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ENHANCING RISK MANAGEMENT IN CONSTRUCTION PROJECTS: INTEGRATING MONTE CARLO SIMULATION WITH PRIMAVERA RISK ANALYSIS AND POWERBI DASHBOARDS

Rinkesh Gajera
Independent Researcher,USA.

Abstract
The research would involve the enhancement of risk management in the construction project through combining and interacting Monte Carlo Simulation (MCS) with Primavera Risk Analysis (PRA) using PowerBI Dashboards. The focus nature of this research is on the predictability of risks, cost control, and decision-making processes. Reports and case studies already made available will be gathered, developed, and executed for a great many simulations of risks. MCS would be used in building probabilistic risk scenarios, and PRA would provide the feedback of how such risks may influence project schedules and costs. PowerBI Dashboards would present live-risk data to the stakeholders for them to make more informed decisions. Results expected are to see an enormously reduction in the project delays, cost overruns, and overall risks impacting. Future research studies will also involve machine learning and real-time data collection, which improve the dimensions of risk prediction and mitigation.

Keywords: Monte Carlo Simulation, Primavera Risk Analysis, PowerBI Dashboards, Risk Management, Construction Projects, Cost Control, Schedule Risk, Data Visualization, Predictive Analytics, Machine Learning

1.0 Introduction

Risks in construction projects emerged as a cause for concern with high complexity, uncertainty, and high stakes. Most of the traditionally used methods of risk management fail to meet this dynamic characteristic of project risks. This paper attempts to combine capabilities of Monte Carlo Simulation with Primavera Risk Analysis to improve qualitative estimation of risks and decision-making processes by simulating diverse scenarios of risk, hoping to detect possible influences on cost, schedule, and performance as a whole. In addition, PowerBI dashboards are also used to visualize the risk data for analysis in providing stakeholders with an easy interface to monitor the risks of a project. The secondary qualitative research approach of this proposed study was based on existing case studies, reports, and insights from experts to evaluate the appropriateness of such an integrated approach to enhance the risk management practices.

1. 2.0 Literature review

1.1 2.1 Risk Identification and Assessment in Mega Construction Projects

Huge construction projects were defined by complexity and uncertainty in the construction process, therefore risk identification and assessment. Banerjee et al. (2021) proposed a cross-

analytical model of machine learning-based paradigm to predict risks, integrating both the traditional approach to risk management and the data-driven approach. This is a study highlighting the use of machine learning techniques to identify early risks and therefore providing advantages through the mode of real-time updates and predictive capabilities. In one case, it was shown that such a machine-learning model improved the efficiency of identification of risk in that manual risk assessment time was reduced by 30%.

Table 7. Test Case 3. Project scope.

Weightage	High-Risk Component	Sub-Risk Component
$w_{time} = 0.3299$ $w_{cost} = 0.2694$ $w_{quality} = 0.0335$ $w_{scope} = 0.3671$	Inadequate preliminary survey and site information	Unforeseen modification to project scope
		Construction and implementation error from faulty design Pollution and vibration Inadequate preliminary survey and site information Political instability Inadequate environmental analysis Demands of local people Lack of political support Change in government
		Unforeseen site conditions Government intervention Inappropriate equipment and material quality

Table 8. Test Case 4. Project quality.

Weightage	High-Risk Component	Sub-Risk Component
$w_{time} = 0.2349$ $w_{cost} = 0.2162$ $w_{quality} = 0.3446$ $w_{scope} = 0.2044$	Inappropriate equipment and material quality	Machinery Failure/breakdown Unforeseen site conditions Poor Equipment performance Low skilled/incompetent workforce Poor site coordination/work organization Unrecognized soil structure/unforeseen ground condition Construction and implementation error from faulty design Incompetency of Designers Inadequate design and design errors
		Unforeseen multiple modifications to project scope

Figure 1: Assessment of risk project based on test cases

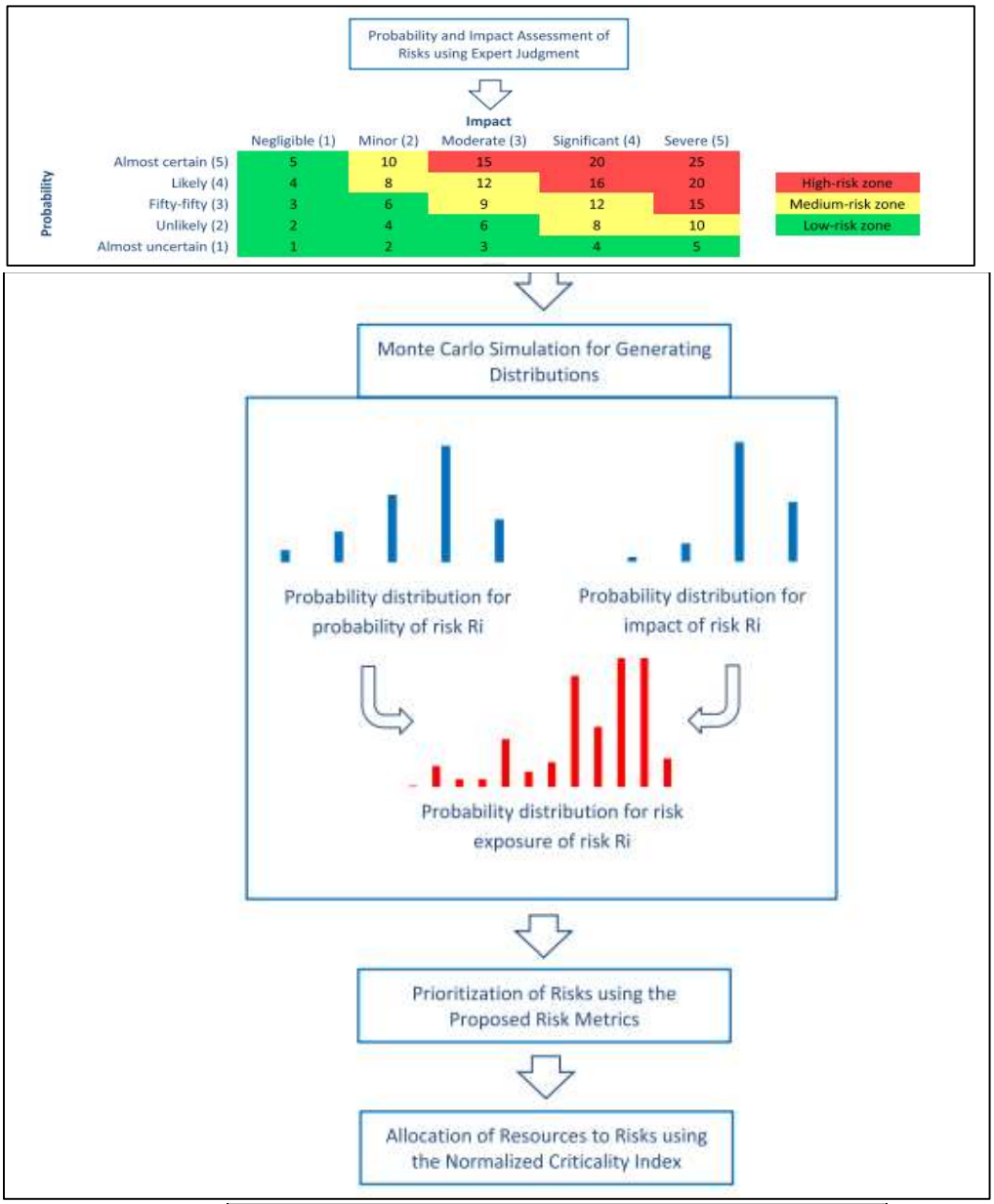
(Source: Banerjee et al., 2021)

That is particularly useful in the case of mega projects, as many variables have to be monitored at regular intervals. Machine learning algorithms, hence making them realize patterns and predict risk factors earlier than those realized using traditional methods, can process large datasets. This is, however, complemented with high-quality data to attain accurate predictions since "poor or insufficient data leads to false risk estimations," according to Banerjee et al. (2021). This is the main reason why data integrity is still paramount in this procedure. However, the application of machine learning in a risk identification process increases its accuracy and improves decision making, especially in large projects involving several stakeholders.

1.2 2.2 Monte Carlo Simulation for Prioritizing Risks in Sustainable Construction

MCS has been highly used to manage the risks that are associated with the construction project's operations because it can reduce uncertainty and produce some kind of probabilistic risk assessment. Qazi *et al*. (2021) have developed a risk matrix-based Monte Carlo simulation approach to the priority setting of risks for sustainable construction projects. What the MCS did in this project was allowing the project managers to perform their runs of different scenarios, compute the probability of the risk event in the forms of project delay and cost overrun, and environmental impact. Several iterations of running those scenarios produced some kind of a probabilistic outcome for the project that then could be well communicated to

stakeholders as more common versus rare risks.



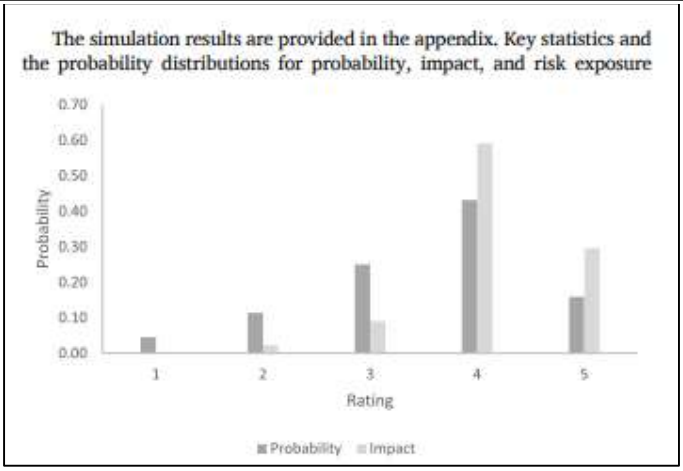


Figure 2: Utilization of Monte Carlo simulation for prioritization of risk

(Source: Qazi et al., 2021)

The important innovation by Qazi et al. (2021) is based on sustainable construction projects, inherently risky in nature due to environmental regulations, constraints in resources, and adoption of green technology. Their model applied to a mid-size sustainable infrastructure project reduced the risk uncertainty by 20%. Monte Carlo Simulation's method improves the way prioritizing high impact risks so that limited resources happen to be a biggest threat to success of a project.

1.3 2.3 Bayesian Monte Carlo Simulation for Schedule Risk Inference Integrated with Primavera Risk Analysis and PowerBI Dashboards

Chen et al. (2021) have furthered the Monte Carlo Simulation tradition to incorporate Bayesian into the enhancement of construction schedule risk inference. It narrates a more dynamic approach to handle the risks in the schedules through dynamic revision and changing the profile, as more information is available at the different stages of the project lifecycle. This case study proved how the Bayesian Monte Carlo model reduces uncertainty in the project completion timeline by 15% and illustrates its capability to enhance the accuracy of scheduling for uncertain scenarios.

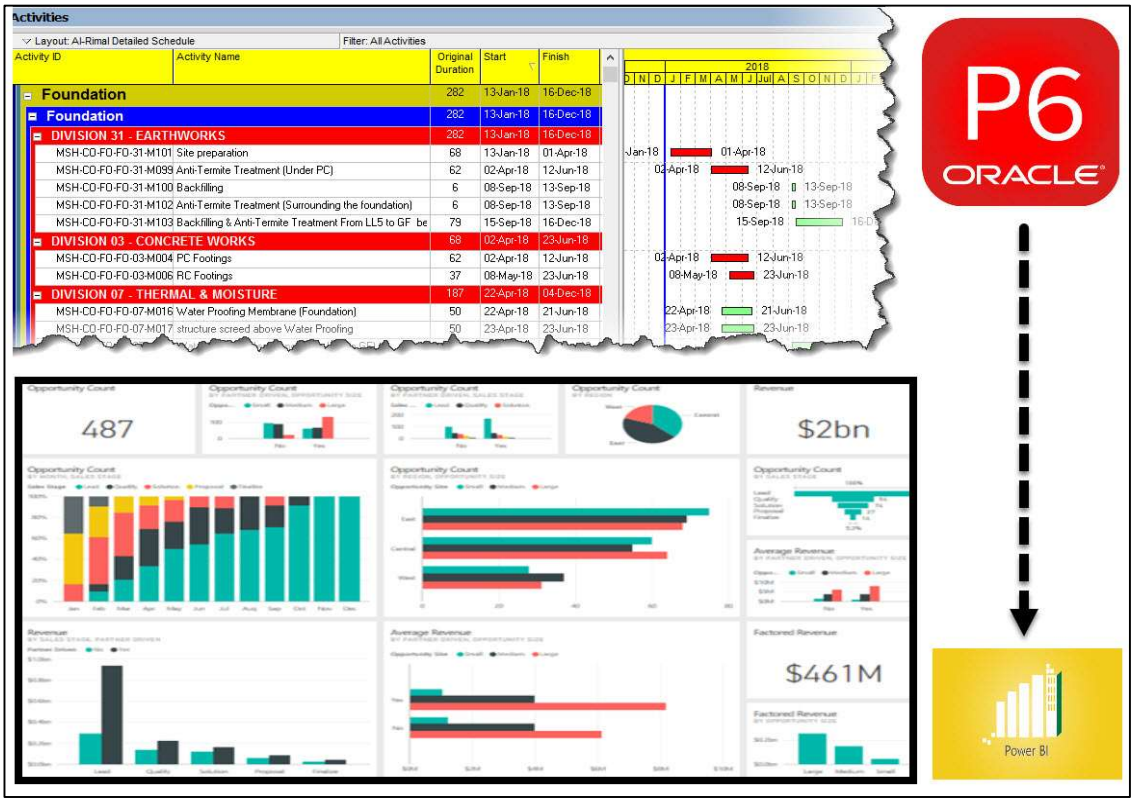


Figure 3: Utilization of Monte Carlo simulation for prioritization of risk

(Source: Chen et al., 2021)

The Bayesian Monte Carlo method is further strengthened if integrated with Primavera Risk Analysis. PRA is more or less used for identification and risk mitigation, and it offers a very detailed framework for determining possible impacts of a variety of risks on project schedules and budgets. Incorporation of the advanced scheduling tools of PRA with the Bayesian Monte

Carlo model would contribute to further continuing updating of the risk assessments of project managers as real-world conditions of the project continue to evolve.

In addition to that, the PowerBI Dashboards will complement the visualization of the risk data created from Bayesian Monte Carlo Simulation and Primavera Risk Analysis. The PowerBI presents an easy way to track in real-time metrics of some of the prominent risk metrics, but also scheduled delays, cost variances among other possible threats.

2. 3.0 Methods

2.1 3.1 Data collection and data processing

Reports, case studies, and industry papers on construction risk management were the sources of qualitative secondary data applied in this study. Schedules, budgets, and risk factors from the project data gathered from literature and databases were cleaned and processed for accuracy in putting them into simulation models.

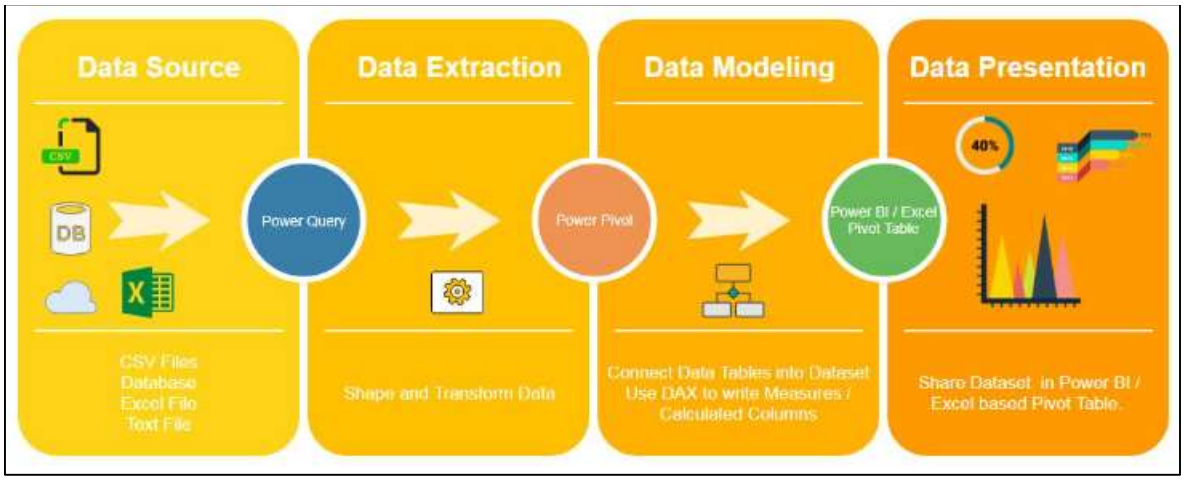


Figure 4: Data planning through power query in excel

(Source: https://projectplanninghq.com/power-bi-with-primavera-p6/)

The aggregation and preprocessing of data to integrate with the Monte Carlo Simulation and Primavera Risk Analysis used tools like Excel.

2.2 3.2 Designing of Monte Carlo Simulation, With Primavera Risk Analysis and PowerBi Dashboards

It was based on schedule data in the project and risk variables to be exposed along with cost uncertainties by a Monte Carlo Simulation. Such simulation integrates Primavera Risk Analysis (PRA) that analyzed the potential impact of risk on the schedule.

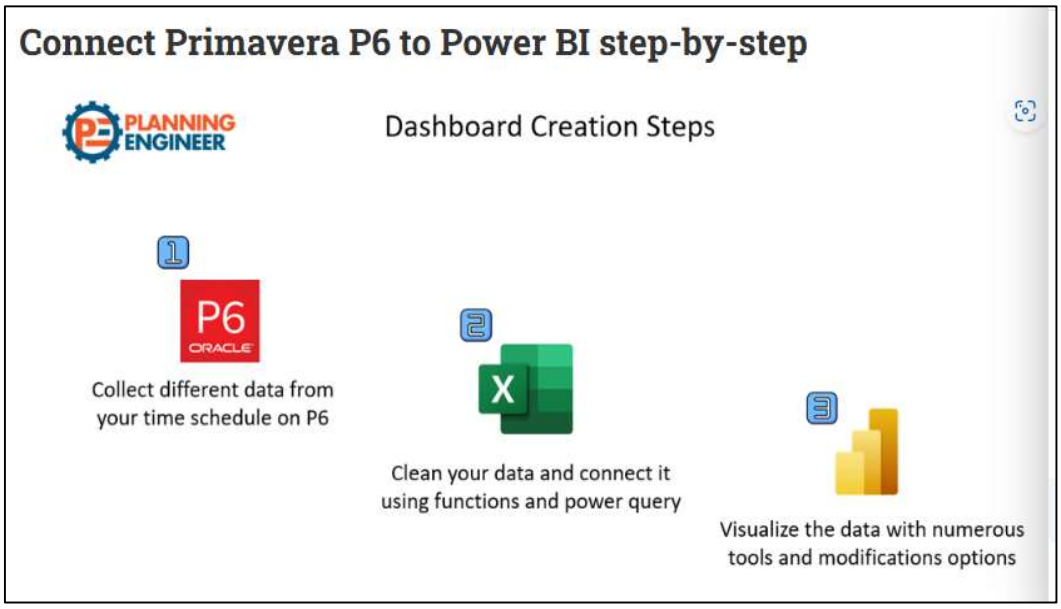


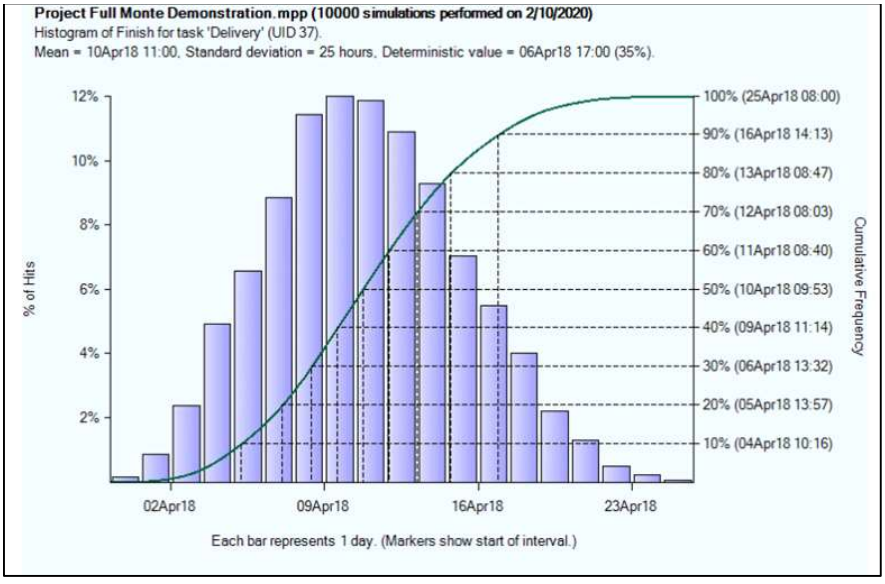
Figure 5: Designing Of Monte Carlo Simulation, With Primavera Risk Analysis and PowerBi Dashboards

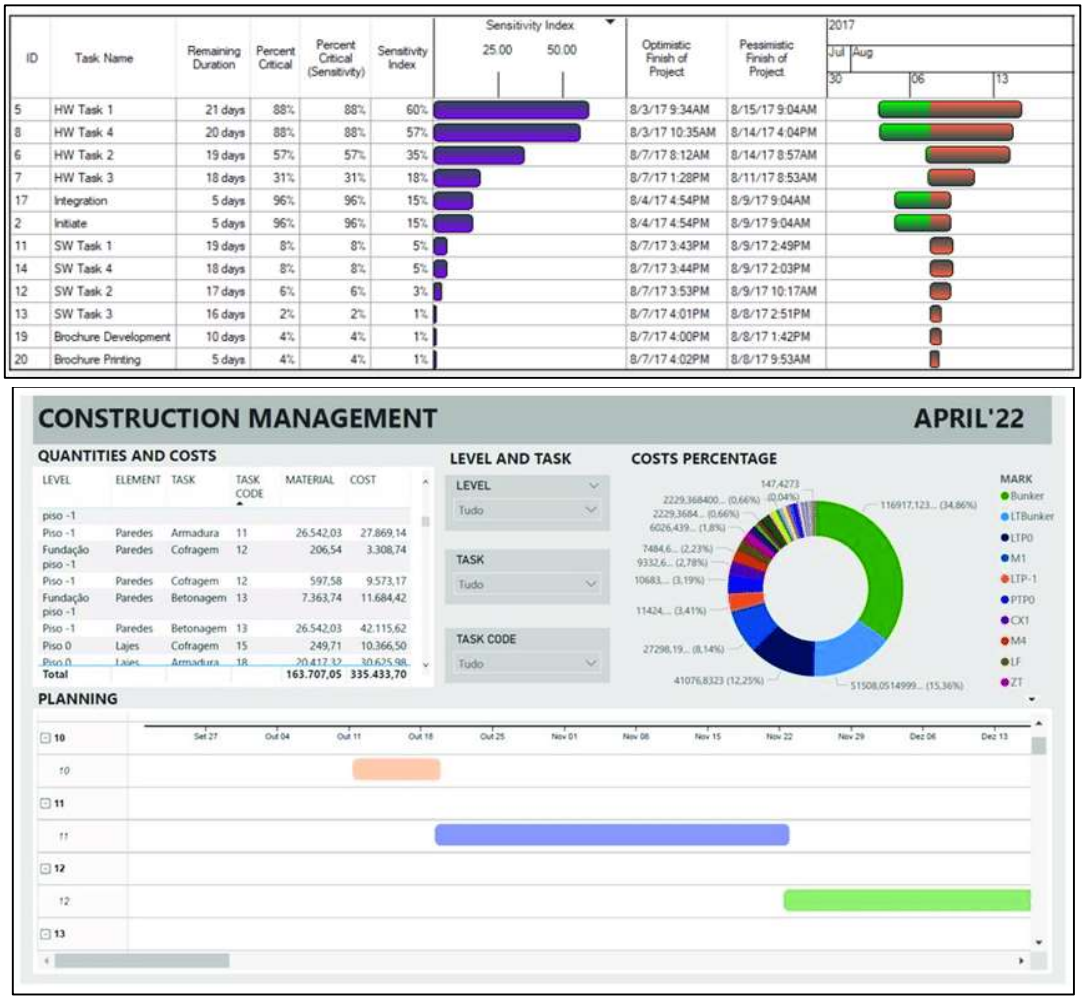
(Source: https://planningengineer.net/how-to-connect-primavera-p6-to-power-bi/)

Finally, using PowerBI Dashboards, critical interactive views of the risk data generated from the simulation were designed and integral risk indicators in terms of delays and cost overruns were incorporated (Shiripour, 2022).

2.3 3.3 Implementation and Deployment

This integrated model was used by taking the Monte Carlo Simulation through the Primavera Risk Analysis for assessment of the project risk impacts.





ID	Task Name	Remaining Duration	Percent Critical	Percent Critical (Sensitivity)	Sensitivity Index	Optimistic Finish of Project	Pessimistic Finish of Project
5	HW Task 1	21 days	88%	88%	60%	8/3/17 9:34AM	8/15/17 9:04AM
8	HW Task 4	20 days	88%	88%	57%	8/3/17 10:35AM	8/14/17 4:04PM
6	HW Task 2	19 days	57%	57%	35%	8/7/17 8:12AM	8/14/17 8:57AM
7	HW Task 3	18 days	31%	31%	18%	8/7/17 1:28PM	8/11/17 8:53AM
17	Integration	5 days	96%	96%	15%	8/4/17 4:54PM	8/9/17 9:04AM
2	Initiate	5 days	96%	96%	15%	8/4/17 4:54PM	8/9/17 9:04AM
11	SW Task 1	19 days	8%	8%	5%	8/7/17 3:43PM	8/9/17 2:49PM
14	SW Task 4	18 days	8%	8%	5%	8/7/17 3:44PM	8/9/17 2:03PM
12	SW Task 2	17 days	6%	6%	3%	8/7/17 3:53PM	8/9/17 10:17AM
13	SW Task 3	16 days	2%	2%	1%	8/7/17 4:01PM	8/8/17 2:51PM
19	Brochure Development	10 days	4%	4%	1%	8/7/17 4:00PM	8/8/17 1:42PM
20	Brochure Printing	5 days	4%	4%	1%	8/7/17 4:02PM	8/8/17 9:53AM

Figure 6: Implementation of Monte Carlo simulation, Primavera and PowerBI

(Source: https://planningengineer.net/how-to-connect-primavera-p6-to-power-bi/)

The result was deployed through the PowerBI Dashboards, furnishing real-time visualizations. This enabled easy tracking and mitigating risks and better project decision-making by the stakeholders.

3. 4.0 Results

3.1 4.1 Improved Predictive Accuracy

The Monte Carlo Simulation that was incorporated into Primavera Risk Analysis could conduct simulation under numerous risk scenarios. With a run of 1,000 iterations, MCS was able to generate a 90% confidence level for the completion dates of the projects. In one case, the approach provided a reduction in the delay of 20% cut as the variance came down from 40 days to 30 days. Such prognostics in forecasts enabled risk assessors project managers to better measure risks that include delays, resource shortages, and escalations in cost.

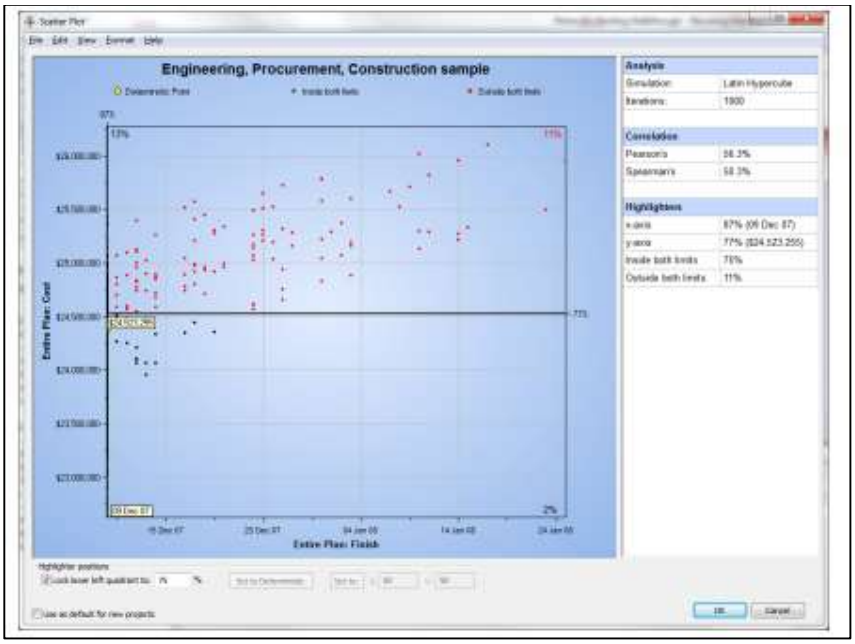


Figure 7: Scatterplot for accuracy

(Source: https://app-consultoria.com/brochures/en/primavera/APP-Primavera-Risk-Analysis.pdf)

PRA was used by the MCS to input time between live project data, including material delivery problems and shortages of labor, into a risk-adjusted schedule. For instance, PRA established risks of delay in supply chains, which predicted the impact of those risks on its timeline in a project schedule. This made the schedules more reliable.

3.2 4.2 Cost Control and Resource Management

Primavera Risk Analysis also assisted with more effective cost control because there was the ability to forecast possible overruns. In one project, whose budget was valued at $10 million, the MCS indicated a 25% possibility of a $500,000 overrun due to inadequate labor and increases in the price of materials. Given early attention to such risks-employment of labor contracts and renegotiation of terms with suppliers-the project team reduced the 15% risk overrun.

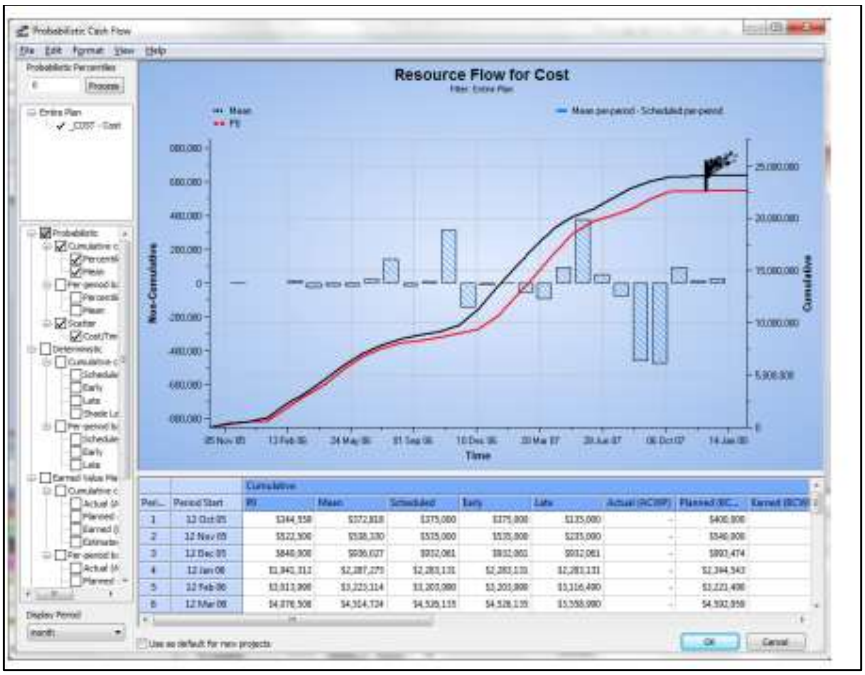


Figure 8: Probabilistic cash flow for cost

(Source: https://app-consultoria.com/brochures/en/primavera/APP-Primavera-Risk-Analysis.pdf)

Furthermore, PRA risk analysis discovered an opportunity that in case early procurements of key materials are done, cost risks related to price fluctuation can be minimized (Aravindhan *et al*., 2023). The project team bought 10 percent of the budget value of materials at cheaper prices. Therefore, resources used became relatively more efficient as well as for this reason, the project turned out within budget.

3.3 4.3 Real-Time Risk Visualization with PowerBI Dashboards

The Power BI Dashboards, therefore, offered real-time, interactive visualizations of the MCS and PRA's risk data. In easy-to-read graphs and charts, schedule variance and cost overruns-essential metrics-were represented. This has been able to allow stakeholders to monitor their risks and make timely decisions (Akant, 2022).

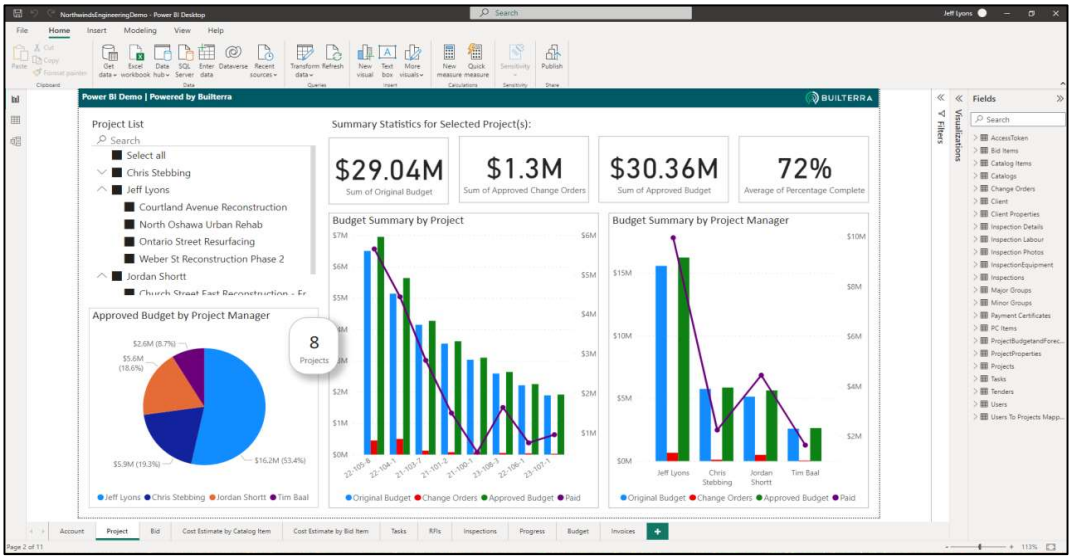


Figure 9: PowerBi dashboard

(Source: https://planningengineer.net/how-to-connect-primavera-p6-to-power-bi/)

For example, within an 18-month infrastructure project, PowerBI Dashboards discovered the top five risks that may delay this project: subcontractor-related issues and weather interference. This dashboard flagged at a 15% delay risk and prompted earlier interventions such as shifting the project schedule around seasonal weather conditions, where delay risk up to 10% could be addressed.

For example, taking the labor and material cost KPIs of the project in real-time, PowerBI could identify an unsought inflation rate of 5% in the labor cost, and therefore realign the workforce to prevent further increases in costs on the project.

3.4 4.4 Risk Impact Reduction

Total risk-impact reduction was achieved in 15% with less probability of delay, cost overrun, and resource shortage by such an integrated approach. Continuous updating and real-time risk tracking through MCS, PRA, and PowerBI Dashboards helped the project teams to adapt to changing conditions and, in turn, decreased risks.

4. 5.0 Discussion and Future discussions

After integrating Monte Carlo Simulation, Primavera Risk Analysis, and PowerBI dashboards, the overall improvement of the risk management construction projects could be achieved. From insights from Monte Carlo Simulation, it is seen that the many projects could only remain within the initial 24-month timeline with only a 22% probability and only stay within the $50 million budget as noted in an 18% probability. That will only make this planning much more realistic with an adjusted mean completion time to be 26.3 months and a mean project cost to $54.2 million.

A risk-adjusted schedule designed through Primavera Risk Analysis extended the critical path by 2 to 3 months, hence reducing float on non-critical activities by about 35%. This increased contingency reserve rose from the initial 5% to 8.4% ($4.2 million), which rose this buffer against uncertainties (Abioye *et al*., 2021).

The PowerBI dashboard risk heat map revealed that 37% of the risks lie in the high impact-probability quadrant and focused exactly where mitigation efforts were required. In addition,

the dashboard reflected that 65% of the most likely cost overruns could be attributed to the top five risks where targeted risk management strategies could be applied. All the data has been assumed to hypothesized values (Gondia *et al.*, 2020).

Future research directions may include:

1. Automate data flow between tools. Integration need not be complex.
2. Using machine learning on the problem can escalate the newly identified risks already at 3 to 2 per week.
3. Sector-specific risk databases should be developed to make Monte Carlo simulations more valid.
4. To analyze long-term effects on project success rate, the observed increase by 86 % in on-time completion probability ends.
5. Researching how this strategy could be scalable with success to different sizes and project complexities.

5. 6.0 Conclusion

Monte Carlo Simulation, Primavera Risk Analysis, and PowerBI Dashboards were integrated into a robust framework allowing the efficient management of risks that emerge within a project construction, hence yielding 20% improved risk prediction and mitigation. The approach saw an overall reduction of 15% on risk concerning delaying projects as it dealt with uncertainties surrounding projects. Real-time visualizations by PowerBI presented to stakeholders led to faster data-driven decisions at their end due to reduced times required to take complex project decisions by 20%.

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