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Simulation Modeling and Analysis of Truck Fleet Assignment in Earthwork Operations

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Abstract— *One of the main activities in the construction industry is earthwork operation, which involves excavation, transportation, and disposal of materials. Fleets of trucks, excavators and loading equipment are used to handle and move large volumes of material in usually uncertain environments with unpredictable times. Repetitive uncertain tasks need to be analyzed carefully to estimate the required amount of equipment, such as excavators, loaders, and trucks. Moving the earth, loading and routing the trucks and returning them back for reloading operations involve task times, which are usually random and probabilistic in nature. Determination of the optimum truck fleet to be assigned to excavators and loading equipment may be complicated. Past analysis indicates that the planning of these activities can be significantly improved by using discrete-event simulation instead of traditional tools.*

This paper investigates the optimization of earthwork operations using ARENA simulation tool due to its flexibility and ease in analyzing various construction activities. The study considers a specific case study in Neom City, the line spine project in Saudi Arabia. A simulation model is built and developed that mimics real-world earthwork operations. By simulating different operation scenarios, the model results are used to determine the optimum capacity and assignment of truck fleet to hauling equipment with respect to minimum task times and cost values.

Index Terms: *Earthwork Operations, Neom City, Arena Software, Simulation Modeling, Earthwork Operation Optimization, Cost Analysis, Optimum Strategy.*

I. LITERATURE REVIEW

The line's spine project serves as the lifeline of Neom City, which connects different districts and facilities within the city. The Line Spine project has a very broad scope, including large areas of arid land and a variety of geographical challenges. From constructing bridges and roads to setting up utility infrastructure, the Line Spine project requires careful planning, advanced engineering knowledge, and creative problem-solving. However, the successful implementation of the line spine project depends on efficient earthwork operations, which form the foundation of the construction activities. Earthwork operations such as excavation, hauling, and dumping are critical in shaping the physical landscape of Neom City and laying the groundwork for subsequent development phases. Despite the paramount importance of earthwork operations, challenges arise in optimizing resource utilization, minimizing project durations, maximizing productivity, and reducing expenses. Also, efficient use of equipment, such as excavators and dump trucks, with an optimal operation strategy represents challenges that must be addressed to ensure the timely and cost-effective completion of the line spine project. A study by Guilherme et al. (2022) and M. Abduh et al. (2010) also highlights the challenges and complexities involved in optimizing earthwork operations. The research by focuses on the complexities of primary aspects such as earthwork planning within a given project. The author argues that the dynamic nature of such operations needs special considerations when it comes to the project scope, regularity requirements, site topography, and the state of the soil.

The hypothesis guiding this research is that by simulating earthwork operations within a specific area of the spine project, it is possible to identify opportunities for improvement, evaluate different operational strategies, and optimize resource utilization to provide an optimal and cost-effective operation strategy that can ensure the completion of the line spine project within the framework of the project. Through a comprehensive analysis of construction earthwork operations using arena simulation modeling, this study seeks to identify key parameters influencing operational efficiency, develop simulation models for scenario analysis, and evaluate the effectiveness of optimization strategies and cost analysis, contributing valuable insights and recommendations about the earthwork operations processes. (Placeholder1)

II. SIMULATION MODELING

According to Biruk and Rzepecki (2021) and Elbeltagi et al. (2012), simulation modeling plays a primary role in analyzing and optimizing the construction processes to improve managing construction projects. First, a study by Birk and Rzepecki (2021) discusses the use of simulation modeling for excavation operations in building construction to predict production rates and unit costs. The author states that utilizing simulation during the planning phase for resource optimization combined with optimization techniques improves production rates and cost-effectiveness in excavation operations (Biruk & Rzepecki, 2021). Similarly, Elbeltagi et al. (2012) support the research by testing two simulation approaches to efficiently manage the logistics of construction earthwork operations, concluding that models can be effectively utilized for simulating construction operations. In other words, stakeholders can explore various excavation strategies and evaluate which operation strategy is effectively best for their project.

III. ARENA SIMULATION

A study by Allen (2011) explores Arena software and its features, primarily applied in analyzing and modeling complex processes and systems in construction projects. The study further states that the concept contains a graphical user interface (GUI), which facilitates the development of simulation models, making it easier to navigate for both experienced and beginner users (Allen, 2011). Similarly, Lazar Živković (2021) explores how arena software facilitates effective management in construction projects. Through aspects such as visualization, the model enhances a better understanding of processes and the impact of different scenarios, resulting in improved processes and decisions made by stakeholders in the construction industry. Sağlam and Bettemir (2018) support the study above, which states that, with the use of backhoe excavators coupled with Monte Carlo simulation, stakeholders can correctly predict the duration and hence decide on better allocation strategies when it comes to the available equipment in a construction project.

Additionally, considering other aspects such as soil type and depth of excavation aids in better allocation strategies. A study by Fu (2013) argues that with the detailed analysis of different scenarios using the results from simulation, stakeholders can optimize logistics processes, and reduce delays and costs, therefore having a successful project.

IV. CASE STUDY

Located in the center of Neom City, The Line is an empirical city spanning 170 kilometers that connects the Red Sea to the desert valley. Initially, plans called for a subterranean railway that could move trains at a speed of 510 km/h (317 mph), which would enable them to travel 20 minutes to reach either end of The Line. The railway's first tunnels were excavated in 2023, and work has begun on developing a prototype train. (NEOM, THE LINE, 2024). This study aims to simulate earthwork operations, like hauling and dumping activities, within a designated excavation area of the NEOM City Spine Project, Zones 2 and 3, to identify opportunities for improvement to enhance the efficiency of resource utilization and evaluate the relationship between operational efficiency of construction equipment with construction cost by simulating different operation scenarios.

V. BUILDING THE MODEL

We had to understand how the actual operations work to build the simulation model. After that, arena simulation software enabled us to assemble the system components, such as excavators, trucks, loading area, haul routes, dumping area, and other logic components defined within the model. reflecting the key elements of the earthwork operation processes.

A. Simulating the case problem

For our case study, we had different material types and a difference in the amount hauled. So, we built two models with the same procedure but with changes in the material type, capacity, and project durations to simulate each type separately. First, the rock model simulates the hauling and dumping of 109150.00 m3 of rock materials from the excavation site to the dumping area, which is 3 km away from the excavation site.

B. Data Collection and fitting

The collected data, such as excavation processes, material types, equipment details, and hauling and dumping durations, was gathered with the help of project managers working on the spine project and then fitted into the model to ensure its accuracy in representing the actual operations. Overall, the model considered various factors such as loading and unloading times, loaded/unloaded travel times, truck travel distance, unloading procedures, and return time to optimize the hauling and dumping operations. Table 1 and Table 2 show the collected data for 30 trucks hauling and dumping rocks and mixed materials in minutes. After getting those data, we had to convert them and fit them to their right distribution, The next step was defining the data for the simulation model in the Arena software using its input analyzer tool, by defining the loaded /unloaded travel times and loading and unloading times for each material type. Tables 3 and Table 4 show the input analyzer results for rocks and mixed materials.

C. Simulation Model Development

For building the models First, for the Rocks earthwork operation model, this model simulates the hauling and dumping of rock materials from the excavation site to the dumping area. Figure 1 shows the rocks earthwork operation simulation model built on the arena interface. Here are the steps used to build the models to simulate the actual operations:

a) *Generate turks:* This process begins the simulation by generating trucks for rocks loading with the specified number of trucks for each scenario.

b) *Amount to Load:* This assign module recognizes the capacity that the truck carries, which is uniform between 16 and 18 m3.

c) *Loading:* This process simulates loading the rocks onto trucks based on the distributed data.

d) *Loaded Travel:* This process simulates the time it takes to move the hauled materials to the dumping area using the distributed data for this process.

e) *Dumping:* This process simulates the time it takes to move the hauled materials to the dumping area using the distributed data for this process.

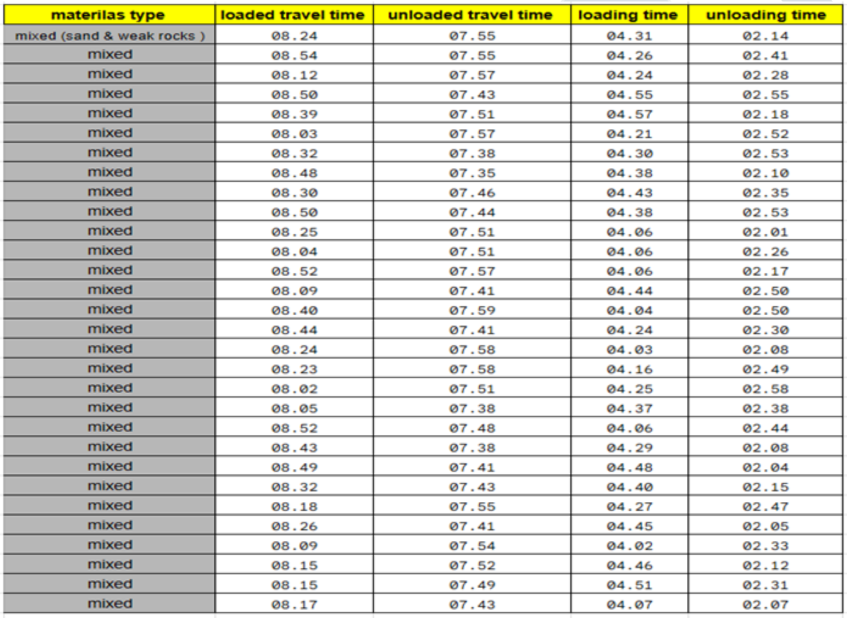
f) *Reduce Rocks Load:* After dumping, the load of rocks is reduced. This assign module reduces the capacity of rocks after each dump from the total stocked rock piles.

g) *Return time:* This process represents the time taken by the unloaded trucks to return to the loading area after dumping the rock. To present the actual time, the distributed data for this process was used to simulate this process.

h) *Rocks stockpiles finished:* This process represents the time taken by the unloaded trucks to return to the loading area after dumping the rock. To present the actual time, the distributed data for this process was used to simulate this process.

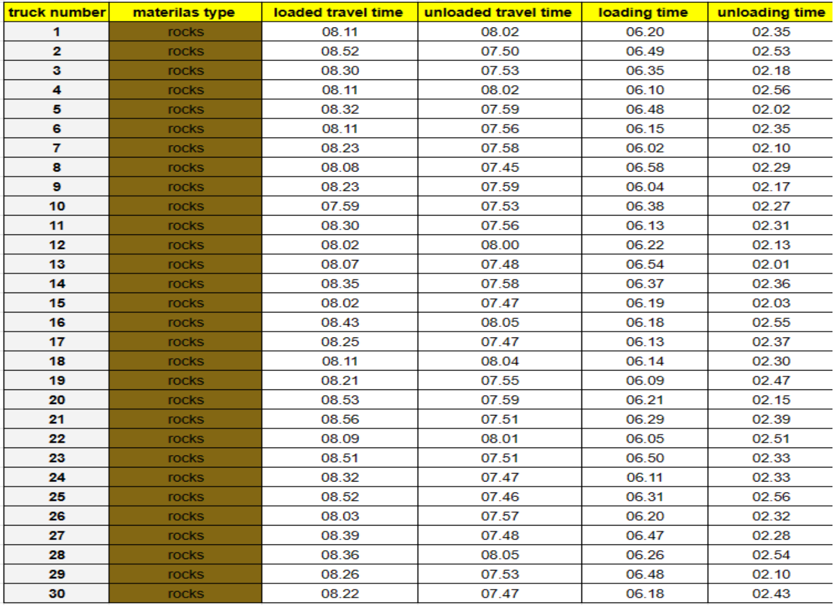
i) *Work finished:* Finally, using the disposal module, this step signifies the completion of all tasks related to rock loading and dumping.

Table I: Data For 30 Trucks Hauling and Dumping Mixed Materials.



materilas type	loaded travel time	unloaded travel time	loading time	unloading time
mixed (sand & weak rocks)	08.24	07.55	04.31	02.14
mixed	08.54	07.55	04.26	02.41
mixed	08.12	07.57	04.24	02.28
mixed	08.50	07.43	04.55	02.55
mixed	08.39	07.51	04.57	02.18
mixed	08.03	07.57	04.21	02.52
mixed	08.32	07.38	04.30	02.53
mixed	08.48	07.35	04.38	02.10
mixed	08.30	07.46	04.43	02.35
mixed	08.50	07.44	04.38	02.53
mixed	08.25	07.51	04.06	02.01
mixed	08.04	07.51	04.06	02.26
mixed	08.52	07.57	04.06	02.17
mixed	08.09	07.41	04.44	02.50
mixed	08.40	07.59	04.04	02.50
mixed	08.44	07.41	04.24	02.30
mixed	08.24	07.58	04.03	02.08
mixed	08.23	07.58	04.16	02.49
mixed	08.02	07.51	04.25	02.58
mixed	08.05	07.38	04.37	02.38
mixed	08.52	07.48	04.06	02.44
mixed	08.43	07.38	04.29	02.08
mixed	08.49	07.41	04.48	02.04
mixed	08.32	07.43	04.40	02.15
mixed	08.18	07.55	04.27	02.47
mixed	08.26	07.41	04.45	02.05
mixed	08.09	07.54	04.02	02.33
mixed	08.15	07.52	04.46	02.12
mixed	08.15	07.49	04.51	02.31
mixed	08.17	07.43	04.07	02.07

Table II: Data For 30 Trucks Hauling and Dumping Rocks Materials.



truck number	materilas type	loaded travel time	unloaded travel time	loading time	unloading time
1	rocks	08.11	08.02	06.20	02.35
2	rocks	08.52	07.50	06.49	02.53
3	rocks	08.30	07.53	06.35	02.18
4	rocks	08.11	08.02	06.10	02.56
5	rocks	08.32	07.59	06.48	02.02
6	rocks	08.11	07.56	06.15	02.35
7	rocks	08.23	07.58	06.02	02.10
8	rocks	08.08	07.45	06.58	02.29
9	rocks	08.23	07.59	06.04	02.17
10	rocks	07.59	07.53	06.38	02.27
11	rocks	08.30	07.56	06.13	02.31
12	rocks	08.02	08.00	06.22	02.13
13	rocks	08.07	07.48	06.54	02.01
14	rocks	08.35	07.58	06.37	02.36
15	rocks	08.02	07.47	06.19	02.03
16	rocks	08.43	08.05	06.18	02.55
17	rocks	08.25	07.47	06.13	02.37
18	rocks	08.11	08.04	06.14	02.30
19	rocks	08.21	07.55	06.09	02.47
20	rocks	08.53	07.59	06.21	02.15
21	rocks	08.56	07.51	06.29	02.39
22	rocks	08.09	08.01	06.05	02.51
23	rocks	08.51	07.51	06.50	02.33
24	rocks	08.32	07.47	06.11	02.33
25	rocks	08.52	07.46	06.31	02.56
26	rocks	08.03	07.57	06.20	02.32
27	rocks	08.39	07.48	06.47	02.28
28	rocks	08.36	08.05	06.26	02.54
29	rocks	08.26	07.53	06.48	02.10
30	rocks	08.22	07.47	06.18	02.43

Table III: Input fitted distribution data for the mixed materials model.

Activity	Distribution and parameters	Duration
Travel Loaded Time	Uniform (minimum value, Maximum value)	UNIF(8.02,8.54)
Travel Unloaded Time	Uniform (minimum value, Maximum value)	UNIF(7.35,7.59)
Loading Time	Normal (Mean, Standard deviation)	NORM(4.28,0.171)
Unloading Time	Normal (Mean, Standard deviation)	NORM(2.3,0.186)

Table IV: Input Fitted Distribution Data for the Rock Model.

Activity	Distribution and parameters	Duration
Travel Loaded Time	Normal (Mean, Standard deviation)	NORM(8.24,0.206)
Travel Unloaded Time	EXPO (Mean)	EXPO(7.64)
Loading Time	Triangle (Minimum value, Mode, Maximum value)	TRIA(6.02,6.26,6.58)
Unloading Time	Normal (Mean, Standard deviation)	NORM(2.31,0.168)

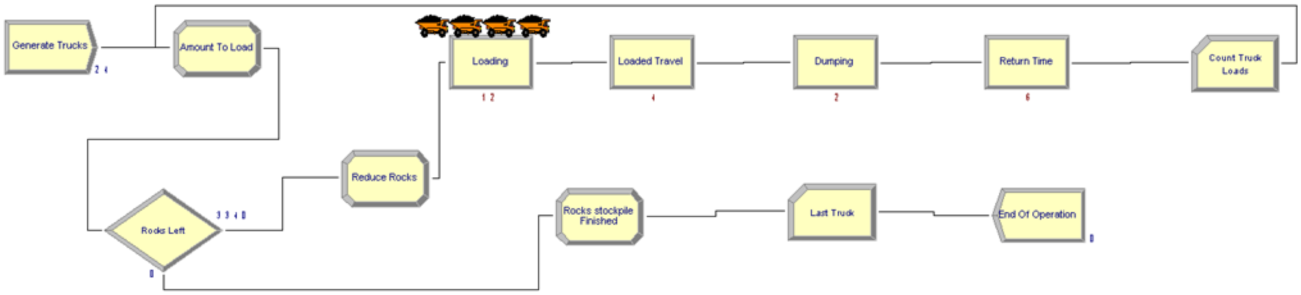


Figure 1. Rocks Arena Simulation Model

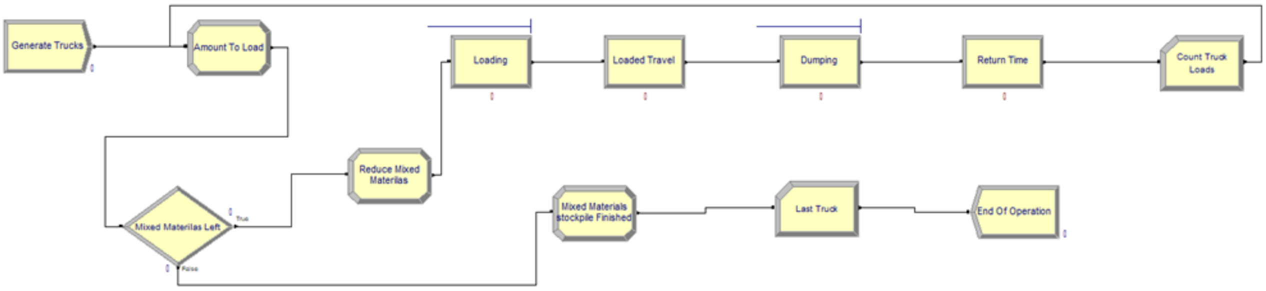


Figure 2. Mixed Materials Arena Simulation Model

This model simulates the process of hauling and dumping excavated materials, providing insights into optimizing the efficiency of these operations and providing an opportunity to simulate different operating scenarios to evaluate and ensure the optimal number of excavators and haul trucks is met to haul the target material within the given duration.

Following the same procedure, the mixed materials earthwork operation model was developed. This model simulates the process of hauling and dumping mixed materials from the excavated site to the dumping area, as shown in Figure 2. Those two models provide insights into optimizing the efficiency of these operations and an opportunity to simulate different operating scenarios to evaluate and ensure the optimal number of excavators and haul trucks is met to haul the target material within the given duration.

VI. OPTIMIZATION TECHNIQUES

A. Scenario analysis:

For both simulation models, different operations scenarios were tested to define the optimal operation strategy, In the Rocks model, the capacity of the materials used is 109150.0 m3 When we run the model, hauling and dumping operations take place to haul the total capacity of the rock and after it finishes hauling this amount the simulation stops. Several scenarios were tested to assess choosing the optimal operation strategy, each scenario has a different set of excavators and trucks. Table 5 shows the number of scenarios and the number of equipment tested for the Rocks model.

Table V: Operation Scenarios Tested for the Rocks Model.

Scenario Number	1	2	3	4	5	6	7	8	9	10
Excavators Number	3	3	4	4	5	5	6	6	7	7
Trucks Number	12	15	16	25	25	28	20	30	25	30

For the mixed materials model, the capacity of the materials used is 75000.0 m3. When we run the model, hauling and dumping operations take place to haul the total capacity of the mixed materials, and after it finishes hauling this amount the simulation stops. Also, for this model several scenarios were tested to assess choosing the optimal operation strategy, each scenario has a different set of excavators and trucks. Table 6 shows the number of scenarios and the number of equipment tested for the mixed materials model.

Table VI: Operation Scenarios Tested for the Mixed Materials Model.

Scenario Number	1	2	3	4	5	6	7	8	9	10
Excavators Number	3	3	4	4	5	5	5	6	6	6
Trucks Number	15	18	16	25	25	28	30	20	25	36

Simulating each model scenario set and recording its results enabled us to evaluate those and choose the optimum operation scenario with the least time to finish. Following the scenario analysis, a cost analysis was conducted to assess choosing an optimum operations strategy regarding time and cost.

B. Statistical Analysis:

Running the simulation scenarios shown in Tables 5 and 6, using 10 replications, enabled us to get statistical measures such as half-width which allowed us to calculate the confidence interval of 95% to ensure the accuracy and reliability of the results. Using a 95% confidence interval results in better estimates for our performance measures, such as the total truck load for each operation scenario. Using the following formula:

Confidence Interval = $\bar{x} \pm$ Half Width (1)

Where,

Confidence interval = Range of values, above and below the statistic's mean

Half width = Arena's output variability

C. Time Analysis:

Using the results from running the simulations, the total time required to complete the operation for each scenario was measured, and the relationship between the number of equipment used in each scenario and the total project completion time was analyzed to identify the most efficient strategy.

D. Cost Analysis:

For both models, a detailed cost analysis was conducted for each scenario, considering the fixed and variable costs associated with equipment usage The hourly total cost of equipment was calculated using the following procedure: to calculate the hourly total cost of the excavator, the following formula was used:

TC excavator = (Fixed cost) per hour + (operation & Maintenance cost) per hour (2)

where:

fixed cost (rent price /hour + operator salary) = 153.85 SAR /hr

Operation & maintenance costs = 27 SAR /hr

Second, to calculate the hourly total cost of the truck, the following formula was used:

TC truck = (Fixed cost) per hour +(operation & maintenance cost) per hour (3)

where:

fixed cost (rent price/hour + operator salary) = 57.69SAR /h

Operation & maintenance costs = 19.24 SAR /hr

The hourly total rent cost of equipment was calculated using the following formula:

Equipment rent cost = TC excavator + TC truck (4)

to calculate the total cost for the scenarios load, we need to sum the total cost of the equipment used with their operation and maintenance costs, which in our case includes the equipment operator's salary and expenses and multiply it by the total busy hours for each equipment. The following formula was used to calculate the Total cost for the scenario load:

TC scenario = ((TC excavator * Number of excavators) + (TC truck * Number of trucks))* Total operation time/ hr (5)

where,

TC excavator = Hourly total cost of the excavator

Number of excavators = Number of excavators in the Scenario

TC truck = Hourly total cost of the truck

Number of trucks = Number of trucks in the scenario

After calculating the total cost for each scenario load, we can compare each model scenario and their total costs. Finally, by comparing the total time to finish the operations and the total cost, we can choose the scenario with the optimum outcomes regarding the time and the cost for each model.

VII. RESULTS AND ANALYSIS

A. Operation Strategy Total Finish Time

Starting with the scenario operation analysis as mentioned in the methodology, comparing different operation strategies will enable us to find the optimum operation strategy with the least time to finish the total materials we have. First, for the Rocks model, the results in Table 7 show the number of equipment used and the total time to finish, which is the total time taken for hauling and dumping operations of the 109150.0 m3 total rock. From the table, the potential optimal scenario for balancing the resources and the total time appears to be scenario 8, which uses 6 excavators and 30 trucks to achieve a completion time of 112.4 hours. The results show that increasing the number of trucks while keeping the number of excavators constant results in a noticeable decrease in the project time, increasing the number of both excavators and trucks leads to the most significant decrease in the total time of the operation.

Second, for the mixed materials model, the results in Table 8 show the number of equipment used and the total time to finish, which is the total time taken for hauling and dumping operations of 75000.0 m3 of the total mixed materials. From the table, the potential optimal scenario for balancing the resources and the total time appears to be scenario 10, which uses 6 excavators and 36 trucks to achieve a completion time of 52.8 hours.

In conclusion, the optimal scenarios that achieved the least completion time were chosen regarding the total time to finish, however the selection of the optimal scenario cannot be only based on the total time, it’s crucial to consider the total cost associated with each scenario so a cost analysis along with the time will determine the overall efficiency of the scenarios.

B. Hourly Cost of Operation Strategy

The hourly rent cost of equipment is the sum of fixed cost per hour and operation and maintenance cost per hour. Starting with the rocks model scenarios, Table 9 shows the results of calculating each scenario's equipment hourly cost of rent and the total cost of the scenario in Saudi Riyal (SAR), obtained by following the calculations and procedures explained in the cost analysis section, the results indicate that increasing the number of trucks and excavators leads to higher total cost per hour.

Following the same procedure for the mixed materials scenario, Table 10 shows the results of calculating each scenario's total cost of equipment and the total cost of the scenario for the rocks scenarios, also here the results indicate that increasing the number of trucks and excavators leads to higher total cost per hour.

C. Operation Strategy Truck Loads

To confirm that the models were able to perform the real-world earthwork operations and conduct the hauling and dumping operations of the provided material capacities for both models. From Table 11 and Table 12, it can be concluded that the completion of each operation scenario results in the successful prediction of the total trucks load for both mixed materials and rocks providing the same capacities with minor variations. the halfwidth values and the narrow confidence interval indicate that the models are stable and reliable confirming that the models are effective tools for planning and optimizing earthwork operation.

D. Comparison Of Scenarios Total Cost and Total Time

Comparing the key metrics total time and total cost, will assess us in choosing an operation strategy with optimum outcomes. For the rocks model, the data in chart 1 compares the rocks operation scenario with their total cost in SAR and the total time to finish the earthwork operations.

The results show that while increasing the number of excavators and trucks generally, time efficiency improves. It also significantly increases the costs. Chart 1 shows that for selecting the optimal operation scenario both the total time to finish and the total cost were considered, the optimal scenario should ideally minimize both cost and time. Scenario 9 achieves the following by providing a reduction in the completion time (105.9 hr) at a reasonable total cost (337772 SAR) compared to the other scenarios.

For the mixed materials model, the data in chart 2 compares the mixed materials operation scenario with their total cost in SAR and the total time to finish the earthwork operations. Chart 2 shows that for selecting the optimal operation scenario both the total time to finish and the total cost were considered, the optimal scenario should ideally minimize both cost and time. Scenario 5 achieves the following by providing a reduction in the completion time of 134.8 hours at a lower total cost of 381518 SAR compared to the other scenarios.

It's clear that after considering both time and cost analysis in assessing the selection of the optimum scenario, we got a better view to choose the optimal scenario that can ideally minimize both cost and time. As shown in charts 1 and 2, comparing both metrics results in choosing new optimized operation scenarios compared to the ones we got from Table 7 and Table 8.

Table VII: Rocks Earthwork Operation Scenarios simulation results

Scenarios number	Number of Excavators	Number of Trucks	Total time to finish per hour
1	3	12	224.9
2	3	15	224.5
3	4	16	168.6
4	4	25	168.5
5	5	25	134.8
6	5	28	134.7
7	6	20	132.1
8	6	30	112.4
9	7	25	105.9
10	7	30	96.4

Table VIII: Mixed Materials Earthwork Operation Scenarios simulation results.

Scenarios number	Number of Excavators	Number of Trucks	Total time to finish per hour
1	3	15	110.5
2	3	18	105.3
3	4	16	103.1
4	4	25	79.2
5	5	25	66.4
6	5	28	63.3
7	5	30	63.2
8	6	20	82.4
9	6	25	66.1
10	6	36	52.8

Table IX: Rocks Earthwork Operation Scenarios Total Cost.

Scenarios number	Number of Excavators	Number of Trucks	Equipment's hourly cost of rent	TC scenario
1	3	12	1466.55	329868.40
2	3	15	1697.55	381134.77
3	4	16	1955.40	329714.01
4	4	25	2648.40	446338.38
5	5	25	2829.25	381518.70
6	5	28	3060.25	412316.15
7	6	20	2625.10	381724.67
8	6	30	3395.10	381724.67
9	7	25	3190.95	337772.69
10	7	30	3575.95	344774.03

Table X: Mixed Materials Earthwork Operation Scenarios Total Cost.

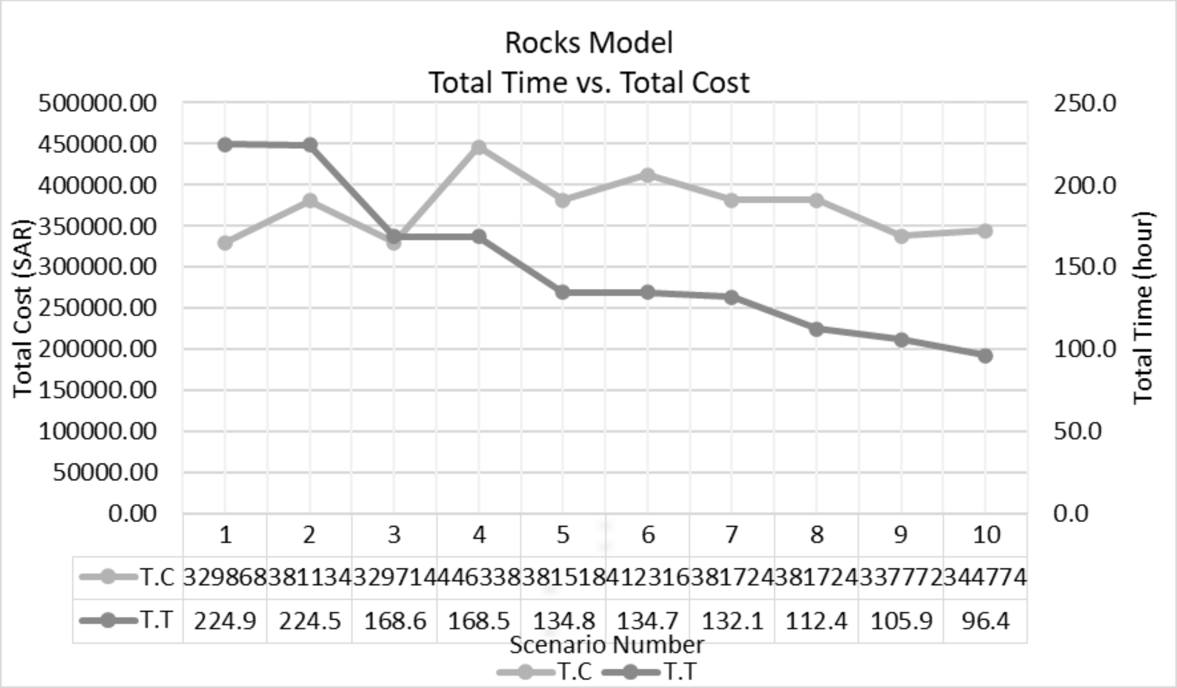
scenarios number	Number of Excavators	Number of Trucks	Equipment's hourly cost of rent	TC scenario
1	3	15	1697.55	187640.10
2	3	18	1928.55	203000.78
3	4	16	1955.40	201545.69
4	4	25	2648.40	209628.36
5	5	25	2829.25	187947.08
6	5	28	3060.25	193742.39
7	5	30	3214.25	203253.63
8	6	20	2625.10	216353.30
9	6	25	3010.10	198852.22
10	6	36	3857.10	203712.74

Table XI: Mixed Materials Total Trucks Load Per Scenario

Scenario number	Number of Excavators	Number of Trucks	Average Trucks Load	Half Width	Minimum Average	Maximum Average	95% Confidence interval
1	3	15	4411.80	1.68	4409.00	4415.00	CI (4410.12,4413.48)
2	3	18	4410.50	1.03	4409.00	4413.00	CI (4409.47,411.53)
3	4	16	4410.90	1.60	4408.00	4414.00	CI (4409.30,4412.5)
4	4	25	4410.10	1.41	4407.00	4414.00	CI (4408.69,4411.51)
5	5	25	4410.60	1.27	4408.00	4414.00	CI (4409.33,4411.87)
6	5	28	4410.20	1.50	4407.00	4413.00	CI (4408.07,4411.7)
7	5	30	4411.50	1.82	4408.00	4415.00	CI (4409.68,4413.32)
8	6	20	4411.50	1.69	4408.00	4415.00	CI (4409.81,4413.19)
9	6	25	4411.10	2.04	4407.00	4415.00	CI (4409.06,4413.14)
10	6	36	4411.60	1.48	4409.00	4415.00	CI (4410.12,4413.08)

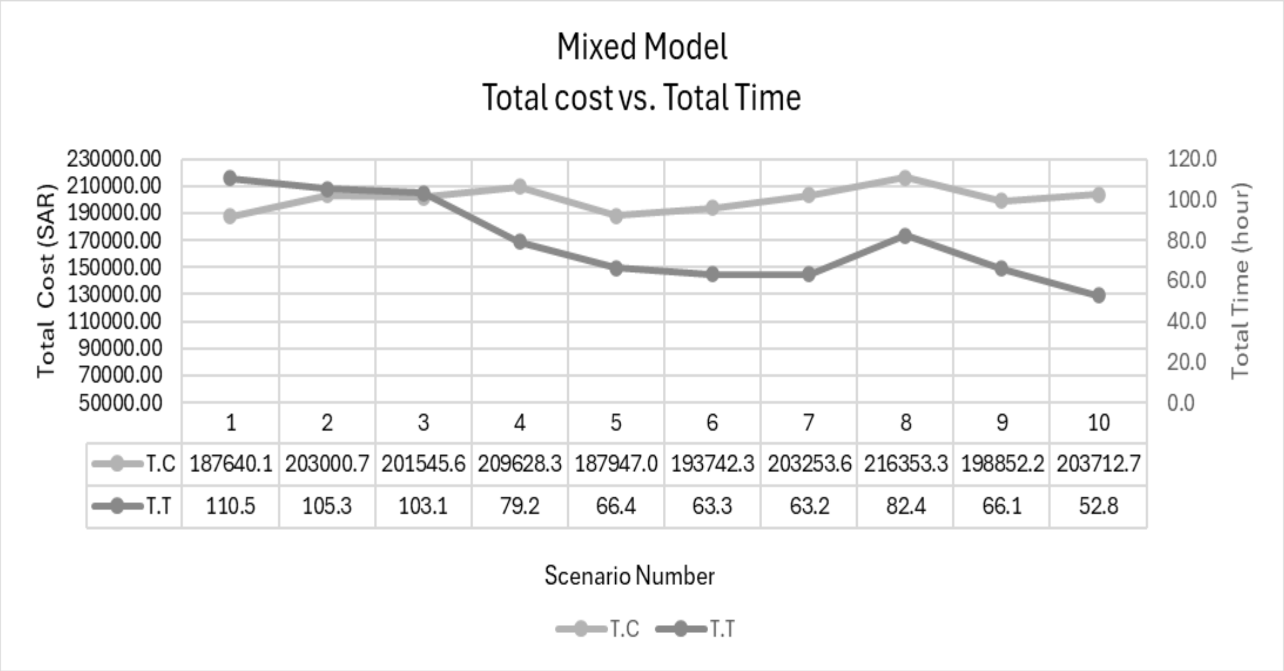
Table XII: Rocks Total Trucks Load Per Scenario

Scenario number	Number of Excavators	Number of Trucks	Average Trucks Load	Half Width	Minimum Average	Maximum Average	95% confidence interval
1	3	12	6419.90	2.17	6415.00	6427.00	CI (6417.73,6422.07)
2	3	15	6421.00	2.02	6418.00	6427.00	CI (6418.98,6423.02)
3	4	16	*6420.00*	*1.88*	*6418.00*	*6427.00*	CI (6418.12,6421.88)
4	4	25	6419.90	2.79	6414.00	6429.00	CI (6417.11,6422.69)
5	5	25	6419.90	2.04	6416.00	6423.00	CI (6417.86,6421.94)
6	5	28	6420.00	2.37	6414.00	6425.00	CI (6417.63,6422.37)
7	6	20	6420.30	2.36	6414.00	6426.00	CI (6417.94,6422.66)
8	6	30	6419.00	1.22	6416.00	6422.00	CI (6417.78,6420.22)
9	7	25	6420.90	1.67	6417.00	6424.00	CI (6419.23,6422.57)
10	7	30	6419.00	1.76	6414.00	6423.00	CI (6417.24,6420.76)



	1	2	3	4	5	6	7	8	9	10
T.C	329868	381134	329714	446338	381518	412316	381724	381724	337772	344774
T.T	224.9	224.5	168.6	168.5	134.8	134.7	132.1	112.4	105.9	96.4

Chart 1: Comparison between total time and total cost for rocks operation scenarios



	1	2	3	4	5	6	7	8	9	10
T.C	187640.1	203000.7	201545.6	209628.3	187947.0	193742.3	203253.6	216353.3	198852.2	203712.7
T.T	110.5	105.3	103.1	79.2	66.4	63.3	63.2	82.4	66.1	52.8

Chart 2: Comparison between total time and total cost for mixed materials operation scenarios

VIII. CONCLUSION AND RECOMMENDATIONS

A. Research objectives

For this research, a deep review of the existing literature was conducted to evaluate the effect of analyzing construction earthwork operations using simulation techniques, particularly arena software.

This research demonstrates that simulation modeling is a powerful tool for optimizing the truck fleet operation by evaluating different operation scenarios and choosing the one with the optimum time and cost-effective outcomes. Accurate real-world data, provided by civil engineers and project managers, was essential for building reliable simulation models. The models successfully simulated earthwork operations and provided insights for optimal operation strategies. Key findings include:

a) Model Stability and Reliability: The simulation model for both rocks and mixed materials proved stable and reliable, effectively predicting total truck loads with minor variations.

b) Cost Analysis: A detailed cost analysis of each scenario, along with the total time to finish, highlights the importance of balancing time efficiency and cost-effectiveness.

c) Optimal Scenario: Scenario 9 (rocks model) and scenario 5 emerged as the optimal choices, significantly reducing project completion time while maintaining moderate costs, highlighting the importance of evaluating both metrics to identify the most cost-effective and time-efficient operation strategy.

B. Limitations

The accuracy of the results depends on the reliability of the input data. Using accurate data of real-world operations can lead to accurate conclusions.

C. Suggestions for Future Research

a) Future research should utilize real-time data collection methods to enhance the accuracy and reliability of input parameters, such as GPS tracking of equipment.

b) It's recommended to explore a broader range of scenarios by varying the number of equipment, including different types of machinery, and their potential impacts on both costs and completion, providing a more comprehensive analysis.

c) Testing this model in the field by engaging stakeholders, including project managers, operation managers, and project cost controllers, to gather practical insights and feedback will help refine the models and ensure the proposed improvements are practical and implementable.

d) different types of projects and different geographical locations following the same procedure will help researchers and stakeholders understand the applicability and limitations of the model in various contexts. This will result in generalizing and assessing the adaptability of the findings.

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