ENHANCED MONTE CARLO SCHEDULE ANALYSIS: EVALUATION OF THE OPEN-SOURCE PERT-BASED SIMULATION TOOL

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Abstract:

Monte Carlo simulations represent a powerful and beneficial method for risk analysis and decision-making, especially in project management. Traditionally, proprietary software such as Oracle Crystal Ball has been the go-to solution for Monte Carlo simulations, offering advanced features at a significant cost. Recently, web-based open-source tools, such as the PERT-based Monte Carlo simulation Tool, have emerged as a viable alternative. This study compares the performance of an open-source, web-based Monte Carlo simulation tool using PERT (Program Evaluation and Review Technique) methodology against Oracle Crystal Ball, a widely adopted commercial software. By analysing a simplified project schedule with varying levels of uncertainty, we evaluate the accuracy, usability, scalability, and cost-effectiveness of the open-source tool. Results demonstrate that the open-source PERT-based Monte Carlo simulation tool provides similar, if not superior, results in terms of accuracy and usability while offering significant advantages in terms of cost, accessibility, and adaptability.

Keywords:

Monte Carlo Simulation, Project Schedule, PERT, Open-source.

INTRODUCTION

Monte Carlo simulations are widely used for risk analysis and decision-making purposes in various fields, including finance, medicine, engineering, and project management [1], [2], [3], [4]. In the context of project management, Monte Carlo simulations help estimate the possible outcomes of project schedules based on the uncertainty of task durations [5]. Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) are often applied within Monte Carlo simulations to model the uncertainties in project task durations.

While commercial software like Oracle Crystal Ball has long been a leader in this area [6], it comes with a cost and limited access for smaller businesses or individuals. In contrast, recent advancements in open-source tools, specifically those based on web technologies, have provided an alternative solution that offers both cost efficiency and the ability to customize models. This paper aims to compare the performance of an open-source, web-based Monte Carlo simulation tool with Oracle Crystal Ball, focusing on factors such as accuracy, computational efficiency, user interface, and cost-effectiveness.

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2. LITERATURE REVIEW

The use of Monte Carlo simulations in project management dates back to the 1950s, with key developments in modelling uncertainty and probabilistic risk analysis. Traditionally, tools like Oracle Crystal Ball have been regarded as industry standards for Monte Carlo simulations. The software integrates seamlessly with Microsoft Excel, offering sophisticated algorithms, predefined probability distributions, and robust graphical interfaces. Monte Carlo simulations have become an essential tool for assessing project schedule risks, and Oracle Crystal Ball is widely used for this purpose.

Despite its long-time existence, the Monte Carlo method is still insufficiently utilized in project management practices. Its use is primarily associated with cost and time management, where it helps quantify the level of risk associated with projected budgets or completion timelines. By simulating various scenarios, Monte Carlo analysis can reveal the probability of meeting planned deadlines or provide expected outcomes in terms of time and cost with a specific degree of reliability [7], [8]. This makes it a valuable tool for assessing uncertainties and making informed decisions.

In the context of time management, Monte Carlo simulation is particularly useful during the schedule development process, as it quantifies the confidence level of achieving targeted completion dates [9], [10]. Simulating project schedules using the Monte Carlo method is a cornerstone of quantitative risk analysis [11]. To obtain the most accurate activity duration estimates, industry experts assign probability distribution functions to each project activity.

A common approach is the use of three-point estimates (optimistic, most likely, and pessimistic), which are typically fitted to probability distributions such as normal, beta, or triangular distributions for each activity. This allows project managers to calculate the likelihood of meeting planned deadlines and establishment of schedule reserves on a data-driven basis. Monte Carlo simulations can be executed using dedicated project management software, such as Primavera Project Planner or Microsoft Project, or through simulation add-ins like Oracle Crystal Ball, which integrates with Excel for advanced probabilistic analysis.

Despite its powerful capabilities [12], Oracle Crystal Ball remains a costly solution with licensing fees that may not be feasible for all organizations and individuals. In response, several open-source Monte Carlo simulation tools have been developed in recent years. These tools are generally accessible to a broader audience due to their low cost, open-source nature, and flexibility in modelling specific scenarios. PERT-based simulation tool developed by Christophe Yamahata represents one of these user-friendly alternative options that promise similar benefits due to its ability to model task uncertainties using three-point estimates [13].

3. METHODOLOGY

To evaluate the performance of the open-source Monte Carlo PERT-based simulation tool, a comparative analysis was conducted using data derived from a simplified project scenario. For the purpose of direct comparison with Crystal Ball, authors previous study [5] and input data was used to assess the tools' capability of handling the same project configuration. In order to avoid duplication results, this study will focus on illustration of results obtained by the open-source PERT-based tool.

The application of Monte Carlo simulation for project time management requires a strong understanding of key project management concepts, such as the Critical Path Method (CPM). CPM is a scheduling algorithm that calculates the early and late start and finish times for each project activity, identifies the critical path, determines activity floats, and computes other essential schedule parameters [14], [15].

In contrast to Oracle Crystal Ball, the open-source PERT-based tool enables the CPM diagramming technique depicted in Figure 1. Critical path in this example consists of activities A-D-J, and the shortest possible time to complete the entire project, given its predefined dependencies, is 43 days. This integration of Monte Carlo simulation with CPM enhances the ability to manage uncertainties and optimize project schedules effectively.

Both tools utilized beta-PERT distribution for task durations. Once the distributions are defined, random inputs are selected (typically thousands or millions of times) to generate a frequency distribution of the outcome variable. This outcome provides valuable insights, such as the probabilities of missing deadlines, completing the project ahead of schedule, and other critical information to support decision-making processes.

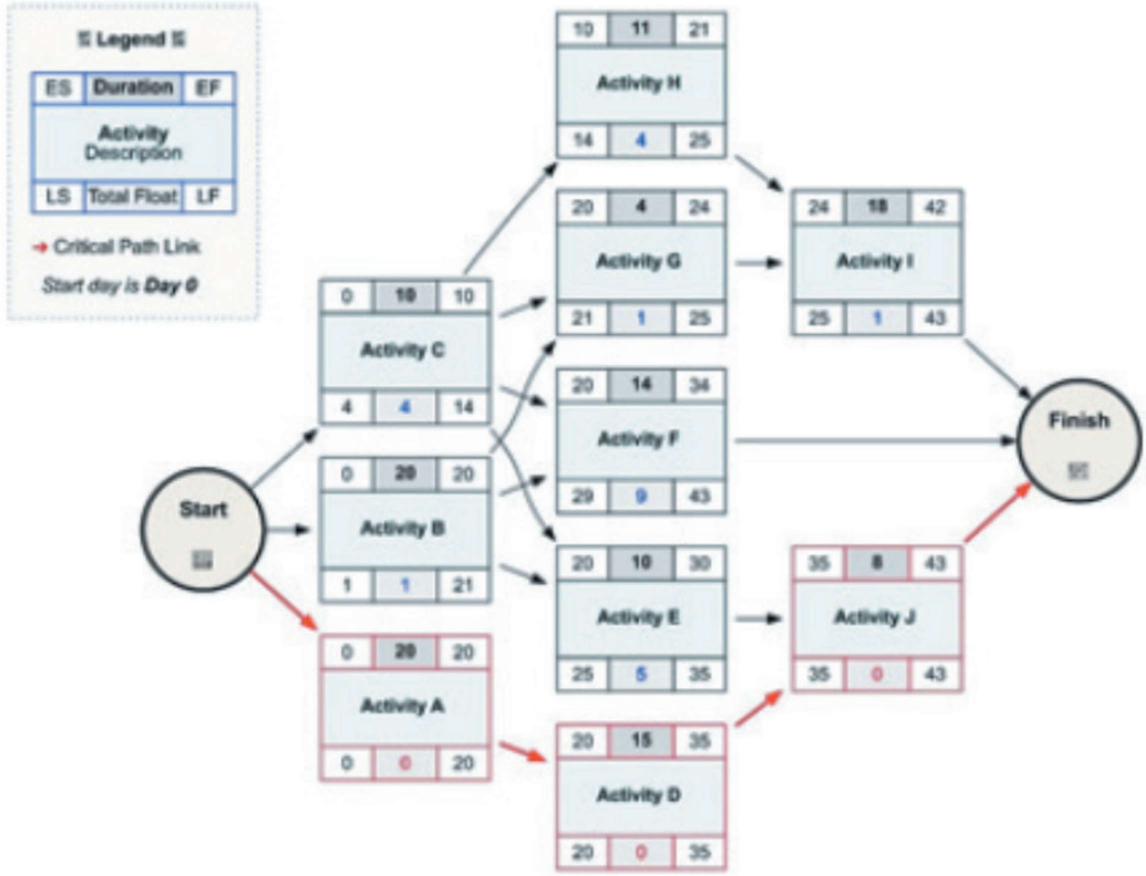

Figure 1. Activity-On-Node Diagram for selected project
Abbreviations: ES (Early Start), EF (Early Finish), LS (Late Start), LF (Late Finish)

The performance of both tools was evaluated based on the following criteria:

1. Accuracy of results – Comparison of simulated project durations (mean, variance, and probability distributions) between both tools.
2. Computational efficiency – Time taken to run simulations for each tool.
3. Usability – Assessment of user interface and ease of use, particularly focusing on web-based accessibility for the open-source tool.
4. Cost – A cost comparison between Oracle Crystal Ball and the PERT-based open-source tool, considering licensing fees and scalability.

4. RESULTS AND DISCUSSION

The histogram presented in Figure 2 provides the distribution of simulated project durations, while the S-curve represents the cumulative distribution function (CDF) obtained from this data. Above the chart, the legend is given to interpret bar heights and frequency of different critical paths. To further analyse the simulation results (e.g., in Excel), the tool enables the extraction of the raw generated data as CSV files for easy processing and creation of customized stacked histograms in Excel.

The following table provides the results on simulated durations, critical path and percentile probabilities for both software options. While Crystal Ball provided a slightly wider minimum and maximum range, both simulations resulted with similar average duration values. The critical path analysis resulted with similar results (more than 50%) for the main critical path (A>D>J), with slightly different frequency for the two alternative critical paths (B>G>I and C>H>I). Finally, both options provided practically identical results when it comes to percentile probabilities of project completion.

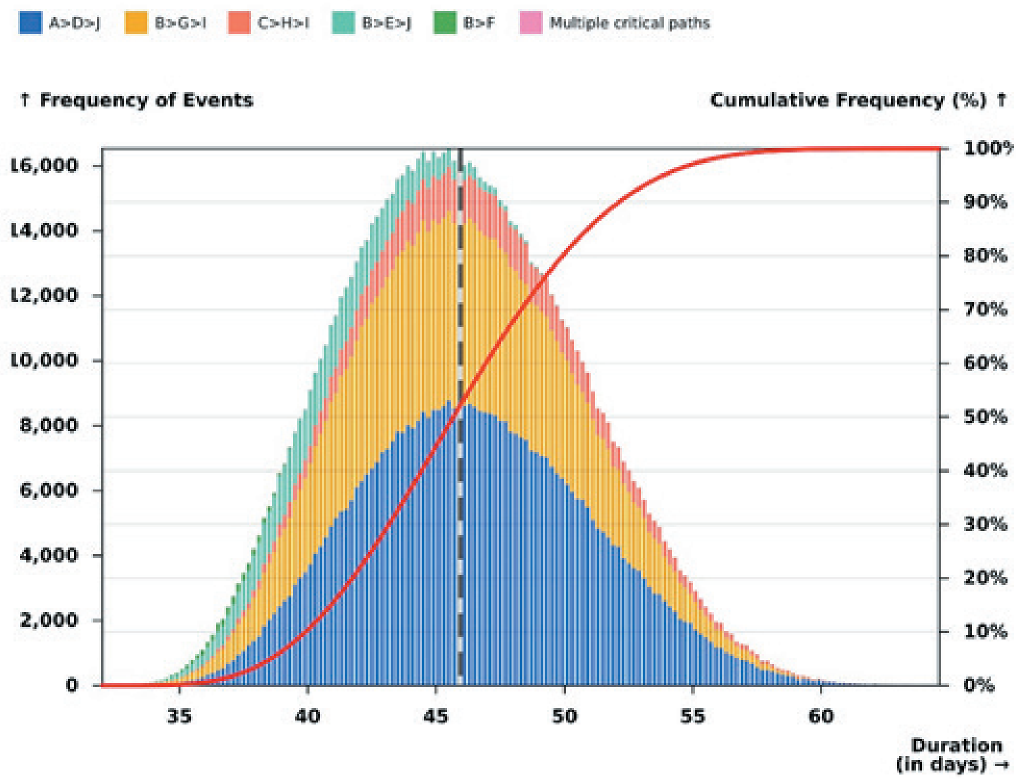

Figure 2. Open-source beta-PERT tool - Frequency chart for project completion time

Table 1. Summary statistics, critical path and percentile probabilities of project completion

	Summary	Oracle Crystal Ball	Open-Source PERT tool
Statistics	Minimum	31.79 days	33.04 days
	Maximum	64.69 days	60.52 days
	Average (μ)	45.95 days	45.89 days
	Standard deviation (σ)	4.60 days	5.17 days
	Variance (σ^2)	21.131 [$days^2$]	26.73 [$days^2$]
Critical Path	A>D>J	54.1%	50.7%
	B>G>I	23.6%	34.2%
	C>H>I	17.3%	8.3%
	B>E>J	4.8%	6.3%
	B>F	0.1%	0.4%
	Multiple critical paths	0.1%	0.1%
Percentile probability	50%	46 days	46 days
	60%	47 days	47 days
	70%	49 days	48 days
	80%	51 days	50 days
	90%	53 days	52 days
	100%	61 days	62 days

4.1. ACCURACY OF RESULTS

Both software tools produced highly accurate and comparable results in terms of the mean, variance, and probability distributions of project durations. The slight differences observed were negligible and within the expected tolerance, depending on random sampling. Before its release, the open-source tool was rigorously tested, including assessments with multiple probability distributions, to confirm its reliability. The normal and beta-PERT distributions are recommended, as they more accurately represent the natural variability in project timelines.

When using the normal distribution, activity durations might sometimes exceed the PERT bounds, which could lead to inconsistencies in the critical path list. This occurs because the random value generation method relies on a normal distribution calculated from the specified mean (μ) and standard deviation (σ), derived from PERT formulas. Although this method provides a close approximation of PERT distributions, it does not inherently respect the optimistic and pessimistic bounds defined by a PERT distribution.

4.2. COMPUTATIONAL EFFICIENCY

The computational time for both tools was found to be similar, with Oracle Crystal Ball taking slightly longer due to the overhead of running within the Microsoft Excel environment. The open-source tool, being web-based, was optimized for parallel processing and handled larger datasets efficiently. The simulation runs relatively quickly, but its speed depends on your computer's performance.

This web-based tool takes advantage of modern browser optimizations, offering notable benefits compared to Excel and Visual Basic for Applications (VBA). By utilizing JavaScript, it delivers faster computation, improved management of large datasets, and greater interactivity, resulting in a more efficient and adaptable solution. However, a user can still download the raw simulation data as a CSV file for further analysis in Excel or any other spreadsheet software.

4.3. USABILITY

The user interface of Oracle Crystal Ball, while robust, requires training in setting up a model and is less flexible when integrating with non-Excel environments. In contrast, the open-source tool's web-based interface is intuitive and can be accessed from any device, requiring minimal setup. This flexibility makes the open-source tool an attractive option for users with limited technical expertise.

The open-source PERT tool has effectively simplified Monte Carlo schedule analysis by demonstrating how quickly a simulation can be executed in just a few seconds. Additionally, it automatically generates an activity-on-node diagram, further enhancing the efficiency and streamlining of the schedule analysis process (Figure 1).

The open-source nature enables further upgrades, customization and modifications for advanced users [16]. For those interested in exploring alternative distributions, the JavaScript file includes functions like normInv = f(mean, stdDev) for the Normal Distribution and betaPERT = f(O, ML, P) for the beta-PERT Distribution. Additionally, users can create custom distribution functions tailored to their specific needs, all of which are called by the runMonteCarloSimulation() function [13].

4.4. COST

The most significant advantage of the open-source tool is its cost, which is zero. In contrast, Oracle Crystal Ball incurs significant licensing fees, which can become prohibitively expensive for smaller firms or individual users. Current prices for Oracle Crystal Ball vary between $410 for university users, $1,100 for the standalone installation on-premises, and 2,200 for the bundle installation with Crystal Ball Decision Optimizer.

5. CONCLUSION

This study demonstrates that the open-source Monte Carlo PERT-based simulation tool is a viable and effective alternative to traditional software like Oracle Crystal Ball. It provides similar accuracy, computational efficiency, and usability, with the added benefits of being cost-free and highly accessible. As project management increasingly shifts towards more cost-effective and flexible solutions, open-source Monte Carlo simulation tools hold great promise for the wider use of advanced risk analysis techniques in project scheduling.

Both tools produced highly accurate results, with negligible differences in mean, variance, and probability distributions. The open-source tool, which supports normal or beta-PERT distributions, underwent rigorous testing and effectively approximates PERT distributions, though the normal distribution may occasionally produce values outside PERT bounds.

In terms of computational efficiency, both tools performed similarly, but the open-source tool, being web-based and leveraging JavaScript, offered faster processing, better handling of large datasets, and enhanced interactivity compared to Oracle Crystal Ball, which experienced delays due to its Excel integration.

Usability and cost are key differentiators. Oracle Crystal Ball's interface, while robust, requires training and represents a less flexible option. In contrast, the open-source tool features an intuitive, web-based interface accessible from any device, making it user-friendly for those with limited technical expertise. Its open-source nature also allows for customization and upgrades, appealing to advanced users. Most notably, the open-source tool is free, which makes it a more accessible and attractive option, particularly for smaller firms or individual users.

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