International Journal of GEOMATE, Aug., 2020, Vol.19, Issue 72, pp. 88 - 95
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2020.72.9355
Special Issue on Science, Engineering and Environment

MULTIPLE PLANTS MULTIPLE SITES READY MIXED CONCRETE PLANNING USING IMPROVED ANT COLONY OPTIMIZATION

*Sakchai Srichandum[1] and Saravuth Pothiya[2]

[1]Faculty of Technical Education Rajamangala University of Technology Isan Khonkaen Campus, Khon Kaen, Thailand; [2]Expro Overseas Inc., Bangkok, Thailand

*Corresponding Author, Received: 19 Sep. 2019, Revised: 25 Nov. 2019, Accepted: 27 Feb. 2020

ABSTRACT: The purposes of this paper were to optimize the schedule of dispatching Ready Mixed Concrete (RMC) trucks with multiple plants multiple construction sites (MPMS) in order to minimize the transportation cost under various construction constraints i.e., limited traveling, casting time, number of truck, allowable weight for transfer and distance from multiple RMC Batch plants to different construction sites using Improved Ant Colony Optimization (IACO). The IACO introduces some additional techniques for improvement of search processes such as neighborhood search and re-initializations. The procedures are: firstly, develop the mathematical model of MPMS for RMC truck schedule dispatching in term of an optimization problem. After that, use the IACO to solve the optimal schedule dispatching of RMC with MPMS and truck operation. To demonstrate the effectiveness of IACO, two different problems are tested, and its results are compared with those obtained by conventional approaches such as the Genetic Algorithm (GA) and the conventional Ant Colony Optimization (ACO). Test results show that the IACO approach is relatively capable of delivering a higher quality solution, faster computation time, and efficiency schedule dispatch compared to traditional GA and ACO approaches.

Keywords: Ant colony optimization, Heuristic algorithm, Optimization problem, Ready-mixed concrete, Truck dispatching

1. INTRODUCTION

Recently, the construction industry is growing and evolving in terms of the construction process, methods, and materials. Ready-mixed concrete (RMC) is one of the most popular building materials in the construction industry in modern construction because of its many advantages. The benefits of RMC are convenient to manage, reduce labor costs, and offer many types of concrete for many construction sites and high standards [1]. Unfortunately, RMC delivery has many limitations due to the rapid solidification of the mixed concrete. The dispatching of RMC trucks will need to be scheduled for many of the requested sites over a continuously limited transport and casting time, the number of trucks, the permitted transfer weight, and the distance from the RMC batch to many sites [2,3].

Delivering RMC effectively to construction sites is an essential issue for the batch plant manager. The master needs to consider both timeliness and flexibility to develop an effective schedule for delivery of RMC trucks that balances on-site and batch operations. The current dispatching schedule depends mainly on the experience and preferences of the sender. A systematic approach to addressing this problem has rarely been used due to the complexity and uncertainty of the dispatching process. Therefore, it is necessary to develop a systematic model that optimizes the delivery schedule of RMC trucks as a combined optimization problem [4-6].

Previously, many studies in literature reviews devoted to RMC production or truck delivery schedules based on optimization problems and solved the problem with heuristic algorithms such as the Genetic Algorithm (GA) [7], Particle Swarm Optimization (PSO) [8], Hybrid heuristic algorithms [9] and the Bees Algorithm (BA) [10].

In practice, RMC companies provide several plants to supply RMC with different types of concrete in different zones to meet more customer demand. This affects the dispatching of RMC as the model adds complexity.

This paper proposes a new mathematical model for the RMC dispatching problem for multiple plants to multiple locations (MPMS) with three concrete types (floor, column, and beam) to minimize the total fuel cost of RMC trucks, which are considered the shortest route and minimum waiting time of RMC trucks on construction sites.

Besides, the development of Ant Colony Optimization (ACO) called “Improved Ant Colony Optimization (IACO)” is purposed to solve this problem.

IACO can provide a better solution compared to traditional approaches such as GA and ACO.

2. PROBLEM FORMULATION

2.1 RMC Delivery Process

The RMC delivery process consists of five major components: material production, production loading, truck transport, placement, and truck return, as shown in Figure 1. This process must be carefully planned to avoid the early formation of concrete. Therefore, RMC's production schedule and delivery of trucks do not affect delivery efficiency but also operational costs. For the truck dispatching, there are many factors need to be considered as follows.

2.2 RMC dispatching Formulation

In this section, the RMC's dispatching formulation for multiple plants and multiple sites can be explained in three parts: the dispatching model, the feasible solution, and the fitness function.

2.1.1 Dispatching Model

The dispatching model consists of four components, which are input parameters, decision variables, constraints, and system output, as shown in Fig 2.

Input parameters: these parameters include the required concrete type, number of RMC deliveries, traveling time, casting time, mixing time, and allowable buffer duration. The allowable bumper duration represents the maximum duration that a construction site can wait for an RMC truck to arrive.

Decision variable: the order in which each RMC truck is targeted from different plants to different sites is defined as a “dispatching sequence”. Therefore, the order of delivery of RMC trucks is considered as a decision variable.

Constraints: The requirement, which is continuously being dumped, limits the amount of time the construction site waits for RMC trucks to arrive, and is shorter than the permitted bumper duration. This constraint applies to the removal of infeasible dispatching schedules.

System output: The goal of developing an efficient delivery schedule for RMC trucks is to minimize the total fuel costs of RMC trucks without interrupting concrete casting.

2.1.2 Feasible Solution

The purpose of this study is to find the most efficient and effective sequence of RMC dispatching delivery for multiple plants and construction sites. Therefore, the feasible solutions are the sequence of RMC dispatching delivery.

2.1.3 Fitness Function

To evaluate the fitness function of the RMC MPMS problem, we first define the indices, parameters, and decision variables as follows.

Indices

i : Index of RMC plant, $i \in \{1, p\}$.

j : Index of the construction site, $j \in \{1, m\}$.

t : Index of RMC truck dispatching sequence from plant i to construction site j $t \in \{1, n\}$.

Variables

p : Number of RMC plants.

m : Number of construction sites that request RMC deliveries.

n : Total number of the RMC delivery round for all construction sites, $n = \sum_{j=1}^{m} k_j$.

NT : Total number of the RMC trucks that all batch plant owns.

D_{ij} : Distance RMC from plant i to construction site j (km).

SCT_j : Start casting time of construction site j .

R_j : Required quantity of the RMC by construction sites j (m^3).

PT_j : Placement type at a construction site j . RMC recipe for each type requires pouring time. The pouring time for the floor, beam, and column are 4, 7, and 9 min/ m^3 , respectively.

ABD_j : Allowable buffer duration of a construction site j (min).

ABT_j : Allowable buffer time of RMC truck (min).

MD_t : Mixed duration of RMC for each placement type for RMC dispatching sequence t , which is 2 min/ m^3 .

CD_t : Casting Duration at construction for each placement type by RMC dispatching sequence t (min), where $CD_t = R_t \times PT_t$.

k_j : Required RMC truck deliveries for the construction site j .

TDG_{ij} : Traveling time from the plant to the construction site j (min).

TDB_{ji} : Returning time from construction site j to the plant (min).

FDT_i : First departing time of RMC truck from a plant i .

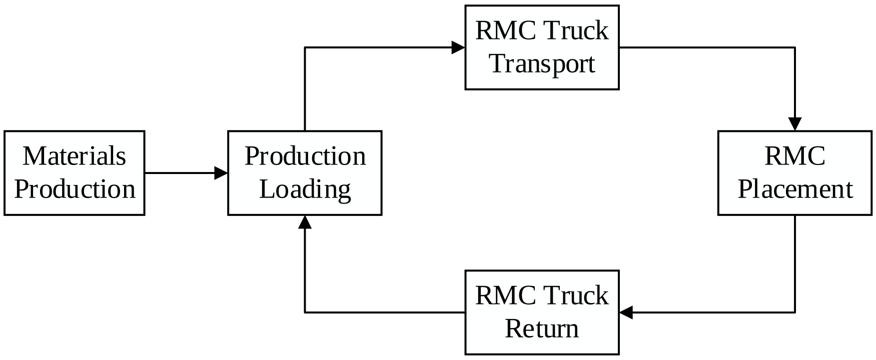

Fig.1 RMC delivery process

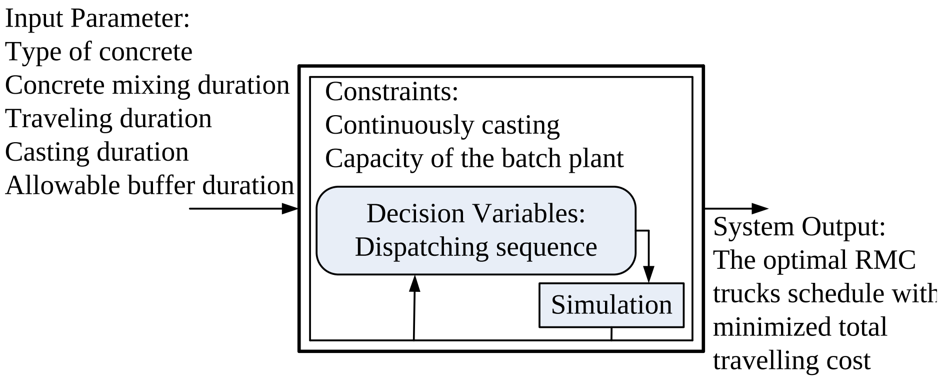

Fig.2 RMC dispatching model

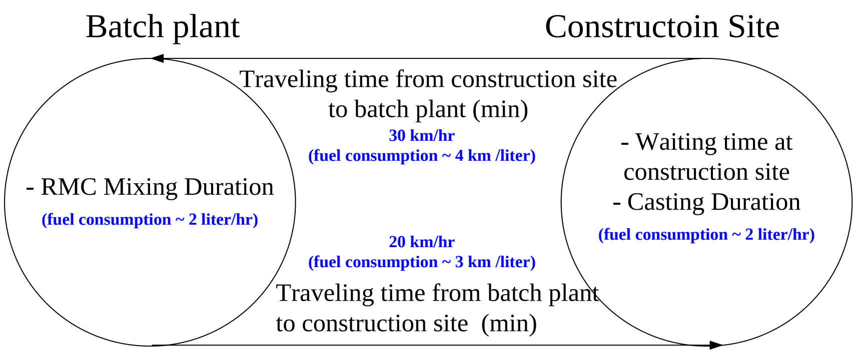

Fig. 3 RMC delivery process and vital variables.

DT_{it} : Departing time of RMC truck round t from plant i .

SDT_{it} : Simulated departing time of t dispatched truck from a plant i .

TAC_{jt} : Arrival time of dispatched truck t at the construction site j .

PTF_{jt} : Start pouring time of the construction j t if dispatched truck arrived at the construction site j .

$WC_{jt} > 0$: Waiting Duration that dispatched RMC truck t waits at the construction site j .

$WC_{jt} < 0$: Waiting Duration that construction site j waits for the arrival of the dispatched RMC truck t .

LT_{jt} : Leaving time of t dispatched truck from a construction site j .

ATB_{it} : Arrived Time of the t dispatched travels back to the batch plant i .

TFC_{ij} : Total fuel cost of RMC truck t for dispatching to a construction site j .

The RMC MPMS problem aims to minimize fuel costs from multiple plants to multiple construction sites. This duration covers the loading and mixing of concrete into the RMC truck mixer, the transport from the batch plant to the construction site, the waiting time at the construction site, the duration of the casting and the journey back to the batch plant. The process flow of the RMC trucks is shown in Fig. 3. Essential parameters for fitness function are transportation speed and fuel consumption in each activity.

The total fuel cost per minute for RMC trucks for each operation consists of two parts. In this paper, we use a fixed fuel cost of 1.33 $/liter. It refers to fuel costs in Thailand.

First of all, during the transport of RMC truck: According to historical data, the average fuel consumption of a RMC truck leaving a batch plant to a construction site is approximately 3 km/liter, while the average traveling speed at 20 km/hr. Thus, fuel cost per minute of TDB_{ji} which is 0.1481 $/min. Meanwhile, the average fuel consumption of a RMC truck returning from construction site to batch plant is 4 km/liter at 30 km/hr. Hence, the fuel cost per minute TDB_{ji} is 0.1667 $/min. In this section, the total fuel cost of RMC truck can be minimized by selecting the shortest route from plant i to a construction site j.

Also, the distance (km) from the batch plant to the construction site can be found using Google map. In this study, the average speed of a RMC truck from a batch plant to a construction site is 20 km/hr. Therefore, traveling duration from t batch plant to construction site j (in a minute) TDG_{ij} can be determined in Equation (1). Meanwhile, the average speed of RMC truck from construction site back to batch plant is 30 km/hr. Thus, traveling duration from construction site j to batch plant (in a minute), TDB_{ji} can be calculated in Equation (2).

$$TDG_{ij} = \frac{D_{ij} \times 60}{20} \quad (1)$$

$$TDB_{ji} = \frac{D_{ji} \times 60}{30} \quad (2)$$

Secondary, when the RMC truck parks while mixing at the plant: casting during construction and waiting to be dumped, assume an average fuel consumption of 2 km/liter or 0.0444 $/min. This fuel cost could be reduced by minimizing waiting time on all construction sites, as mixing and casting times are fixed.

Three truck operations have an impact on the total fuel cost. They are 1) concrete loading and mixing at the plant (MD_t), 2) waiting time of RMC truck (WC_{jt}), and 3) Casting time of RMC at the construction site (CD_t). These operations occur when the truck is parked while the agitator is moving. When the truck is stationary, the average fuel consumption is about 2 liters/hr. Also, the fuel cost is 1.33 $/liter. Therefore, the fuel cost per minute MD_t WC_{jt} CD_t is 0.0444 $/min. As mentioned earlier, the ideal delivery of RMC trucks is timely. Because mixing and casting times are necessary, the overall fuel cost of RMC trucks can be minimized by selecting the RMC truck sequence that has a minimum waiting time at all construction sites and the summation of all WC_{jt}.

In summary, the fitness function is equal to the summation of fuel cost per minute multiplied by total duration for each operation of RMC trucks by Equation (3).

$$\begin{aligned} TC = 0.15 \times \sum_{t=1}^{n} TDG_{ij}^{t} + 0.17 \times \sum_{t=1}^{n} TDB_{ji}^{t} + \\ 0.04 \times \left(\sum_{t=1}^{n} WC_{jt} + \sum_{t=1}^{n} MD_t + \sum_{t=1}^{n} CD_t \right) \end{aligned} \quad (3)$$

3. ANT COLONY OPTIMIZATION

Marco Dorigo introduced the Ants System (AS), inspired by the collective behavior of a real ant colony, in his Ph.D. thesis in 1992, and further research by Dorigo et al. [11]. The features of the artificial ant colony include positive feedback, distributed computing, and the use of constructive greedy heuristics. Positive feedback means finding good solutions quickly, decentralized computing avoids premature convergence, and greedy heuristics help to find acceptable solutions early in the application process.

A significant weakness of the conventional ACO algorithm is stoppage, which means that other ants take the same position. If this problem occurs, the algorithm may be trapped locally at the optimum point [5]. To alleviate the stagnation problem with conventional ACO algorithms, two enhancement procedures are applied to improve the ant colony optimization method to ensure ants diversity. This approach is called improved ant colony optimization (IACO). Additional procedures include a specific improvement algorithm (called neighborhood search) and re-initializations.

During the search process, the search process gets a repeated solution for a long time. This means that the process could not find better solutions or escape with this solution. So this solution can be either local or global solution. If the global solution is known, the search process will be interrupted because it has received the best solution. On the other hand, a global solution is unknown. The algorithm assumes that this solution is a local solution. If the process is a blow to the local solution for a long time, the re-initialization process will be used. This mechanism helps the process continue its search and find better solutions. IACO flow chart, as shown in Fig. 4.

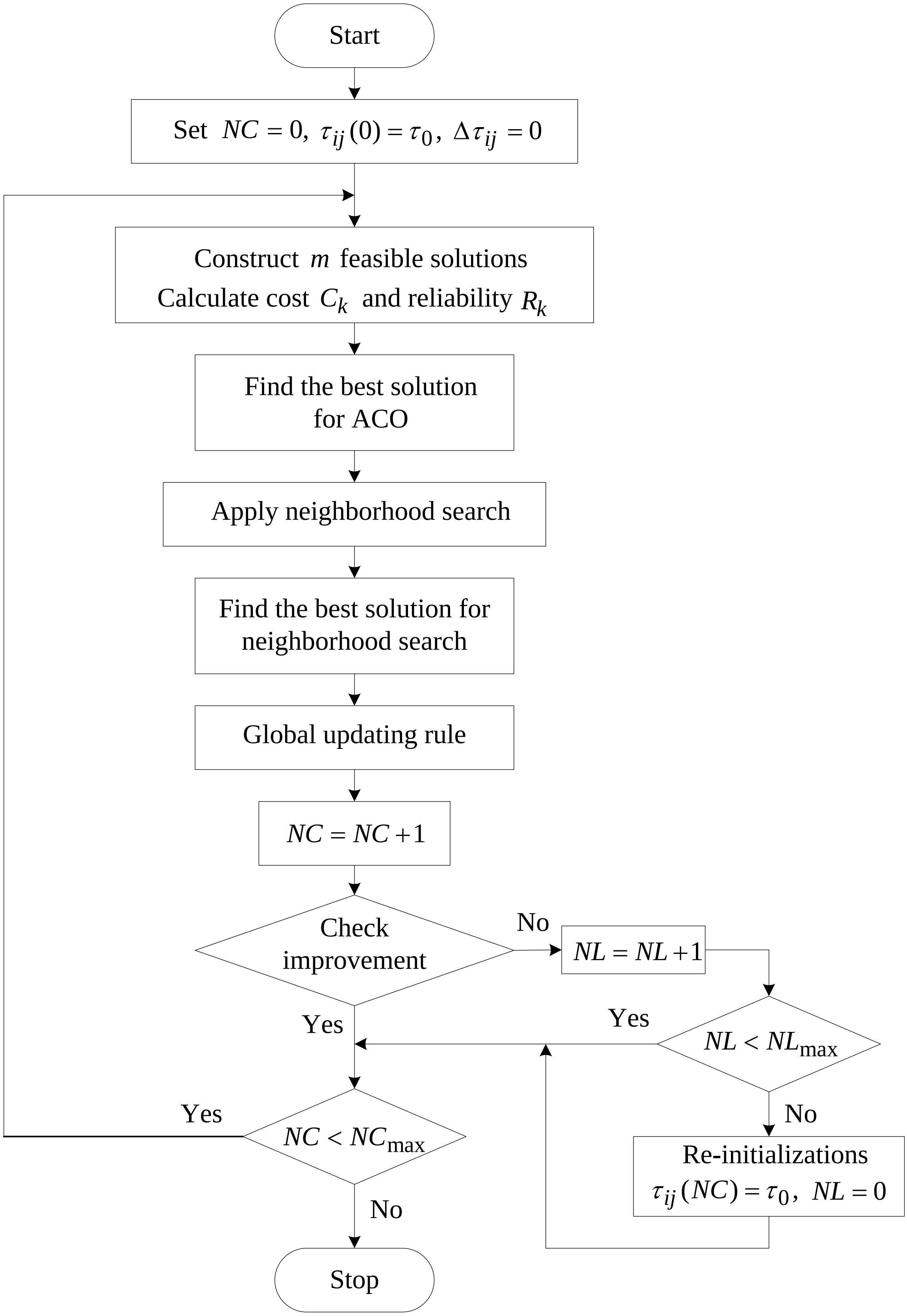

Fig. 4 Flow chart of IACO algorithm

4. NUMERICAL SIMULATION AND RESULTS

Two case studies are proposed to evaluate the feasibility of the proposed IACO and the comparison methods, ACO and GA. All methods are performed 30 trials with the same fitness function and individual definition to compare their resolution quality, convergence capability, and computational efficiency. The software was implemented using MatLab® languages on an Intel® Core i5-5200u, 2.20GHz notebook and 4GB RAM under Windows 8.

For case studies, RMC Company has two batch plants, the first and the second batch plants have three and two RMC trucks, respectively. The information about dispatching operation is listed in Table 1.

As the infeasible solutions are mentioned, there are, 1.03×10^{7} and 1.96×10^{12} different dispatching schedules for case studies 1 and 2. After solving the case studies with 30 trials, the best solutions from all the case studies are shown in Table 2. The $Plant\ ID$ and $Site\ ID$ are determined RMC trucks dispatching sequence. For example, in case study 1, the RMC truck starts dispatching from plant 2 in the first sequence of $Plant\ ID$ to construction site 2 in the first sequence of $Site\ ID$ for the first round. Next, RMC truck needs to dispatch from plant 2 to construction site three and follow this sequence until a final total of 8 dispatching orders.

For all case studies, the IACO can obtain minimum fuel costs without interruption. In addition, the results of Case Study 1 and 2 are also validated by exhaustively enumerating all possible solutions. Interruption of concrete pouring occurs when the construction site waits for the RMC truck to arrive longer than the permitted buffer duration. As shown in Table 2, the best interruption time is zero, which means without interrupting concrete pouring.

4.1 Comparison of Three algorithms

4.1.1 Solution Quality

The results of the IACO method are compared with those obtained by ACO and GA with respect to maximum, average, minimum cost, standard deviation, and average computation time, as shown in Table 3. Apparently, all methods have succeeded in finding a satisfactory solution in all case studies. In order to demonstrate the effectiveness of the IACO method, the outline distribution of the best solutions for each trial will be considered. Fig. 5 and 6 show the outline distribution of the best solution for each study. Almost all of the optimal costs obtained by the IACO method are lower costs and variation in both case studies. This ensures that the IACO method has a better solution quality.

Table 1 Information for RMC trucks scheduling for all problems.

Case Study	Site	SCT_j	R_j (m^3)	PT_j	D_{ij} $i=1$	D_{ij} $i=2$	ABD_j	ABT_j
1	1	8:00	10	*Floor*	10	15	45	45
	2	8:00	14	*Beam*	8	10	45	45
	3	8:00	15	*Post*	15	12	45	45
2	1	8:00	8	*Floor*	10	15	45	45
	2	8:00	9	*Beam*	8	10	45	45
	3	8:00	10	*Post*	15	12	45	45
	4	8:30	12	*Beam*	8	12	45	45
	5	8:30	15	*Post*	11	14	45	45

Maximum load of trucks 5 (m^3) and the duration of mixing concrete (MD) is 2

Table 2 Optimal solution by all methods of case studies.

Case Study	Optimal Dispatching Sequence: *Plant ID*	Optimal Dispatching Sequence: *Site ID*	Min Fuel Cost ($)	Best Interruption Time (minutes)
1	[2 2 1 1 1 1 1 2]	[2 3 1 1 3 2 2 3]	83.77	0
2	[1 1 2 1 2 2 1 1 1 1]	[1 1 3 5 2 3 2 4 4 5]	98.81	0

Table 3 Performance comparison for both case studies.

Case Study	*Algorithm*	*Min cost ($)*	*Avg cost ($)*	*Max cost ($)*	*S.D.*	*Avg CPU time(sec)*	*%Get Optimum*
	GA	83.77	83.77	83.77	0	6.8	100
1	ACO	83.77	83.77	83.77	0	30.06	100
	IACO	83.77	83.77	83.77	0	3.94	100
	GA	98.81	99.98	102.70	1.39	445.91	53.33
2	ACO	98.81	99.10	100.41	0.54	293.15	76.67
	IACO	98.81	98.81	98.81	0	78.08	100

4.1.2 Computation Efficiency

Table 3 shows the average computation time for the 30 trials for all methods. The computational time was set to a running time of 500 seconds per trial. The computational time for the IACO method is the lowest compared to other methods. Besides, the convergence characteristics of IACO, ACO, and GA are shown in Fig. 7. The convergence of IACO to the optimal solution is faster than other methods.

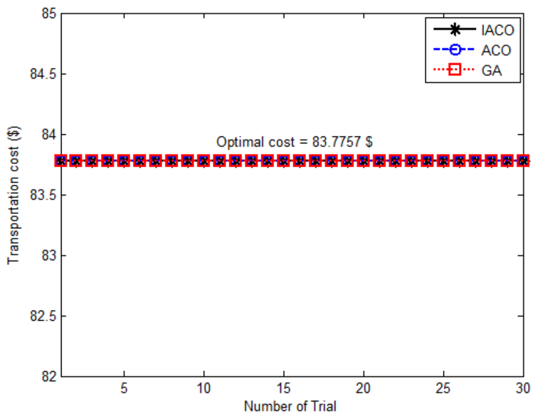

Fig. 5 Distribution of fitness values of all methods of case study 1.

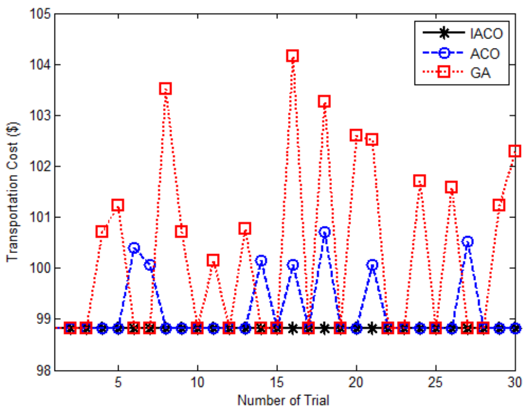

Fig. 6 Distribution of fitness values of all methods of case study 2.

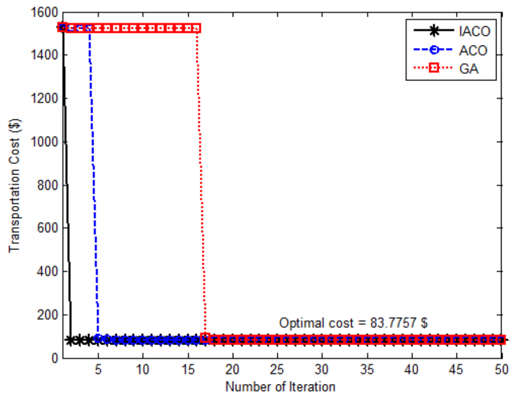

Fig. 7 Convergent graph of fitness values of case study 1.

5. CONCLUSION

This study presents a systematic approach to modeling the process of dispatching RMC trucks for multiple plants and multiple sites. The results show that by applying the proposed RMC dispatching model to IACO and simulation technique, the batch plant manager can quickly generate an efficient and flexible delivery schedule for RMC trucks, which not only improves the batch plant operation but also enhances the RMC batch plant service.

6. REFERENCES

[1] Sakchai S. and Thammasak R., Production Scheduling for Dispatching Ready Mixed Concrete Trucks using Bee Colony Optimization. American Journal of Engineering and Applied Sciences, Vol. 3, Issue 1, 2010, pp.7-14.

[2] Chung-Wei F., Tao-Ming C. and Hsien-Tang W., Optimizing the Schedule of Dispatching RMC Trucks through Genetic Algorithms. Automation in Construction, Vol. 13, Issue 3, 2004, pp. 327-340.

[3] Belles A., Coves AM. and Santos MA., A Multi-Start Algorithm for Solving Ready Mix Concrete Production and Delivery Scheduling Problem (RMCPDSP). Int. Conf. on Industrial

Engineering and Industrial Management, 2012, pp. 268-275.
[4] Achmad Y.F.F., Komarudin and Armand O.M., Simulation-Optimization Truck Dispatching Problem using Look-Ahead in PIT Mines. International Journal of GEOMATE, Vol.13, Issue 36, 2017, pp.80-86.
[5] Komarudin, Melianna F.C.P., and Irvanu R., Multi-Period Maritime Logistics Network Optimization using Mixed Integer Programming. International Journal of GEOMATE, Vol.13, Issue 36, 2017, pp.94-99.
[6] Al-Araidah O., Momania A., AlBashabsheha N., Mandahawi N., Fouadb R.H., Costing of the Production and Delivery of Ready-Mix-Concrete. Jordan Journal of Mechanical and Industrial Engineering, Vol. 164, Issue 6, 2012, pp. 163-173.
[7] Gulcag A., and Ugur A., Investigation of Ready Mixed Concrete Transportation Problem using Linear Programming and Genetic Algorithm. Civil Engineering Journal, Vol.12, Issue 10, 2016, pp.491-496.
[8] Pan L., Liya W., Xihai D., and Xiang G., Scheduling of Dispatching Ready Mixed Concrete Trucks Trough Discrete Particle Swarm Optimization. Conference Proceedings - IEEE International Conference on Systems, Man and Cybernetics, 2015. pp. 4086- 4090.
[9] Guochen Z. and Jianchao Z., Optimizing of ready-mixed concrete vehicle scheduling problem by hybrid heuristic algorithm. Computer Modelling & New Technologies, Vol. 18, Issue 12C, 2014, pp. 562-569.
[10] Natana M., Wuthichai W., Optimized Ready Mixed Concrete Truck Scheduling for Uncertain Factors using Bee Algorithm. Songklanakarin Journal of Science and Technology, Vol. 37, Issue 2, 2015, pp. 221-230.
[11] Dorigo M., Maniezzo V. and Colorni A., Ant System: Optimization by a Colony of Cooperative Agents. IEEE Transactions on System, Man and Cybernetics Part B (Cybernetics, Vol. 26, Issue 1, 1996, pp. 29-41.