Modular and offsite Construction Summit
July 28-31,2025 Montreal, Canada

Activity Sequencing Optimization in Petroleum Projects Using Simulation Modeling

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ABSTRACT
Project management benefits from mathematical models that enhance resource allocation, scheduling, and cost efficiency while managing uncertainties. Although optimization is well-studied in construction, its use in sequencing petroleum project activities remains unexplored. This study develops an integrated simulation and optimization model to refine scheduling in refinery upgrades, minimizing project duration and addressing operational complexities. This paper presents a simulation-based optimization model designed to improve scheduling efficiency in a refinery upgrade project, where multiple tasks must be executed concurrently without extending the overall project duration. The model accounts for interdependencies among activities and resource requirements across internal and external work teams, ensuring optimal coordination and utilization. Developed using AnyLogic®, the simulation framework employs a random number generator to systematically explore task sequencing variations, leading to a refined execution strategy. The optimization results indicate a 20% reduction in the project's total duration. While resource utilization was assessed, it was not the model's primary objective. The utilization of resources has shown mixed outcomes; specific resources demonstrated an improvement of nearly 50%, yet the overall average utilization significantly decreased to just 0.12%, falling below the typical baseline of 40% observed in most resources. The model's performance and the optimization outcomes are analyzed, offering a decision-support tool for complex project management scenarios.

KEYWORDS
Activity Sequence; Simulation; Petroleum projects, Refinery upgrade

INTRODUCTION
Project managers can use many techniques and mathematical models to ensure successful project delivery and manage uncertainties in construction projects. These techniques can help in resource allocation, schedule performance enhancement, cost reduction, and optimizing the activity sequence. Many efforts have been made to create efficient modeling tools that might be useful in forecasting and resolving uncertainties to fast-track the project or reduce expenses (Curto, 2022). To the best of the author's knowledge, the literature has not yet explored optimization techniques specifically for sequencing activities in petroleum projects.
Simulation modeling, initiated in the early 1960s, can assist in accurately analyzing the performance of new project designs and modifications to current operations by creating replicates of real-world activities. Moreover, simulation modeling can be considered a realistic alternative to actual modeling, and hence, it is beneficial for solving challenging problems.

An integrated simulation and optimization model is developed to improve the project management strategy used in a petroleum refinery upgrading project. The model imitates the project management strategy using scheduled activities and aims to optimize the process by sequencing different tasks containing multiple correlated activities, yielding the minimum duration.

BACKGROUND

Activity Sequencing and Optimization

Activity sequencing is crucial for project completion and relies on historical data, expert insights, and scenario analysis to estimate task durations. Optimization theory (Caballero, 2012; Alby, 2023) identifies the optimal order to reduce duration, costs, and resource use while considering constraints. Challenges arise from interdependencies (Cong Liu, 2023; Zhou, 2023), limited resources, unexpected obstacles, and changes in scope (Hegazy, 2008; Sadeh, 2021). Bottlenecks due to labor shortages and external dependencies require proactive risk management (Sadeh, 2021). Khodakarami (2007) proposed a dynamic risk model using Bayesian networks to incorporate uncertainty into construction schedules, emphasizing the need to identify additional risks. Specific risks related to construction schedules must be identified, requiring thorough analysis of schedule predictions under uncertainty for successful project execution (Ustinovičius, 2007). Flood (2017) examined activity correlation through Monte Carlo simulation, demonstrating its efficacy in statistically assessing project outcomes and performance indicators.

Many optimization techniques are used in project management to find optimal solutions for multiple variables. Schedule delays are common and are viewed as delays despite correlated losses (Flyvbjerg, 2005). Baldwin (2014) discussed various planning methodologies, both manual and computer-assisted, highlighting their effect on project delivery. Tsai (2014) focused on optimization methods in fields like multicriteria decision-making. For example, Nasir (2003) proposed a stochastic network technique that simulates project durations with random values. Hegazy (2008) developed a genetic algorithm optimization model for high-rise building scheduling, minimizing costs while meeting timelines and resource constraints. However, it synchronized crews only for identical teams, overlooked varied activities, and did not directly address project duration. Emam (2025) explores scheduling methods for infrastructure projects, focusing on network-based (CPM, PERT) and graphical (LOB) techniques. Abdelbasset (2023) developed a multi-objective optimization model for repetitive construction, using a scheduling module to coordinate crews and a genetic algorithm to optimize sequences. This model achieved an 8% reduction in duration and a 0.78% reduction in costs. Cong Liu (2023) integrated genetic and simulated annealing algorithms to optimize assembly sequences for diverse prefabricated components.

Petroleum Projects Scheduling Optimization

In the oil and gas industry, maintaining continuous production is essential. Periodic inspections and maintenance ensure refinery efficiency despite extreme conditions (Bijvank, 2004; Alfares, 2022). Some tasks require planned shutdowns for safety, carried out by specialized contractors. Simulation modeling optimizes refinery scheduling by analyzing scenarios to minimize project duration while addressing uncertainties. It aligns with CPM and PERT principles, offering a structured framework for managing large-scale upgrades and proactively resolving bottlenecks (Alfares, 2022).

RESEARCH MOTIVATION AND OBJECTIVE

The exponential growth of sequences poses challenges in large projects with numerous activities. Without adequate storage and processing power, finding the optimal sequence is infeasible. Combinatorial Optimization identifies optimal solutions from a finite set of sequences, ensuring the best arrangement based on criteria. Literature often examines route, schedule, and assignment optimization for specific objectives, with examples like the traveling salesman problem, graph coloring, and task scheduling in computing.
The research objective is to develop a framework that optimizes the sequence of activities for a refinery upgrade project involving multiple tasks managed by different contractors, which generates a vast number of optimal solutions. The aim is to minimize the total project duration while enhancing overall performance.

MODEL FRAMEWORK

This research uses a fast-tracking schedule to shorten the project's duration while maintaining the quality of a petroleum project. Following the framework in Figure 1, this study focuses on upgrading a petroleum refinery with construction activities that must proceed without halting operations. Inspections assess the operational status during maintenance. Effective coordination relies on understanding unit interdependencies and contractor resource availability. Safety procedures are integrated into all activities, ensuring compliance with hazardous environments while outlining durations and specialized labor. The approach prioritizes resource allocation to critical tasks, minimizing duration, overlaps, and scheduling conflicts among contractors.

Monte Carlo Simulation

The literature applies mathematical methods for optimal activity sequencing, with this research explicitly favoring Monte Carlo simulation. This stochastic approach evaluates project duration impacts by sampling probability distributions, offering advantages over fixed activity durations.

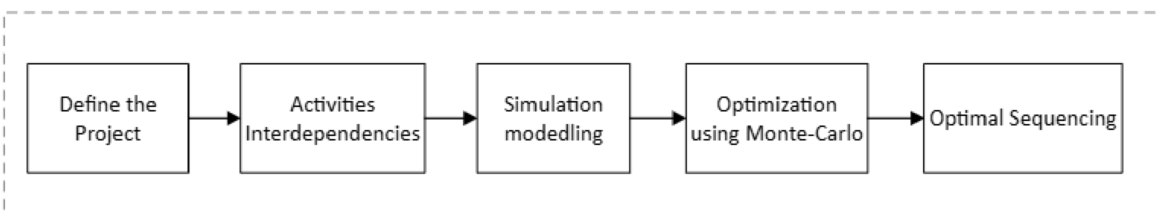

Figure 1. Model framework.

MODEL DEVELOPMENT

Petroleum Refinery Upgrades

The refinery upgrading project understudy requires a construction task to replace some deteriorated parts in the refinery’s units during the shutdown period. Meanwhile, the periodical inspection and maintenance tasks, which involve internal and external activities, must be completed, and these tasks must be executed efficiently in the same shutdown period. During the scheduled shutdown, four major tasks must be executed for twenty-two units according to each unit's requirements and current technical status: internal inspection, internal maintenance, external maintenance, and construction. The main goal is to keep the shutdown period to a minimum so the refinery can resume operation. Choosing the optimal activity sequencing for this project is problematic because it involves 34 activities across four required tasks.

Data Acquisition

All project details were gathered using Microsoft Excel® to acquire the optimum activity sequence. The data for the 22 units, the four tasks that should be implemented, and the interrelated activities of the four tasks were gathered from past similar projects. For each task, the resources necessary per activity were gathered from similar past projects, and the activity durations were assumed to follow a triangle distribution.

Figure 2 shows the original arrangement of the tasks, where each task is given a unique number from one to four to facilitate rearranging the tasks per unit in the model.

Model Logic

The simulation tool used is Anylogic®, a popular choice due to its ability to visualize multiple scenarios when planning complex projects. Figure 3 shows the model logic, presenting the possible decisions according to the required task per unit.

	[illegible]	task	task_number	db_column
1	U1	Construction1	4	
2	U1	Inspection1	1	
3	U1	Maintenance1	2	
4	U2	Inspection1	1	
5	U2	Maintenance1	2	
6	U3	Inspection1	1	
7	U3	Maintenance1	2	
8	U3	Maintenance2	3	
9	U4	Maintenance1	2	
10	U4	Maintenance2	3	
11	U5	Inspection1	1	
12	U5	Maintenance1	2	
13	U5	Maintenance2	3	
14	U6	Inspection1	1	
15	U6	Construction1	4	
16	U6	Maintenance2	3	
17	U7	Inspection1	1	
18	U7	Maintenance2	3	
19	U8	Construction1	4	
20	U8	Inspection1	1	
21	U8	Maintenance1	2	
22	U9	Construction1	4	
23	U9	Maintenance2	3	
24	U9	Inspection1	1	
25	U10	Inspection1	1	
26	U11	Inspection1	1	
27	U11	Maintenance1	2	
28	U11	Maintenance2	3	
29	U12	Maintenance1	2	
30	U13	Inspection1	1	
31	U14	Maintenance2	3	
32	U15	Maintenance1	2	
33	U15	Maintenance2	3	

Figure 2. Assigned tasks per unit.

Tasks are checked with a yes or no answer. The model has four tasks: inspection, internal maintenance, external maintenance, and construction. The Inspection requires eight activities for execution, and nine activities are planned for Internal Maintenance. External Maintenance has nine activities, and Construction has eight planned activities.

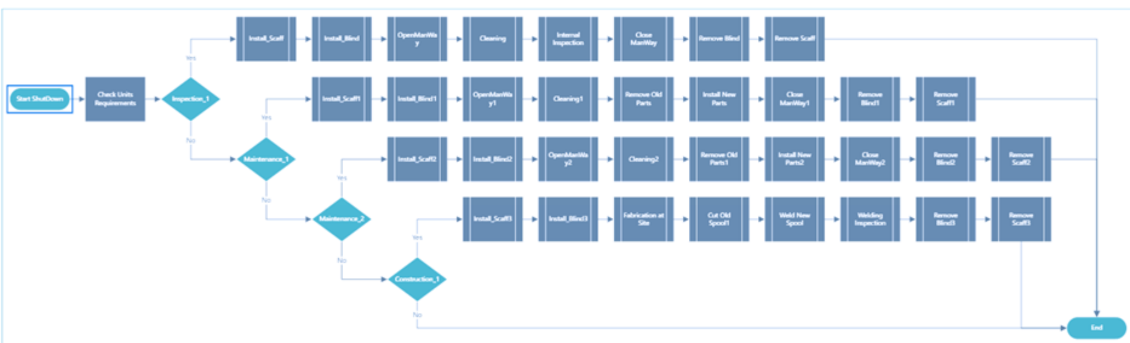

Figure 3. Model logic.

Each activity in a task has a predecessor and a successor. Therefore, the model reflects the relationships between activities within each task, which is finish-to-start in this model. However, some activities from other tasks should be implemented simultaneously without jeopardizing the task's internal activity sequence if these activities are unrelated. This means that some interactions between tasks can occur while creating the model.

Generating Construction Sequences

A random seed generates a sequence of random numbers for unit selection, and each iteration explores all viable probabilities using a new random seed.

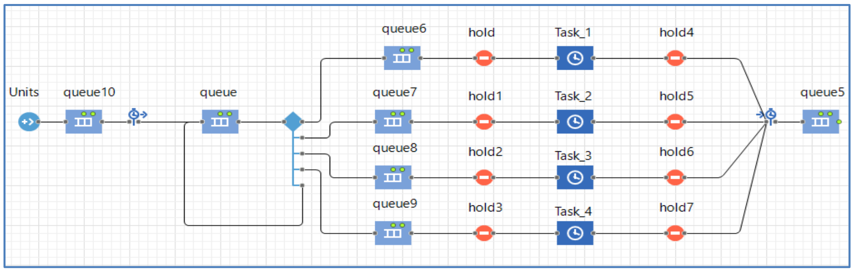

Figure 4. The main model.

The total number of planned activities is 34, distributed across four tasks, as shown in Figure 3. Figure 4 represents the developed model. Each task is treated as an event and activated through the inject function. This function is adaptable, especially with many activities involved. The model structure of using queue, hold, and delay blocks is essential for maintaining randomness and checking availability in unit selection. Agents are held after the queue to ensure the selection process respects the predefined activity order and does not proceed prematurely. This holding mechanism operates based on specific conditions aligned with the sequence logic. For example, inspection activities must be completed before maintenance activities to identify deteriorated parts. Additionally, the delay blocks act as controlled timing elements that introduce randomness and enable varied sequencing outcomes. The subsequent hold blocks following the delays ensure compliance with precedence requirements before progressing to the next activity. Each activity is allocated the required labor and equipment resources. Activity duration is characterized by a triangular distribution.

Monte Carlo Simulation and Optimization

Optimization using the OptQuest engine minimizes project duration through a Monte Carlo simulation. Resources are assumed to be readily available to prevent production delays, while site congestion is controlled by limiting teams per unit for safety compliance. Skilled labor requirements adjust dynamically based on availability and demand. The model runs 5,000 iterations with two RNGs to refine sequence shuffling and explore all possible outcomes.

Results and Discussion

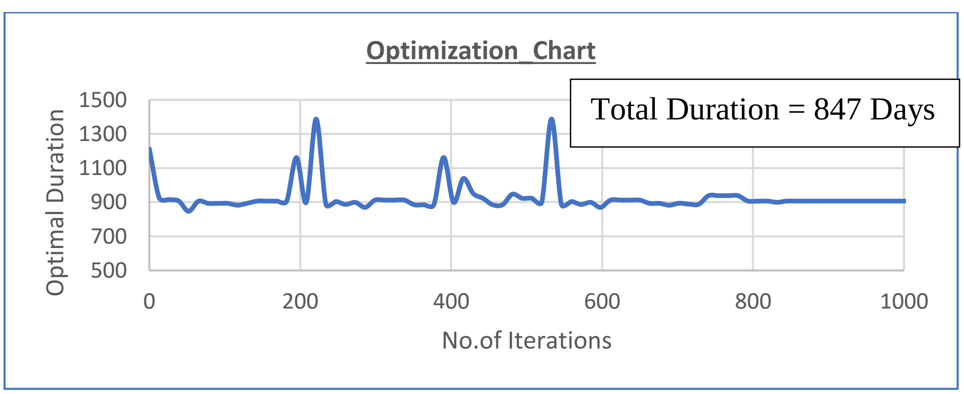

Figure 5. Optimization results.

Figure 5 shows the optimization results. The minimum duration achieved is 847 days compared with the original 1,107 days. The optimal activity sequence achieved is shown in Table 1. Seven parameters are utilized in the optimization, representing the availability of skilled labor, which affects project duration and ensures realistic modeling.

Table 1. Activity sequence results.

ID	Unit	Task	ID	Unit	Task
1	U1	Maintenance1	26	U15	Maintenance1
2	U3	Maintenance2	27	U15	Maintenance2
3	U1	Inspection1	28	U15	Construction1
4	U1	Construction1	29	U16	Maintenance1
5	U2	Maintenance1	30	U16	Maintenance2
6	U4	Maintenance2	31	U7	Inspection1
7	U3	Maintenance1	32	U17	Maintenance1
8	U5	Maintenance2	33	U19	Construction1
9	U2	Inspection1	34	U17	Maintenance2
10	U6	Construction1	35	U21	Maintenance1
11	U4	Maintenance1	36	U8	Inspection1
12	U6	Maintenance2	37	U18	Maintenance2
13	U5	Maintenance1	38	U22	Maintenance1
14	U3	Inspection1	39	U22	Construction1
15	U7	Maintenance2	40	U21	Maintenance2
16	U8	Construction1	41	U9	Inspection1
17	U8	Maintenance1	42	U10	Inspection1
18	U9	Maintenance2	43	U11	Inspection1
19	U5	Inspection1	44	U13	Inspection1
20	U11	Maintenance1	45	U16	Inspection1
21	U11	Maintenance2	46	U18	Inspection1
22	U9	Construction1	47	U19	Inspection1
23	U12	Maintenance1	48	U20	Inspection1
24	U14	Maintenance2	49	U21	Inspection1
25	U6	Inspection1	50	U22	Inspection1

Figure 6 illustrates the accumulated total project duration chart and a breakdown of the total duration across four tasks. The inspection task is the most critical, as it is required for most refinery units. In contrast, construction activities account for the shortest duration. Internal and external maintenance tasks hold nearly equal shares in the total project duration. The total project duration was approximately 1,107 days, occasionally exceeding 1,200 days across multiple runs. After optimization, the total project duration was reduced by around 20%, achieving an average of 847 days. Figure 7 shows the results of resource utilization. Resource utilization exhibited mixed outcomes. While some resources showed a nearly 50% improvement, the overall average utilization dropped significantly to just 0.12%, reflecting a decrease below the typical baseline of 40% observed in most resources. These results mean rearranged sequences might cluster certain activities, leading to uneven resource usage across project phases. Resources might be heavily used during specific intervals but underutilized in others.

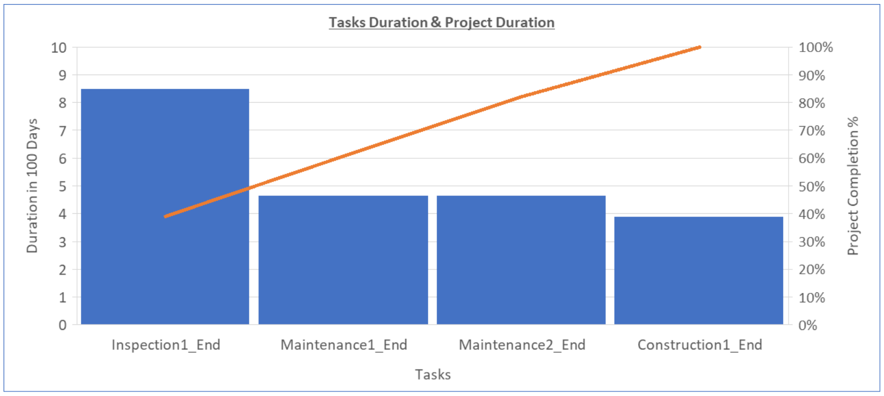

Figure 6. Tasks and project duration.

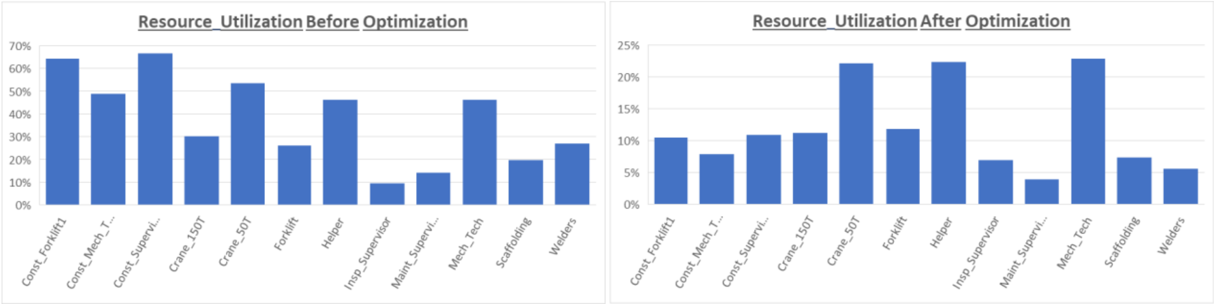

Figure 7. Resource pool utilization.

CONCLUSIONS AND RECOMMENDATIONS

Traditional scheduling methods like CPM and PERT emphasize task dependencies and duration estimates but fail to account for dynamic interactions among correlated activities. The proposed model bridges this gap by replicating real-world project dynamics, capturing activity interdependencies, and refining sequencing strategies to reduce project duration while ensuring operational feasibility. This paper presents a simulation model optimized for activity sequencing to minimize project duration. The model incorporates multiple tasks: Inspection, Internal Maintenance, External Maintenance, and Construction, to be executed during the shutdown period. The optimization results demonstrate a notable impact on project performance metrics, showcasing advancements in specific areas and identifying key aspects that need further refinement to ensure optimal resource distribution and overall efficiency. Moreover, the locations of units can be considered in future work using a geographic information system, as it may affect the activity sequence to facilitate labor and equipment movement. Moreover, future model iterations should integrate risk assessment and mitigation strategies specific to operational refineries to provide a more comprehensive and realistic optimization framework.

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