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Research paper

APPLICATION OF THE SIMULATION MODEL FOR READY MIXED CONCRETE SUPPLY

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Abstract

The construction of many buildings requires ready mixed concrete (RMC) delivery from concrete plants. It is common to supply multiple construction sites, simultaneously, from one or more concrete plants. In such cases, a crucial task is planning the appropriate delivery schedule to each construction site in order to minimize or avoid machinery idling. This paper presents the application of an original model developed in AnyLogic simulation software. The model is based on a hybrid approach, combining two simulation techniques: discrete event and agent-based simulation. This model addresses the supply chain problem, or transportation problem, and can solve the duration and cost of concrete delivery from up to three concrete plants to a maximum of three construction sites simultaneously. The model allows for cost optimization and several other analyses. The fleet of mixers included in the model can be adjusted before running the simulation through the OptionPlant excel file. This paper analyzes a case study based on real parameters obtained from a specific concrete plant and construction sites. Two construction sites and one concrete plant are considered. The costs of transportation, total costs, as well as pump and mixer penalty costs, are calculated. Different analyses and discussion based on conducted results are provided to improve the concrete delivery process.

Key words: *Cost, Simulation, Delivery, Transportation, Ready Mixed Concrete, Supply Chain*

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1. INTRODUCTION

Proper planning of concrete delivery (Ready-Mix Concrete Delivery Problem – RMCDP) is a challenge, especially when pouring takes place simultaneously at different construction sites supplied by the same concrete plant. This issue becomes even more complex when different construction sites require different types of concrete. The RMCDP becomes significantly more complicated when multiple construction sites simultaneously require various types of Ready-Mix Concrete (RMC), necessitating the involvement of multiple concrete plants [1]. Challenges include supply in crowded areas, setting up pump supply lines, determining the quantity of the last Transit Mixer (TM), and the need for advance planning. A delay at one site, for any reason, will alter the schedule of the entire delivery line. Additionally, regular repairs and maintenance of the plant, pump, and truck mixers during peak seasons add to the complexity, as does the coordination and timing of dispatch and the distance from the plant to the site [2].

The majority of ready-mix concrete orders require precise timing and the staggered operation of several trucks [3]. The use of a larger number of truck mixer vehicles with different drum volumes can result in unnecessary costs due to improper scheduling.

The decision-maker must determine how many vehicles of each type to use, given a mix of vehicle types with differing capacities and costs. They must also decide when to begin picking up the orders and when each order should be assigned to a vehicle, ensuring that the orders are optimized into an efficient delivery route. The operational decision-making process involves determining the minimum total cost, which includes fixed vehicle costs, variable routing costs, and penalty costs for violating time windows [4].

Constructors require an uninterrupted supply of concrete; therefore, the time between consecutive deliveries must be minimized as much as possible [5].

Since this process involves risk and is subject to elements of probability, stochastic planning and decision-making methods are most effective for determining the optimal parameters. This paper presents an original model developed in AnyLogic© software to address the problem of supplying multiple construction sites with ready-mix concrete from multiple plants in a stochastic environment [6].

2. METHODOLOGY AND INPUT PARAMETERS

In this paper, the problem of simultaneous concrete pouring for foundations at two construction sites supplied by the same concrete plant is analyzed. To address the issue of finding the optimal combination of mixers, a simulation model developed in [6] was applied. Based on data collected from the construction sites and the concrete plant, which serve as the input parameters (Figure 1), the process was simulated. The model was run 50 times for each fleet combination across different mixer combinations available at the considered concrete plant. Additionally, five extra combinations, which are not available at the considered concrete plant, were included to examine the potential benefits of using them.

The amount of concrete required for the counter slab on the first construction site is 325.00 m^3 of class C35/45 (MB45) concrete, out of a total of 2,597.00 m^3.

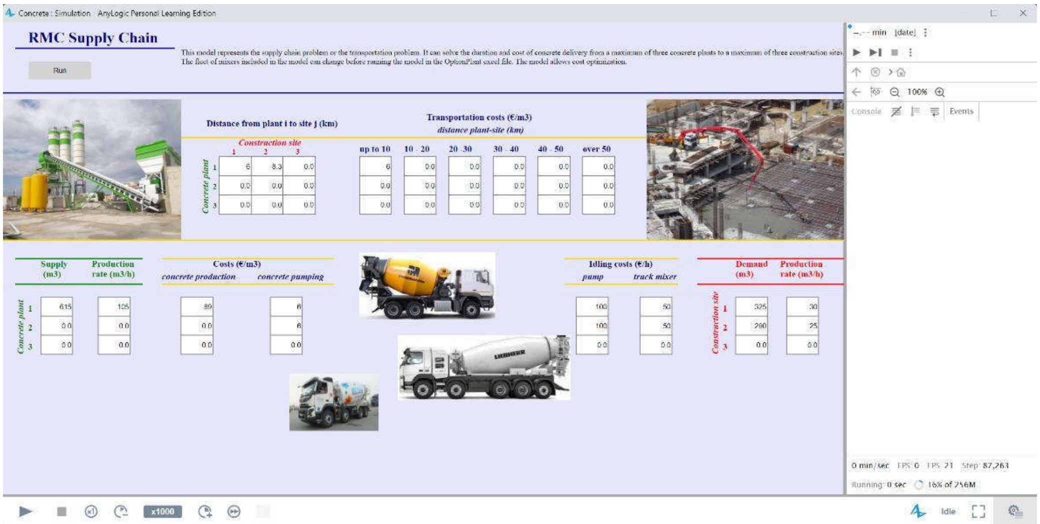

Figure 1. RMC delivery process simulation model: input parameters, author's own creation

The pouring of the counter slab on this project is carried out in 8 stages. The amount of concrete required for the foundations of the single columns at the second construction site is 290.00 m³ of the same concrete class. The first stage of the counter slab at construction site 1 and the foundation columns at construction site 2 are performed simultaneously, with concrete supply coming from the same concrete plant. The concrete plant has a capacity of 105 m³/h and operates with 2 mixers, each with a volume of 7 m³, 3 mixers with a volume of 9 m³, and 3 mixers with a volume of 11 m³. Concrete pumps at the construction sites achieve a performance of 30 m³/h at the first site and 25 m³/h at the second site.

The production cost of concrete for the specified class is 89 €/m³, while the concrete pouring charge is 6 €/m³. The transportation cost is 6 € per m³ for distances up to 10 km. The first construction site is 6 km away, and the second site is 8.3 km from the concrete plant. According to data from the concrete plant, additional charges for waiting time apply only if the waiting time exceeds 45 minutes. If the waiting time exceeds this threshold, each additional 45-minute interval is charged at the applicable rates: 100 € for the pump and 50 € for the truck mixers.

The concrete plant and construction sites are located in the city of Niš.

The idling costs in the model are calculated based on the input unit costs, as shown in equation (1):

$$\text{Penality cost} = \sum_{j=1}^{2}(Cost\ of\ truck\ mixer\ idling_j + Cost\ of\ pump\ idling_j) \quad (1)$$

And total cost of process as shown in equation (2):

$$\text{Total cost} = \sum_{i=1}^{1}\sum_{j=1}^{2}(Production\ cost_i + Transportation\ cost_{ij} + Penality\ cost_j + Pouring\ cost_j) \quad (2)$$

Where:

Penality $cost_j$ – cost of idling (truck mixer and pump) at site *j* (€),

Cost of truck $idling_j$ – cost of idling truck mixer at site *j* (€),

Cost of pump $idling_j$ – cost of idling pump at site *j* (€),

Total cost – total cost of concreting (€),
Production cost_i – cost of concrete production in plant *i* (€),
Transport cost_{ij} – cost of concrete transport from plant *i* to site *j* (€),
Pouring cost_j – cost of concreting with pump at site *j* (€)
n=1 – number of concrete plants
m=2 – number of construction site

Unit cost is calculated according equation (3):

$$\text{Unit cost} = \frac{Total\ cost}{Total\ amount\ of\ concrete} \left({}^{€}\!/_{m^3} \right) \tag{3}$$

The goal of applying the simulation model is to find a combination of mixers that minimizes waiting costs for both the pump and the mixers. During the simulation, the process was monitored using a process chart (Figure 2) and a 2D view (Figure 3).

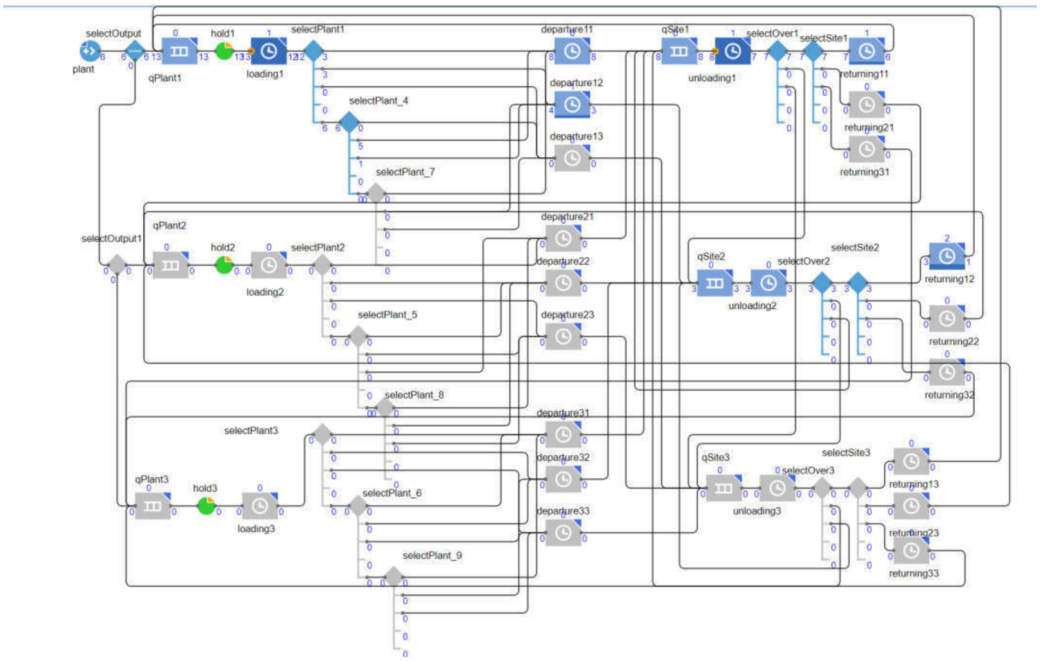

Figure 2. RMC delivery process simulation model: one concrete plant and two construction sites are used, author's own creation

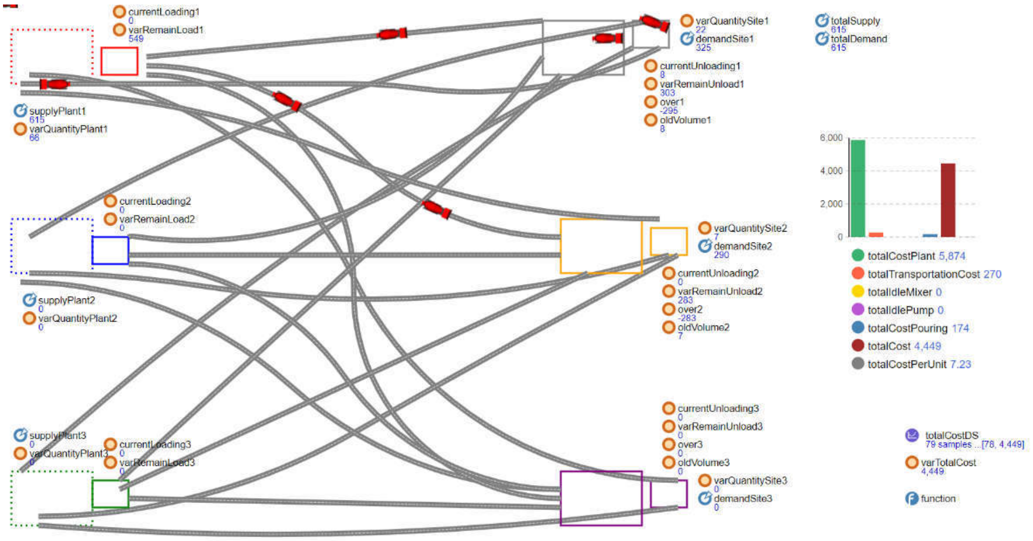

Figure 3. RMC delivery process simulation model: 2D view during simulation, author's own creation

3. RESULTS OF THE SIMULATION EXPERIMENT

All possible acceptable combinations of mixers available at the concrete plant were considered, totaling 18, along with an additional five combinations featuring mixer volumes that the concrete plant does not possess but were assumed to yield better results. A simulation experiment was conducted for each combination by running the simulation 50 times, followed by a statistical analysis.

Table 1 presents the considered scenarios for different truck mixer fleets with their total volumes. The last column of the table shows the process duration as a result of the simulation. The truck mixer fleets that were additionally included are shown in the shaded rows.

Table 1. Fleet combination and duration of process

Scenario	Number of truck mixer in fleet	Truck mixer combination	Total truck mixer volume (m^3)	Process duration (min)
1	3	1×7+1×9+1×11	27	1625
2	4	2×7+2×9	32	1363
3	4	2×7+1×9+1×11	34	1335
4	4	1×7+2×9+1×11	36	1318
5	4	1×7+1×9+2×11	38	1267
6	4	1×7+3×11	40	1222
7	4	2×9+2×11	40	1239
8	5	5×8	40	1141
9	5	2×7+3×9	41	1162
10	5	3×8+2×9	42	1133
11	5	2×7+2×9+1×11	43	1137

12	5	2×8+3×9	43	1124
13	5	5×9	45	1123
14	6	3×7+3×8	45	1070
15	5	2×7+1×9+2×11	45	1148
16	5	2×7+1×9+2×11	45	1116
17	5	2×7+3×11	47	1137
18	5	1×7+2×9+2×11	47	1109
19	6	2×7+3×9+1×11	52	1023
20	6	2×7+2×9+2×11	54	995
21	6	3×9+3×11	60	968
22	7	2×7+3×9+2×11	63	852
23	7	2×7+3×9+3×11	74	764

For each scenario, the idling cost, as well as the total and unit costs, are presented in Table 2. The transportation cost is 3,690 €, the pouring cost is 3,690 €, and the plant production cost is 54,735 €. These costs are constant for all fleet combinations and are excluded from the table.

Table 2. Cost for different fleet size

Scenario	Truck mixer idling cost (€)	Pump idling cost (€)	Total idling cost (€)	Total cost (€)	Unit cost (€/m^3)
1	0	1000	1000	63115	102.63
2	0	400	400	62515	101.65
3	0	600	600	62715	101.98
4	0	600	600	62715	101.98
5	0	300	300	62415	101.49
6	0	400	400	62,515	101.65
7	0	600	600	62715	101.98
8	0	100	100	62215	101.16
9	0	100	100	62215	101.16
10	0	100	100	62215	101.16
11	0	100	100	62215	101.16
12	0	100	100	62215	101.16
13	0	100	100	62215	101.16
14	0	0	0	62115	101.00
15	50	200	250	62365	101.41
16	150	300	450	62565	101.73
17	100	200	300	62415	101.49
18	100	100	200	62315	101.33
19	350	0	350	62465	101.57
20	400	0	400	62515	101.65
21	300	0	300	62415	101.49
22	200	0	200	62315	101.33
23	150	0	150	62265	101.24

Figures 4 and 5 show the cost structure for construction sites 1 and 2, respectively. It can be observed that the largest share of costs comes from concrete production (88%), while other costs are less significant. This cost structure chart represents the best mixer combination after the simulation was completed.

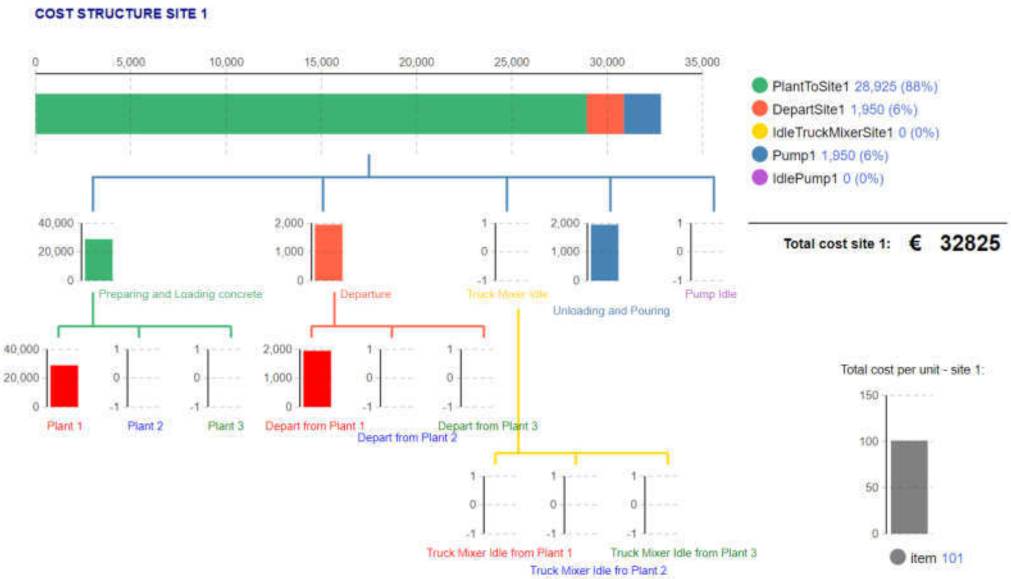

Figure 4. RMC delivery process simulation model: cost structure on site 1, author's own creation

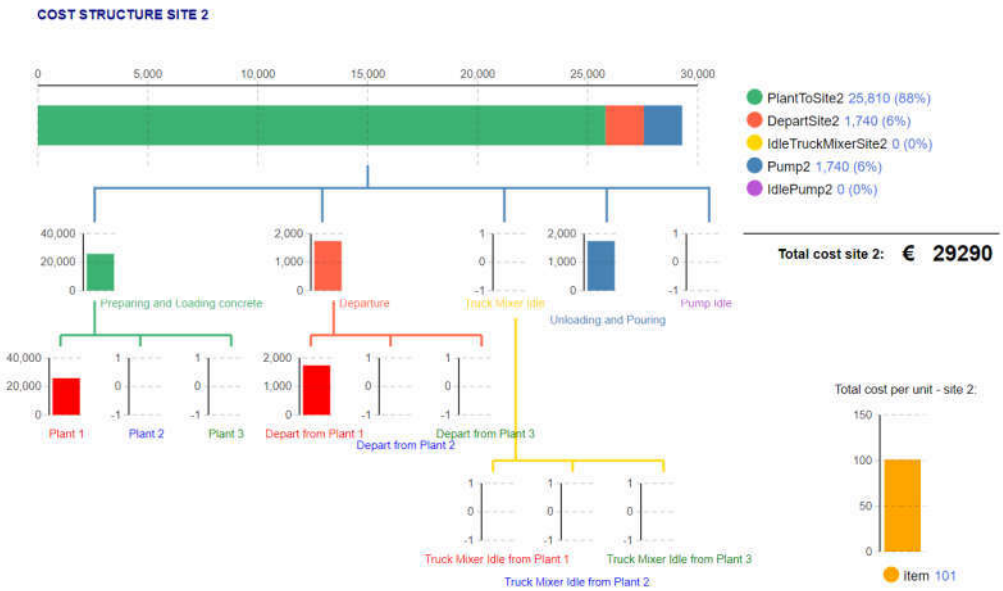

Figure 5. RMC delivery process simulation model: cost structure on site 2, author's own creation

Based on Tables 1 and 2, a graphical presentation of idling costs for different truck mixer fleets is shown in Figure 6, unit costs in Figure 7, and process duration in Figure 8. In each graph, the combinations that provide the best solutions are highlighted.

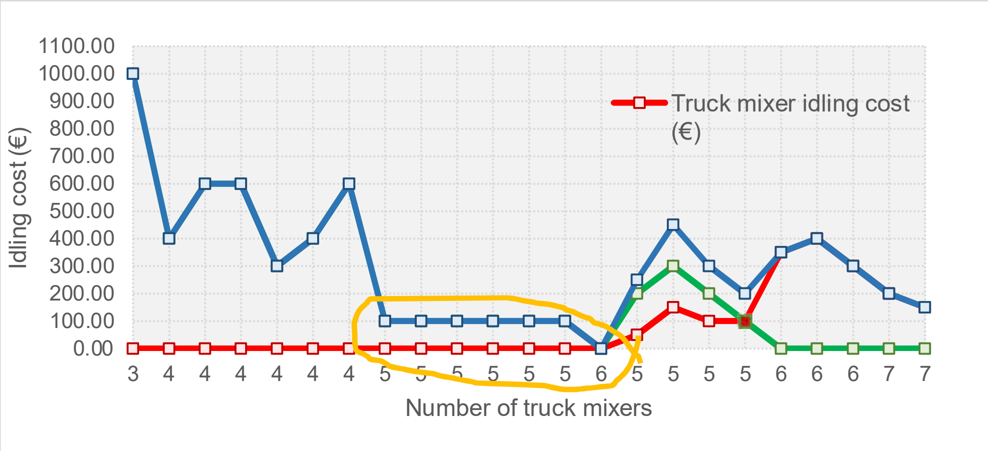

Figure 6. Idling cost for different fleet size, author's own creation

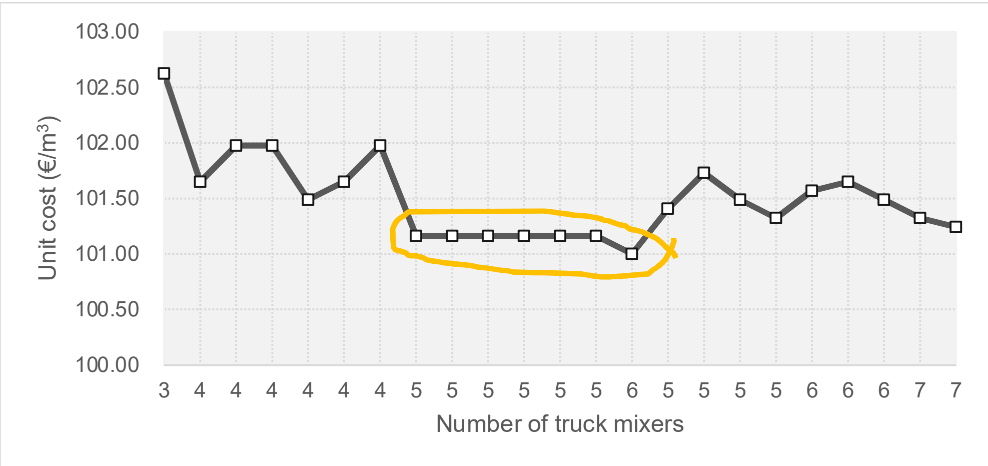

Figure 7. Unit cost for different fleet size, author's own creation

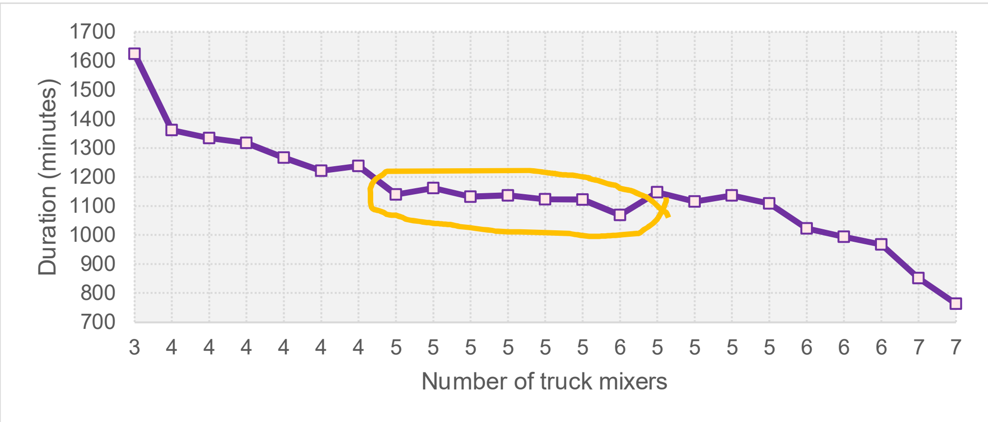

Figure 8. Duration for different fleet size, author's own creation

4. DISCUSSION OF THE RESULTS

The results of the simulation experiment, which varied the number of truck mixers, show that both the number and volume of truck mixers influence idling costs. Based on Figure 6, as the number of truck mixers increases, idling costs at the construction site rise, while a decrease in the number of truck mixers leads to higher pump idling costs. Lower total idling costs were observed in six combinations with five truck mixers and one combination with six truck mixers.

It can also be noted that with an increase in the number of truck mixers, the concreting duration decreases (Figure 8). Transportation costs, plant production costs, and pouring costs remain constant due to the fixed amount of concrete; they are calculated per unit of concrete.

The number of truck mixers affects the reduction in concreting duration, as increasing the number of truck mixers reduces concrete idling time, resulting in a shorter overall time. However, due to longer mixer unloading times, idling costs increase, and the quality of concrete may also be compromised.

Based on the analysis of the model in the considered case study, the optimal truck mixer scenario is scenario 14 (three mixers with a capacity of 7 m^3 and three mixers with a capacity of 9 m^3). By applying this truck mixer combination, waiting costs for truck mixers and the pump at the construction site are minimized, i.e., reduced to zero (Figure 6).

However, this scenario does not yield the shortest concreting duration (Figure 8). The shortest duration is achieved with scenario 23, but the total costs for this scenario amount to 62,265 €, which is 0.24% higher than the total costs for scenario 14 (62,115 €). It is difficult to achieve a minimum for all criteria (work duration and all costs). The criterion for optimal selection may vary.

Given that the objective is to find a truck mixer combination that minimizes idling costs for the considered case, this is best achieved by applying the combination from scenario 14. Simulation results show that selecting the right combination can significantly reduce waiting costs for both mixers and the pump, minimizing idling time and ensuring timely concrete placement without compromising its quality.

5. CONCLUSION

This paper presents the application of an original simulation model to determine the optimal combination of mixers for transporting concrete from a single concrete plant to two construction sites simultaneously. The results indicate significant cost savings when an adequate number of mixers with appropriate drum volumes are used for concrete transportation. These cost savings become even more substantial in large-scale concreting operations.

The simulation model is based on specific parameters derived from years of experience in monitoring concreting processes in the city of Niš. The model is user-friendly, allowing most interested parties to utilize it. By entering the number of mixers and their corresponding volumes into an Excel file before running the simulation, the fleet size is defined. Running the simulation with the given parameters (input data, characteristics, costs, etc.) generates a series of numerical and graphical results.

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