Critical path activities which are the longest path through the project network of dependent tasks that determine the project completion date, have to be constantly monitored as any delay in critical activities will affect the completion of the project. The resource planning and progress tracking are some other functionalities of the

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Primavera schedule which are integrated within the Gantt chart in order to allow the project manager to control project resources (personnel and equipment) and track progress against scheduled milestones and targets. Comparisons of scheduled versus actual progress are then done to identify schedule performance variances which can quantify project delay. These schedule variance values and SPIs can further be used for project corrective action planning. Combined with real time site progress reporting from mobile devices, Primavera can become a dynamic control tool instead of a static schedule. The future forecasts based on the current trend provide the project manager an early notification of predicted completion dates, project risks can be identified before it occurs and recovery actions can be implemented. This would provide a robust and comprehensive project planning and control environment where the scheduling information of Primavera P6 would be associated with BIM models and project dashboards in the DPMS. This would not only create a highly visual representation of project progress but would also improve the clarity and understanding among stakeholders and facilitate decision-making processes.

5.6.9 Executive Dashboard (Power BI)

Pic. 19

Pic. 19 shows the Executive Dashboard created using Microsoft Power BI that aims to provide the senior management a broad view of project execution through real-time KPIs, performance indices and visualizations. The dashboard is used as a central point for decision-making under the proposed Digital Project Monitoring System (DPMS) which would allow for effective monitoring of project progress, identification of gaps and initiation of corrective actions.

The dashboard would aggregate information from diverse sources namely Primavera P6 schedule, BIM model, site execution reports, mobile devices, financial systems and quality databases; automatically integrates the data from these sources and then creates interactive visual reports and graphs that would enable data-driven decisions.

Key Performance Indicators (KPIs) are some of the main information provided by the dashboard. These can include overall project completion percentage (plan vs actual), budget consumption, schedule performance index (SPI), cost performance index (CPI), value earned metrics, productivity figures of workforce/machinery, health and safety index and quality figures. These are useful to have a general idea of project health and performance.

The dashboard would also present performance indices used to gauge the project's efficiency and effectiveness. SPI gives an estimate whether the project tasks are proceeding on the originally approved timeline, whereas CPI shows the cost performance of the project compared to the planned spending for the same stage. These indicators serve to rapidly highlight if there are cost or time overruns or productivity loss on the project.

Graphical representations in the form of bar graphs, line graphs, pie charts, gauges, trends etc. Would be provided for easier comprehension of data. Graphs illustrating plan vs actual progress would demonstrate progress deviations whereas trend graphs would illustrate how project has performed over time. These graphical reports would avoid extensive analysis and thus ensure faster decision making.

Indicators displaying risks and issues would alert the stakeholders to the challenges on project that needs **immediate** attention from management. Risks may involve issues like schedule delays, delays in supply and procurements, lack of resources, design deviations, quality issues, accidents and so on. Early reporting on such issues would enable faster mitigation of risks and avoidance of project loss.

Information regarding resource and productivity statistics is another essential component of the dashboard. It allows for detailed examination of workforce, machinery and material consumption as well as productivity metrics across various project disciplines, helping the project management team to optimize and re-allocate resources accordingly.

The Power BI would also provide drill-down capability which would allow the user to not just obtain high-level summary of project progress but to go down to details, even to the activity level for a project manager, thereby providing a layered view of the project.

In addition to these, the dashboard would be available on desktop computers, tablets and mobile devices ensuring all the stakeholders are able to check project status from any location.

The integration of the BIM models and Primavera P6 schedules would with Power BI create a digital data repository which would form the basis for the entire management system. This connection would integrate planning, execution, monitoring and reporting within one holistic view.

5.6.10 Mobile Field Monitoring

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Pic. 20

Pic. 20 above show the mobile field monitoring interface within the proposed Digital Project Monitoring System (DPMS). This mobile application acts as a real-time data collection and communication tool that connects all project stakeholders including site engineers, site supervisors, contractors, consultants, and project managers within the common digital domain, allowing instant access of project information, effective monitoring, reporting and decision making directly from construction sites.

The mobile interface allows field personnel to update the daily site progress reports, work completion status reports, site observation reports, site inspection reports, safety record reports, quality reports and photographic evidences using smart phones and tablets, thereby eliminating the delay introduced by traditional paper based reporting system and ensuring high degree of accuracy in recorded information.

Live progress reporting module within the interface allows immediate updates on completed activities against the approved project schedule and the data is automatically synced with the central database and integrated with the Primavera P6 schedule, BIM models and the management dashboard in order to facilitate the stakeholders with the most up to date project progress information.

Photo documentation with geotag is also supported within the application allowing engineers to snap site photos along with their geographic position and date and time stamps of photos, which in turn would improve the accountability, transparency and visual evidence of performed work. Photos can be tagged to specific work activities, work packages or BIM elements.

Inspection and quality management module allow users to perform inspections at site and generate checklists, field observation reports, non-conformance reports (NCRs) and monitor corrective actions taken on each of them, thereby improving quality assurance and ensuring that project complies with the specifications and statutory regulations.

Issue tracking and workflow management module will allow site personnel to update about the problems faced at site, such as design conflict, problems with materials delivered on site, breakdowns, safety related issues and other critical events occurring at the construction site. Upon submission of the issues, appropriate responsible parties will be automatically assigned and their resolution will be monitored.

Safety management module within the application allows reporting of safety observations, incident near misses, safety inspections, hazard recording and corrective actions, thereby ensuring better safety and reducing risks in projects.

Digital document management functions are available within the application enabling access to drawings, specifications, method statements, inspection reports, Good-for-Construction (GFC) documents directly from the construction site thus reducing time required for retrieving required documentation and avoiding usage of incorrect documentation on site.

The dashboard interface on the mobile provides a concise snapshot view of project KPIs such as the percentage progress on daily basis, planned versus actual performance and utilization, workforce at site, utilization of construction machinery, safety statistics and quality parameters that helps the site engineers to know and track project progress at a glance and prioritize their tasks efficiently.

The integration between mobile technology and the digital dashboard as well as BIM models of a project ensure seamless communication between site engineers and project management office regardless of any remote location, leading to efficient and concurrent working environment.

Interlinking Mobile technology and the digital dashboard and also BIM models of a project allow clear and transparent communication between site engineers and the project management office (PMO) anywhere from any remotest locations thereby enhancing a concurrent working environment and time-efficient solutions for your project construction.

6. Benefits of Proposed DPMS

Table 4. Expected Benefits

Parameter	Traditional System	DPMS
Reporting Speed	Low	High
Visualization	Limited	Excellent
Delay Detection	Reactive	Predictive
Collaboration	Fragmented	Integrated
Cost Monitoring	Periodic	Real-Time
Lifecycle Management	Limited	Comprehensive

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7. Future scope

There are several aspects that can be considered as the future of the work such as:

• Drone Based Progress Monitoring

• Computer Vision to verify site condition

• generative ai for scheduling optimization

• Iot devices-based tracking equipment on site

• Augmented Reality based site inspection

• Autonomous Digital Twins

These technologies can enhance the overall efficiency and the operations performance.

8. Industry 4.0 & Digital Transformation of Steel Plant Projects

The global steel sector is witnessing a massive transformation driven by the advent of Industry 4.0. Traditional steel plant projects were often marred by manual reporting, fragmented communication, paper-based documentation, and separate project management tools. Such methods invariably led to project delays, cost overruns, lost productivity, and poor decision-making.

Industry 4.0 provides a paradigm where physical assets, digital systems, sensors, software, and human resources are linked via advanced information technology. Technologies like BIM, AI, IoT, Digital Twins, Cloud Computing, Big Data Analytics and Mobile Applications are enabling significant improvements in project execution and operational efficiency (18).

In steel plant expansion projects, typically thousands of engineering activities run concurrently. They range from civil work to structure fabrication, equipment erection to piping and cabling, automation to commissioning. A delay in even a single activity may create cascaded delays to many other work packages.

The proposed Digital Project Monitoring System (DPMS) offers a unified digital environment where every stakeholder can access project related information in real-time. Synchronized BIM model and Primavera schedules help the project manager visualize the project progress and identify deviations as soon as they occur, so corrective measures can be taken before there are schedule slips.

AI based predictive analysis further enhances the control over project management and can forecast possible delays along with remediation strategies. Such tools transition project management from being a reactive practice to a proactive one, enhancing effective decision-making capabilities.

In steel plant projects, Industry 4.0 technologies also improve safety, quality, resource management and transparency amongst all stakeholders. It has thus shifted from being an option to a necessity in steel plant expansion projects.

9. Conceptual Framework of Digital Project Monitoring System

The proposed framework of DPMS consists of 6 major layers:

1) Data acquisition Layer
2) BIM integration Layer
3) Scheduling Layer
4) Analytics Layer
5) Visualization Layer
6) Decision support Layer

The data acquisition layer is where data from field engineers, site supervisors, contractors, sensors and mobile applications are collected. This data includes daily progress reports, photographs, equipment status updates, resource allocation status and material availability reports.

The BIM integration layer acts as a repository for engineering and construction data. It includes all geometric information of the structure, engineering specifications and construction sequence data.

The scheduling layer uses Oracle Primavera P6 to track activity relationships, critical path, resource assignments and baselines. Daily input data from field is auto synchronized with the schedule.

The analytics layer uses AI algorithms for trend analysis, delay forecasting, risk analysis and performance indicator calculation. Historical project data is utilized to train predictive models that identify potential delays in future.

The visualization layer includes graphical reporting, dashboards and interactive project tracking features, allowing the user to assess the project progress visually.

The decision support layer makes project managers capable of taking strategic decisions based on the current performance indicators to appropriately assign resources, accelerate procurement or develop recovery plans for the schedule.

10. Case study: Use of DPMS in steel plant expansion project

A conceptual case study is developed using generic steel plant expansion activity to assess the benefits of proposed framework. Activities include:

1) Structural Steel Erection

2) Equipment Installation
3) Piping Networks
4) Electrical Systems
5) Instrumentation Systems
6) Utility Systems
7) Commissioning Activities

Initially the project progress was managed with conventional reporting. Progress reports are developed weekly and disseminated via e-mail and significant delays only identified at several weeks' time leaving inadequate scope for intervention. With DPMS implementation, progress is available in near real-time with mobile applications enabling field engineers upload photos, activity status, and inspection reports from the field. With BIM integrated to Primavera schedule, management can view ongoing, completed and delayed activities based on the colour code display. The AI forecasting module uses the performance history to alert potential slippage and required intervention. The main benefits achieved:

1) Increased visibility of the project schedule
2) Rapid reporting intervals
3) Improved cross discipline coordination
4) Reduced reworks
5) Enhanced communication with stakeholders
6) Quicker decision-making

It can be concluded from the case study that adoption of these digital technologies can benefit the steel industry tremendously.

Table 5. DPRI Assessment of a Sample Steel Plant Expansion Project

Dimension	Score
PD	80
BI	75
DC	70
PI	65
LM	60

Calculation:

DPRI = $(0.25\times80) + (0.20\times75) + (0.20\times70) + (0.20\times65) + (0.15\times60)$

DPRI = 71

Result: If applied, the classification indicates that it is an 'Advanced Digital Project'.

11. Risk Assessment and Delay Management

Project delays remain one of the major challenges in industrial construction projects. Such delays can be attributed to many sources such as changes in design, procurement constraints, lack of labour, external forces such as weather conditions and unforeseen technical complications. Risk assessment methodology within DPMS framework continuously assesses project conditions:

A. Engineering Risks:

1) Design Changes
2) Poor coordination
3) Lack of clarity in drawings

B. Procurement Risks:

1) Lack of timely procurement from vendors
2) Logistic disruptions
3) Material shortages

C. Construction Risks:

1) Low productivity on site
2) Equipment's breakdown
3) Safety concerns on site

D. External Risks:

1) Regulatory approval delays
2) Environmental conditions
3) Market influences

Each risk category receives both a probability score and an impact score to calculate a Risk Priority Index (RPI) and activities needing management intervention are highlighted. Organizations can hence mitigate uncertainties and improve project schedule.

12. Sustainability and Lifecycle Management

Sustainability is a critical element in any industrial project now. Through the 6D BIM features of proposed framework, sustainability aspect of a project can be addressed:

1) Energy consumption of the project
2) Estimation of carbon footprint
3) Monitoring resource usage
4) Management of construction waste

However, the 7D BIM extends the project information beyond the construction phase into operational phase: information about the facilities like equipment specification, maintenance schedule, warranty, operating manual etc are contained in the digital model. Therefore, the function of BIM can be broadened from the current construction management tool to facility lifecycle management platform; as a result, facility operations can become more efficient and effective.

13. Limitations of Study

There are some limitations for the proposed DPMS framework, first it needs large investment on hardware systems, software systems, and human resource training. Second the integration among various systems can cause several technical difficulties. Third it is greatly influenced by the commitment and maturity of organization towards digital technologies. Fourth the AI forecasting model depends greatly on the historical project data available for training the model. Further research on real-world implementation and quantitative analysis on multiple industrial projects is highly encouraged.

14. Managerial Implication

The presented DPMS framework is expected to offer real time benefit to the project managers, contractors, consultants, plant owners and the decision makers associated with steel plant expansion projects. Through the synergy of Building Information Modelling (BIM), Artificial Intelligence (AI), Digital Twins, Primavera P6 scheduling, mobile monitoring applications, and data analytics in a unified framework, the organizational performance in project planning, execution, monitoring and control can be substantially enhanced through the life of the project. Real-time view of the project performance provided by the DPMS framework can equip project managers with the tools to quickly make decisions, control project schedules, manage risk pro-actively, and implement corrective actions in time.

AI-powered forecasting and prediction will ensure identification of potential slippages in the project schedule in time, thus helping to prevent overspending on the schedule over run.

The benefits for the contractors will include improved communication and coordination amongst the multiple design disciplines and field teams. This framework will help the contractors to identify resource needs better, communicate information efficiently and provide better control over site activities by monitoring project progress, and reduce the non-value-adding time at the project site through elimination of information gap. Similarly, the DPMS framework can support the design, consultants, engineers, project stakeholders and the plant owners through effective communication, quality management, cost control, schedule optimization, project governance, enhanced safety management, and asset lifecycle management. As such, this framework is strategically important for the modernization of steel plant expansion projects and will support the effective adoption of industry 4.0 for a sustainable steel industry. DPRI Framework Digitalization Assessment Index (DPRI)The framework will help organizations assess the digital maturity level, thus can support vendors digital readiness, providing to the project owner the assurance of the digital capability of contractors, consultants and suppliers even prior to project start-up.

The benchmark function will allow organizations to assess different projects across time providing an index-based measurement for digital maturity.

It will support also in identification of priority areas where organizational digital investment must be focus. DPRI will allow Organizations to create effective Industry 4.0 strategy and roadmap and support to monitor continuously the digital progress across project life cycle. Thus, the DPMS framework and the DPRI Framework they will play a very critical role towards sustainable steel plant modernization and Industry 4.0 adoption in the steel industry

15. Validation of Proposed DPRI Framework

DPRI framework was concept-tested with a typical steel plant expansion project. The outcome from assessment resulted in a DPRI score of 71, in the advanced digital project group. The digital readiness was quantifiable in dimensions of planning digitalization, BIM integration, data connectivity, predictive intelligence & life-cycle management. DPRI can provide as an effective tool for measuring & ranking the level of digital maturity of a digital project and also for prioritizing further areas of investment on future digital transformation.

16. Conclusion

In this study a Digital Project Monitoring system is proposed that integrates AI techniques with Multi-Dimensional BIM, Oracle Primavera P6 schedule management, mobile application-based field data collection and digital twin technology for Steel Plant expansion project. The proposed framework addresses the main project management challenges in such projects such as schedule overrun, cost overrun, inefficient communication and the absence of a single integrated data system. The integration of AI based forecasting capabilities with BIM representation and field reports offers a strong decision support environment capable of enhancing the overall project performance through its lifecycle. In the evolving Steel industry, it is essential to adopt a well-integrated monitoring system for better success of projects, operational efficiency and competitive strength in the market.

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