Optimizing Scheduling of Ready-Mixed Concrete Trucks from Multiple Plants Using Whale Optimization Algorithm

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Abstract. *Concrete plants face a challenging scheduling problem, as concrete from multiple plants must be efficiently delivered to various construction sites using different fleets of vehicles. This logistical challenge requires optimizing the dispatching schedules of ready-mixed concrete (RMC) plants. Using proprietary urban traffic data from Udornthani, a major city in Northeastern Thailand, this research aimed to identify the most suitable algorithm for optimizing the dispatching schedule under multi-plant and multi-site operations, using concrete waiting time as a key performance indicator. The study compared simulation results with current practices to analyze factors influencing dispatch efficiency, particularly focusing on trucks. Heuristic techniques, which offer quick solutions using simple rules, were employed. The Whale Optimization Algorithm (WOA) was selected for its high efficiency in solving complex problems. Results showed a significant reduction in median waiting times, from 17 minutes to zero, with a p-value < 0.001. WOA improved scheduling efficiency by reducing waiting times by 40-100%, outperforming the manual calculations performed by dispatch officers.*

Keywords:

Ready-mixed concrete (RMC), Scheduling efficiency, Dispatching schedule, Whale optimization algorithm (WOA), Concrete waiting time.

1. Introduction

Dispatching ready mixed concrete by trucks is an intensely complicated problem since it is the allocation of different resources mainly based on people skills and aiming to optimize benefits under time constraints. Therefore, consistency between plants and demand in concrete use of construction sites should be focused [1]. Two widely used problem solving techniques for scheduling of ready mixed concrete delivery consist exact methods and heuristic algorithms. Exact Method is a problem-solving method which the indicators are determined from the best maximum or minimum value. This used in solving various problems method can be used in solving problems with a few variables. One of the widely used techniques is Integer Linear Programming, whereas heuristic is used for solving problems that are complex with multiple variables. The heuristic method generally determines a near optimal solution. On the other hand, an exact optimum solution can get result from an exact method. In term of calculating time, the heuristic method usually takes short calculation time comparing to the exact method.

In the past, traffic volume was not dense, resulting in shorter travel times and allowing transportation services to cover a wider area. Consequently, concrete plants were typically set up as a single plant – A single machine platform is the most commonly used problem-solving pattern solution model, called RMC Dispatching Schedule Optimizer model [2], which is based on the concept of genetic algorithm (GA) as a solution technique. The model efficiency was assessed from the minimum total waiting time at construction sites. In addition, [3] deployed a simple heuristics algorithm – a solution technique to analyze the ready mixed concrete delivery pattern as the job-shop problem by assuming batch plants and construction sites as operation stations and sequencing jobs assigned to trucks based on Priority Rules technique which is a technique used to construct feasible project schedules with resource constraints. The Early Due Date (EDD) technique as Priority rule type was used to determine the minimum travel cost and the extension to increase efficiency in RMC delivery scheduling. Moreover, it was found in another study that the company could increase purchase orders [4] using combined techniques Early Due Date (EDD) and First Come First Serve (FCFS). Furthermore, the truck had been developed to be an Electric ready-mixed concrete vehicle (ERV). The study of differences between the behavior of delivering by the traditional truck and ERV had been proposed by scheduling optimization methodology for

ERV dispatching with Markov decision process (MDP) based on genetic algorithm [5].

Nowadays, multiple plant is the business management trend according to the growth of rapidly expanded cities. The multiple plants service is being popular, for there are plants distributed over the area to cover the service and thus create business advantages. As a result, the transportation plan has become too complicated for the employees' competency and experiences. Research has been carried out to propose the solution of the problem in various dimensions. Most agreed that the Heuristic Method is in general appropriate for RMC transportation. The selection of the solution techniques could be classified into 2 groups:

Group 1: Evolutionary Algorithms – This group prefers to use the Genetic Algorithm (GA), aiming similarly to others in reducing time for traveling and waiting time for concrete at the site. [6] constructed the Multi-Depot Vehicle Route Problem (MDVRP) Model of Genetic Algorithm (GA) with different objectives to increase the Simulated Annealing Algorithm (SA), which belongs to the Physics-based algorithms. This MDVRP was constructed based on genetic algorithm (GA) with multiple objectives for efficiency increase from constraints in the capacity of different trucks, with consideration on minimal carbon release, traveling time, and total cost of the vehicle. Likewise, [7] saw the importance in the planning of ready mixed concrete spreading for determining the transportation route. Therefore, performed an analysis on the factors affecting RMC spreading and built a simulating model according to GA to determine the most suitable spreading pattern, with an aim to reduce the total waiting time for the vehicle at the construction site. Later, attempts were made to construct a simulation model to set the RMC schedule based on fast messy genetic algorithms (fmGA) and simulation technique to find the schedule that allows total minimal waiting time of RMC vehicle distribution. [8] built a model for scheduling transportation with GA, aiming to reduce unloading time and waiting time that pause at each station. However, there is still no indication for the best method to solve the problems. From observation, GA has limitations in its use due to the multiple steps in the analytical process for the answer that may lead to errors, not to mention a longer time to find the answer. [9] compared GA and PSO and found the different properties in finding the answer. GA tends to take a longer time to reach the answer, and so many research studies have been conducted to find the advantages of other techniques in solving RMC problems.

Group 2: Swarm-based Algorithms – This group uses the technique that simulates the behavior of living things. Most research studies aimed at reducing fuel cost of the vehicle and the waiting time. [10] built Green Multi-Depot Vehicle Routing Problem (GMDVRP) with the Ant Colony Optimization Algorithms (ACO) to increase the solution efficiency under real urban traffic congestion. The parameters taken into account included road speed, vehicle weight and driving distance of the vehicle's route. The emphasis was on total minimal fuel cost. [11], with similar objectives, constructed the MDVRP model to solve the problem based on multiple-objective ACO with the vehicle capacity and constraints. The initial cost of carbon emission, traveling time and maximum income were taken into account. [16] and [17] developed models to optimize multiple objectives like waiting time, income, and carbon emissions. A comparison showed that Grey Wolf Optimizer and Dragonfly Algorithms (GWO & DA) outperformed GA, TS, Bee Colony Optimization (BCO), and Ant Lion Optimizer (ALO).

As previously mentioned, it is evident that no single best technique currently exists, and research is continuously being developed to address the RMC problem using new techniques. WOA represents an alternative heuristic technique with the advantage of flexibility in result application. It demonstrates computational efficiency, particularly in processing datasets of limited size. The effectiveness of the Whale Optimization Algorithm (WOA) was tested against several heuristic methods including Particle Swarm Optimization (PSO), Gravitational Search Algorithm (GSA), Dolphin Echolocation (DE), Fast Evolutionary Programming (FEP), and Evolution Strategy with Covariance Matrix Adaptation (CMA-ES). This was done using 29 mathematical optimization problems divided into four categories: 7 unimodal problems, 6 multimodal problems, 10 fixed-dimension multimodal problems, and 6 composite functions. Each algorithm was executed 30 times with different populations of 500 samples [12]. The results showed that WOA was the most effective or at least the second most effective in finding the optimal solutions, particularly excelling in faster solution searches and being suitable for models with smaller datasets. Additionally, WOA was applied to solve 6 engineering problems, demonstrating comparable performance. Therefore, WOA is a reliable and efficient new approach for solving complex problems, especially those involving limited data. While GA presents certain disadvantages, such as the need for large datasets and complex computational processes, WOA emerges as a more efficient alternative. As a reliable and effective method for solving complex problems, particularly those with limited data, WOA provides a compelling approach for the application of innovative techniques in addressing key challenges within the RMC industry

The objective of this research is to establish guidelines and criteria for scheduling production and delivery of ready-mixed concrete (RMC) from multiple plants, particularly for new or expanding branches with limited data for processing, using the Whale Optimization Algorithm. This new approach has not been previously applied in this context. The benefits include reducing the time required for research and improving solution efficiency under various constraints. For evaluating the research's effectiveness, the primary performance indicator selected is the reduction waiting time. Interviews with practitioners and delivery personnel highlighted the critical importance of minimizing waiting time to significantly reduce overtime costs.

2. Methodology

2.1 Variables and Limitation

The variable used in the analytical process to find the outcome was the limitation of data collection to be within the area of the ring-road around Udon Thani Province, Thailand. The retrospective data of transportation was obtained from GPS installed on each truck. The data collection timing was selected at 8:00 am to 17:00 pm. The field data of the factory, concrete trucks and the site front yard were collected including the production capacity of the concrete mixing machine, number of plants, truck capacity, number of trucks, number of unloading points, amount of concrete each day, etc. This, compiled with the previously analyzed data, the traveling time and concrete pouring time, entered the analysis step using Whale Method to find the appropriate scheduling. The overall data entering and the analytical process are illustrated in the following flowchart:

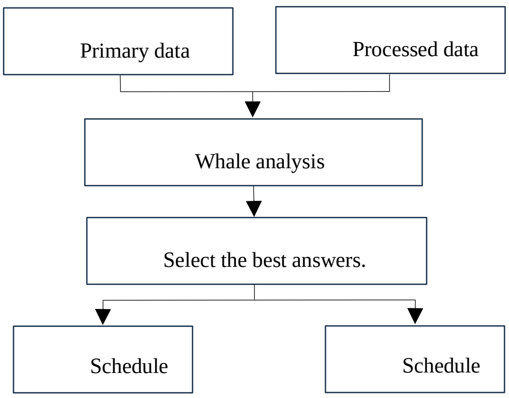

Fig. 1 The Analytical Process Data Flow Chart

The necessary data for the analysis and for finding the answers were classified in accordance with their sources. The data were divided into the 2 following groups:

Group 1: Primary data – the baseline data showing the specific characteristics of the factory, trucks and patterns of customers' orders.

Group 2: Processed data – the data obtained and prepared from the field work, which has been statistically analyzed. This included prediction of travel time, concrete pouring time at each site with its different structure and machinery.

Table 1 Primary data and processed data.

No.	Primary data	Processed data
1	truck capacity	travel time data
2	number of trucks	Pouring time
3	amount of concrete demand	
4	number of sites	
5	number of branches	
6	code of truck mixer	
7	appointed delivery time	
8	on-site construction positions	
9	regular work hours	
10	preparation time in the batch plant	

Precise and realistic answers for transportation scheduling necessitate the data of a precise ready mixed concrete transportation cycle. Thus, this study accented the variables of the two-way travel time and concrete pouring time, for these are the key components in transportation of ready mixed concrete that greatly affect the precise and realistic answers. The variable details are as follows:

2.1.1 Travel Time Data

Travel time data for shipping RMC from plants to customers refers to the data obtained from using a geographic information system (GIS) map within the study area. Data were collected during two times period of the day: from 8 AM to 9 AM and 3 AM to 6 PM and off-peak hours between 9 AM to 3 PM. In this study, the statistics method was designed to assist travel time prediction based on the distance from batch plants. As a result, once delivery sites were pinpointed in the travel time zones, estimated travel time from batch plants to delivery sites were then assessed. The tool was called a travel time prediction model by the application of ArcGIS 10.2 software by defining positions equal to travel time from the batch plant on a map at different times in order to build further connection intervals.

2.1.2 Concrete Pouring Timed Data.

Concrete pouring time data were obtained by gathering from the company data collection. The pouring time data were divided into two groups according to usage of machinery and industrial construction equipment during concrete pouring. The first group included, for example, cement conveyor tanks and cement carts. The second group used equipment, such as cranes, belts, and concrete pumping truck. Moreover, there are subgroups in both groups according to manning building structures.

2.2 Whale Optimization Algorithm (WOA)

This algorithm, developed by Mirjalili and Lewis [13], is based on the emulation of natural phenomena, specifically inspired by the foraging behavior of humpback whales. Humpback whales exhibit a distinctive hunting technique where they encircle their prey with a spiral bubble before rising to the surface to feed. The flowchart outlines the WOA process, starting with the initialization of the population size for each vector (Section 1). A random number [0,1] is generated; if greater than 0.5, the Bubble-net attacking method is used (Section 3). If less, the vector calculates $\bar{A}$. If $\bar{A} \geq 0.5$, Search for prey is applied (Section 4); otherwise, Encircling prey is used (Section 1). Customer waiting times are then calculated (Section 5), and the vector with the shortest time becomes the leader whale. The process repeats for 200 iterations, yielding the shortest waiting time in the final round.

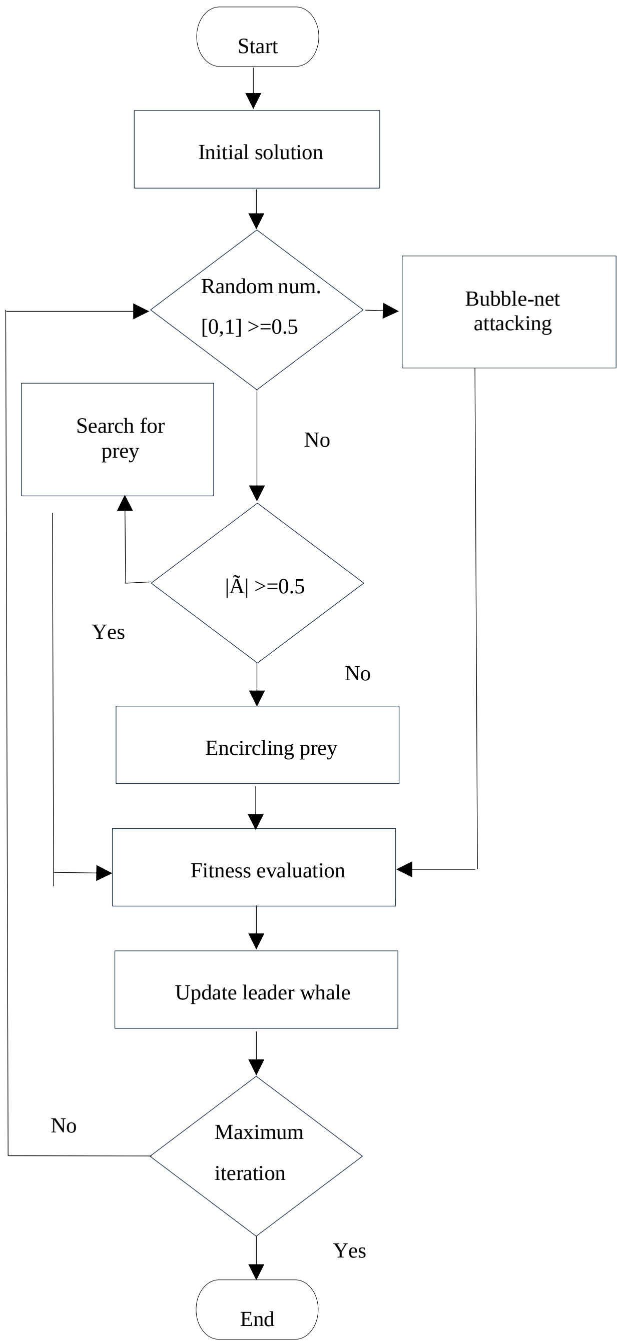

Fig. 2 WOA Flow chart

Table 2 Whale algorithm.

Algorithm 1. Whale optimization algorithm
Input: Data, WOA parameters (b), maximum iteration, NP
Output: Wt
Randomly generate a set of vectors i (i = 1…NP) (Section 1)
While maximum iteration not reached do
For i = 1 to NP
If Random number [0,1] >= 0.5 then
Update position by Bubble-net attacking method (Section 3)
Else If $\lvert\vec{A}\rvert$ >= 0.5 then
Update position by Search for prey (Section 4)
Else then
Update position by Encircling prey (Section 1)
End if
Fitness evaluation vectors i (Section 5)
If vectors i fitness < leader whale fitness then
Assign vectors i to leader whale
leader whale fitness = vectors i fitness
End if
End of while

2.2.1 Initial Solution.

The first step was to construct the initial population size of each vector. The customer's vector was of the same size as the number of customers, and the truck vector was equal to the number of trucks multiplied by the number of customers. At each position in the vector, there are the integers built by random number from 0 to 1. In Figure 3, there are 2 customers and 3 concrete trucks; thus, the customer's vector is 0.85-0.28, and the customer codes are 1-2. The truck vector of the first customer is 0.63-0.14-0.98, while the truck code is 1-2-3. The truck vector of the second customer is 0.15-0.89-0.45, while the truck code is 1-2-3. Thus, the size of this vector was equal to 8 positions:

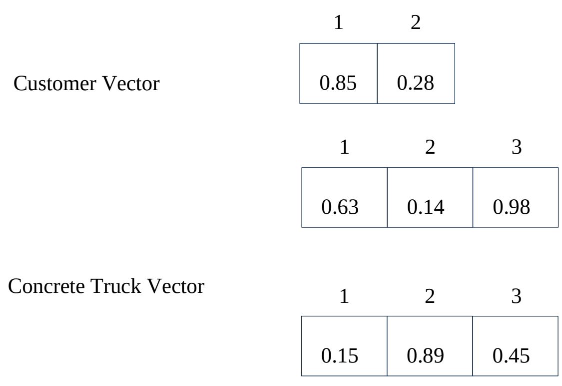

Fig. 3 Construction of initial population

2.2.2 Encircling Prey.

When humpback whales know the location of their prey and surround them, they determine that the best or the closest solution is the location of the target prey. The other solution then updates their position with reference to the prey's position. It is similar to humpback whales swarming around their prey, which behave like Eqs. (1) and (2**).**

$$\vec{X}\ (t+1) = \vec{X}_{best}\ (t) - \vec{A}\cdot\vec{D} \tag{1}$$

$$\vec{D} = \left|\vec{C}\cdot\vec{X}_{best}\ (t) - \vec{X}\ (t)\right| \tag{2}$$

$$\vec{A} = 2\ \vec{a}\cdot\vec{r} - \vec{a} \tag{3}$$

$$\vec{C} = 2\ \vec{r} \tag{4}$$

where $\vec{A}$ and $\vec{D}$ are coefficient vectors, t is current iteration, $\vec{X}$ is position vector, $\vec{X}_{best}$ is the position vector of the best current solution (leader whale), $\vec{r}$ is a random number between 0 and 1, and $\vec{a}$ is a variable that decreases linearly from 2 to 0 during the course of iteration.

2.2.3 Bubble-Net Attacking Method.

This behavior simulates the spiral motion of humpback whales surrounding prey and is represented by Eqs. (5) and (6)**.**

$$\vec{X}\ (t+1) = \overrightarrow{D'}\ e^{b\cdot l} \cos 2\pi l + \vec{X}_{best}\ (t) \tag{5}$$

$$\overrightarrow{D'} = |\vec{X}_{best}\ (t) - \vec{X}\ (t)| \tag{6}$$

where l is a random number from -1 to 1, b is a constant which defines the logarithmic shape.

2.2.4 Search for Prey.

To allow humpback whales to explore more, random searching for prey may be represented by Eqs. (7) and (8).

$$\vec{X}\ (t+1) = \vec{X}_{rand}\ (t) - \vec{A}\cdot\vec{D} \tag{7}$$

$$\vec{D} = \left|\vec{C}\cdot\ \vec{X}_{rand}\ (t) - \vec{X}\ (t)\right| \tag{8}$$

where $\vec{X}_{rand}$ is a random search agent from current population.

2.2.5 Fitness Evaluation.

From the example in Figure 1, the vector answers could be calculated by ordering from low to high, beginning from Customer's vector: 0.28-0.85. The customer order is 2-1. Next, the truck vectors are put in order. The truck vector of the first customer is 0.14-0.63-0.98. The order of the first customer's truck is 2-1-3. The truck vector of the second customer is 0.15-0.45-0.89 and the order of the truck of the second customer is 1-3-2. Allocation of the truck for the customers begins from the second customer. The first truck serves the first customer first, followed by the third truck and then the second truck, respectively. If the first truck is free, it can serve the second customer until completion. Next, the truck is allocated to the first customer, beginning from the second truck, followed by the first and the third truck. In case the truck is not free, or under service for other customer, the waiting time arises, which can be calculated from Equation 9.

$$Wt = \begin{cases} Vt - Ct & if\ Vt > Ct \\ 0 & if\ (otherwise) \end{cases} \tag{9}$$

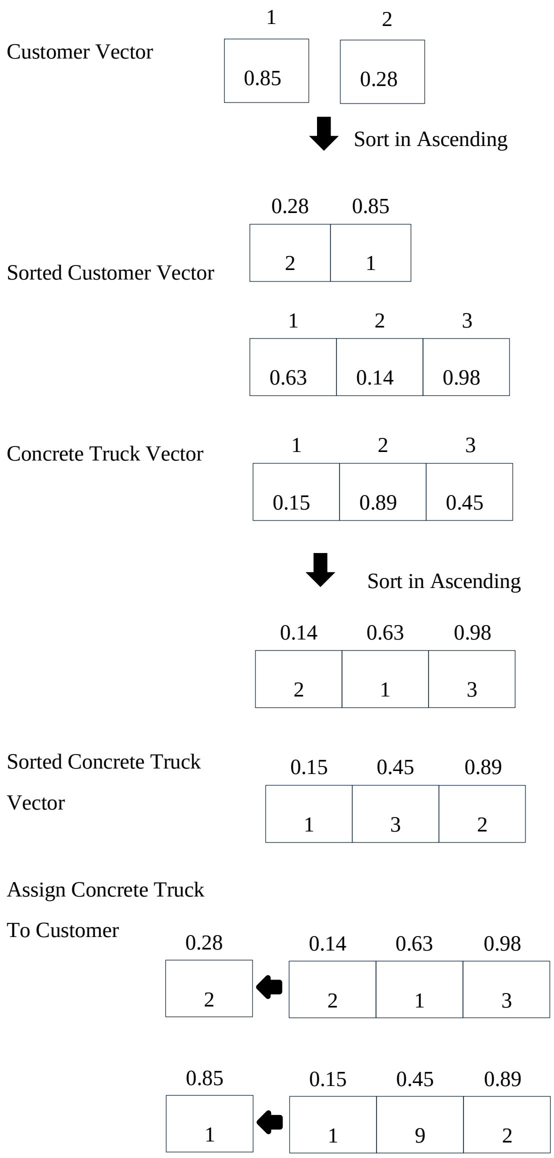

Fig. 4 Evaluation of vector answers

Where Wt is the customer's waiting time, Vt is the truck arrival time, and Ct is the time approved for pouring or the pouring finish time of the previous truck.

3. Results

The tool used to calculate the answers was program writing with Python on a 2.38 GHz PC, with 8 Gbytes of RAM. The parameters for the steps in finding the most appropriate answer as set by Whale was b = 0.5 and the whale = 100 whales. Calculation was done repeatedly for 10 rounds in iteration. The Python program is written based on Figure 2 (WOA flowchart) using the following fundamental modules: 1) Xlwt, for importing data from

Excel, 2) Operator, for sorting vectors by rank of value (ROV), 3) Copy, for duplicating data to avoid altering the original during calculations, and 4) Pandas, for importing Excel data form and the best parameter was found as shown in Table 3.

Table 3 Summary of processing results.

No.	No. of sites	No. of vehicle	Total waiting time Actual	WOA	Reduced (%)
1	9	14	748	0	100%
2	9	14	1382	829	40%
3	9	14	1483	736	50%
4	7	13	1100	607	45%
5	7	14	698	60	91%
6	7	15	712	0	100%
7	4	14	634	0	100%
8	8	16	1107	54	95%
9	8	15	335	0	100%
10	8	15	482	7	99%

Note: Actual = real data from the field (minutes), WOA = results from Whale Optimization Algorithm (minutes)

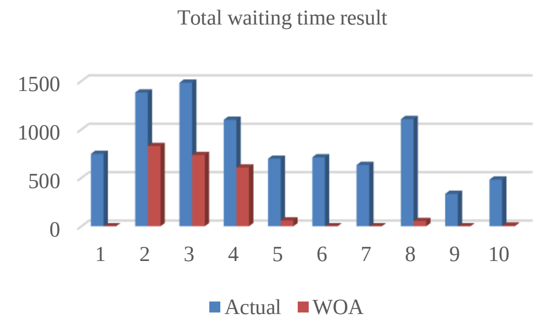

Fig. 5 Total waiting time result

The waiting times derived from WOA were analyzed and compared with the actual waiting times created by dispatch officers using the Wilcoxon signed-rank test in STATA. This analysis was conducted on a sample of 292 trips over a 10-day working period. Using the median as a representative measure, the comparison revealed a statistically significant difference between the median waiting times of the actual data and WOA, with a p-value < 0.001. This indicates that WOA significantly enhances scheduling efficiency by reducing waiting times more effectively than the calculations performed by dispatch officers.

Table 4 Statistic output.

Stats.	Actual	WOA
N	292	291
Mean	29.84932	7.762887
SD	32.01768	46.65422
Min	0	0
Max	171	576
Median	17	0
p25	9	0
p75	40	0
IQR	31	0
z	12.621	
p value	< 0.001	

In this research, we utilized a total of 10 iterations of processing and then selected the schedule with the lowest waiting time that sample as shown in Table 5, detailing customer names, vehicle numbers used for transportation, and the mixing time, measured in seconds, indicating the time taken for concrete pickup at the machinery. The scheduling process begins at 8 am, the start time of factory operations.

Table 5 Sample of truck delivery schedule.

Sites	Truck No.	Mixing time/trips
C1	[11, 2, 0, 8, 4, 1, 6, 9, 3, 10, 12, 13]	[13.0, 362.0, 388.0, 398.0, 408.0, 422.0, 434.0, 436.0, 438.0, 483.0, 485.0, 559.0]
C2	[0]	[37.0]
C3	[2, 12]	[58.0, 48.0]
C4	[10, 13, 4, 8, 7, 9, 2, 12, 1]	[55.0, 85.0, 145.0, 175.0, 205.0, 235.0, 265.0, 265.0, 325.0]
C5	[1, 7, 6, 0, 9, 3, 5]	[112.0, 121.0, 130.0, 139.0, 148.0, 157.0, 166.0]
C6	[0, 8, 4, 10, 9]	[291.0, 301.0, 311.0, 291.0, 332.0]
C7	[13, 3, 6]	[242.0, 239.0, 267.0]
C8	[11, 5, 7]	[295.0, 315.0, 365.0]
C9	[13]	[349.0]

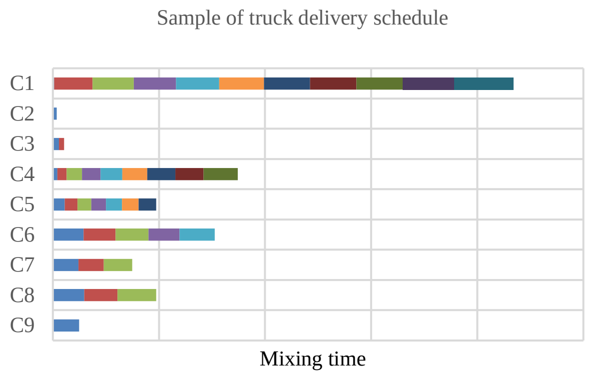

Fig. 6 Daily production schedule

4. Discussion

It was found that Whale Algorithm was able to solve the problems in scheduling production and transportation of ready mixed concrete from multi-plants. It is able to significantly solve the complex prioritization of work of the employees. The indicator, i.e., the total waiting time at the site was found to reduce, when compared to the research work using the same indicator. [14] used GA to solve the problem of multi-plants transportation to reduce the paused pouring time and the waiting time at each station. Whale Algorithm has an advantage over other methods because it can generate multiple delivery plans under the total least waiting time of similar value. This allows for selecting a delivery plan that fits the specific needs of each situation such as the readiness of trucks that is not equal, the drivers whose skills and knowledge of the route are not the same, demonstrating its flexibility in use. Other techniques offer only one answer and so are less flexible when under real use. Moreover, the little time in calculation is the important reason behind using it in the business where the decision-making time to file customers' order is very important.

5. Conclusion

This research proposes a novel approach to address the scheduling and dispatching problems in ready-mix concrete production for multiple plants, particularly for newly established or expanding branches that have limited data for processing, within urban areas with heavy traffic congestion. The complexity of this problem exceeds the capability of human expertise to solve efficiently. The solution employs the Whale Optimization Algorithm (WOA), with the total waiting time at construction sites for truck deliveries used as the performance indicator. When compared with 10 actual scheduling examples using the statistical method Wilcoxon signed-rank test in STATA program, the results demonstrate a significant reduction in total waiting time compared to schedules created by skilled employees. The key innovation of this research lies in the selection of a modern problem-solving technique that can simultaneously process transportation scheduling and order allocation. This method is particularly effective for scenarios with limited data, making it suitable for new branch expansions in the ready-mix concrete business in areas with scarce information. The study's realism in comparing scheduling performance using actual field data is also a notable strength. However, the research has certain limitations: all truck capacities are assumed to be equal, trucks cannot be interchanged between production branches, and both concrete mixers and trucks are presumed to be continuously available. The results cannot be directly implemented because the program processes the delivery schedules of all branches simultaneously, shows the relationship between truck numbers and sites names. Therefore, users need to create sub-schedules based on the groups of trucks assigned to each branch. This research supports a heuristic approach by establishing guidelines for using the Whale Optimization Algorithm (WOA) to solve ready-mixed concrete transportation scheduling problems. For practical application in business, it is recommended to consider conduct a study, collect data, and analyze the actual concrete pouring times for each type of job to create an accurate database for calculating truck operating times. For future research, an accurate travel time database should be used in processing by developing a model to predict the travel time of concrete trucks specifically for service areas [15] predictive model for concrete truck travel time in urban areas should be created by analyzing real data using statistical methods and updating it to reflect changes in community conditions. This will ensure that delivery schedules remain accurate and up to date at all times.

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