Optimizing the schedule of dispatching RMC trucks through genetic algorithms

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Abstract

Effectively and efficiently delivering Ready Mixed Concrete (RMC) to construction sites is an important issue to the RMC batch plant manager. The RMC batch plant manager has to consider both timeliness and flexibility to develop an efficient schedule of dispatching RMC trucks, which balances the operations at the construction sites and the batch plant. The requests of RMC deliveries from different construction sites usually swamp into the batch plant at certain working hours. As a result, the batch plant manager has to quickly decide a dispatching schedule that can satisfy the needs from different construction sites. The existing dispatching schedule mainly depends on the experiences and preferences of the dispatcher. For example, the RMC plant manager may dispatch as many RMC trucks as possible to the busiest construction site. However, such an approach might result in the RMC trucks line up at the busiest job site while keeping other construction sites waiting for the arrivals of RMC trucks. A systematic approach to such a problem has seldom been taken due to the complexity and uncertainty involved within the dispatching process. Therefore, there is a need to develop a systematic model that optimizes the schedule of dispatching RMC trucks. This paper first analyzes the factors that impact the RMC delivery process, then builds a model based on Genetic Algorithms and the simulation technique to find the best dispatching schedule which minimizes the total waiting duration of RMC trucks at construction sites and satisfies the needs of RMC deliveries from different construction sites. In addition, a user-friendly computer program is built to help the batch plant manager streamline the dispatching process. Results show that this new systematic model along with the implemented computer program can quickly generate efficient and flexible solutions to dispatching RMC trucks.

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1. Background

Ready Mixed Concrete (RMC) was first introduced into the construction industry in the early 20th century and has been ever since widely employed. To expand the service of RMC without establishing high cost batch plant at the construction site, the RMC truck was invented to deliver RMC to the construction site. Because of time limitation of RMC delivery, the RMC plant manager usually needs to consider both timeliness and flexibility while matching up the working processes at different construction sites that call for RMC deliveries [1]. From the business point of view, the RMC batch plant manager may want to dispatch RMC trucks to different construction sites as many as possible to maximize the production and profits of the

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plant. However, the job site manager usually wants to avoid discontinuous RMC casting by requiring a substantial number of RMC trucks waiting in queue at the construction site. As a result, when the delivering calls from different construction sites arrive in the same short period of time, it becomes troublesome for the batch plant manager to quickly determine the dispatching sequence of RMC trucks to different construction sites. Consequently, the batch plant manager usually dispatches RMC trucks based on his or her experiences, which can be inefficient and might present the loss of potential profits. Therefore, it is necessary to find a dispatching schedule in terms of balancing the production of the construction sites and the batch plant. However, because of numerous dispatching sequences and various impact factors, such as delays of casting concrete at the job site, load limits of RMC trucks required by the law, and travel duration between job sites and the batch plant, determining an efficient dispatching schedule of RMC trucks is not an easy task. Recently, RMC delivery has become more efficient by applying GPS (Global Positioning System) to the dispatching process. However, a systematic model that optimizes the RMC dispatching schedule is still needed to streamline the dispatching process.

This paper first describes the characteristics of the RMC industry and then analyzes the factors that impact the RMC delivery process. Finally a model that incorporates Genetic Algorithms (GA) and simulation technique is built to find the optimal dispatching schedule which minimizes the total waiting duration of RMC trucks at construction sites and satisfies the needs of RMC deliveries requested by different construction sites. In addition, a user-friendly computer program is developed to help batch plant managers simplify the dispatching process. Results show that this new approach along with the implemented computer program can quickly generate efficient and flexible schedules of dispatching RMC trucks.

2. Characteristics of RMC industry

2.1. No finished products in stock

There are no finished products in stock at the RMC batch plant. Because of the quick solidifying nature of the concrete, RMC cannot be manufactured in advance and should be produced at the time that the job site manager requires the delivery. RMC is manufactured by the specific formulas according to the request of the construction site. Therefore, it is usually prohibited for the RMC batch plant manager to redirect the trucks with loaded RMC to other construction sites unless they request the same grade of concrete. Such an on-call process forces the batch plant manager to develop a flexible scheme which is able to quickly response to the requests from the construction sites.

2.2. Peak hours of dispatching

In practice, there are two types of RMC requests from construction sites. One type is that the construction site places its order in advance. The RMC batch plant manager can arrange the delivering scheme according to the required amounts of RMC from different construction sites. Another type is the last-minute order from the construction site. However, either RMC delivering requests are not known in advance in terms of time because the departing time of each RMC truck has to match up the working processes at the construction sites. In addition, the requests of RMC deliveries from different construction sites usually come very close in time. As a result, the RMC batch plant is very busy at certain working hours. In Taiwan, the peak hours of RMC deliveries are around 9:30 AM to 11:30 AM and 2:30 PM to 5:00 PM. This kind of characteristic forces the RMC batch plant manager to quickly determine the RMC delivering schedule which satisfies the needs of different construction sites. However, generating an efficient schedule of dispatching RMC is far from trivial since the complexity and uncertainty involved within the dispatching process.

2.3. Limited service areas of RMC trucks

RMC usually needs to be cast within 1.5 h after being produced by the RMC batch plant, which limits the service areas of the RMC batch plant. In addition, because of limited service area, the business competition between RMC batch plants is intense. In Taiwan, there are usually more than 5 RMC batch plants in the delivery reachable area. To be competitive, the batch plant not only keeps low cost of operation but also maintains the quality of the RMC and timely delivery.
2.4. Revenues and costs

For a batch plant, most of revenues come from selling RMC. The more amounts of RMC delivered to job sites, the more revenues that the batch plant can receive. Although raw materials, such as sand, cement, and aggregates, present important costs to the batch plant; the costs related to operating RMC trucks could be more critical. There are two major types of costs associated with RMC trucks. One is the cost of owning and maintaining RMC trucks. Another is the opportunity cost because of the improper dispatching schedule. Because discontinuously casting RMC could result in bad quality of concrete, the construction site manager usually calls for a substantial number of trucks to standby at the job site. To serve the customers, batch plant manager might send a substantial number of trucks to the job site as requested. However, such a dispatching approach usually results in that the batch plant is shorthanded with RMC trucks to be dispatched when the other construction sites call for RMC deliveries at the same short period of time. The batch plant may possess as many RMC trucks as possible to avoid the above situation; however, owning and maintaining RMC trucks is costly. In addition, from the productivity’s perspective, any duration that RMC trucks wait at the construction site should be treated as a waste of time and represents the cost of the opportunity. Therefore, an efficient and balanced schedule of dispatching RMC trucks not only reduces the opportunity cost of dispatching operation but also minimizes the cost of owning and maintaining RMC trucks.

3. Factors that impact the schedule of dispatching RMC trucks

3.1. Traveling duration between the RMC plant and the job site

The traveling duration between the RMC batch plant and the job site is determined by the distance between them, so are the speed of the RMC truck and the traffic condition. Therefore, it is not easy to predict the exact duration required to deliver RMC to different construction sites. Long traveling duration between the RMC plant and the job site may represent high possibility of uncertain events, such as the traffic gridlock. The batch plant manager, as a rule of thumb, usually assigns the RMC trucks to the job site far from the batch plant with higher priority to avoid discontinuously casting. However, such an approach might also increase the chance of interrupting the working process at the nearby job site which has fast casting operation. Therefore, the traveling duration between the RMC plant and the job site makes a great deal of deciding the schedule of dispatching RMC trucks. In practice, the average traveling duration between the batch plant and the construction site can be estimated from the history data.

3.2. The operating duration of casting RMC at the job site

The duration of casting RMC at the job site varies with the types of the construction activities, which could affect the dispatching interval between assigning RMC trucks to the same job site. For example, the faster casting operation at the job site, the shorter dispatching interval between assigning RMC trucks to the same construction job site is. If the RMC trucks cannot arrive at the job site in time, it is possible that the whole job site is idle, which impacts the working process at the job site tremendously. The batch plant manager may assign the RMC trucks to the busiest job site as many as possible. However, such an approach might cause RMC trucks to line up for casting concrete.

3.3. Number of deliveries needed

The number of deliveries needed to deliver RMC to a construction site depends on the amounts of RMC requests, loading capacity of the truck, and the road bearing limit permitted by the regulation. For example, one construction site requests 300 m³ RMC. Although the RMC truck can be loaded with concrete up to 9 m³, the regulation may only permit the RMC truck to be loaded with 6 m³ on the road. As a result, the number of RMC deliveries to this job site increases from 34 to 50 trucks, which extends the duration to finish the delivering process of this construction site.
4. The dispatching model

In this section, a systematic approach to modeling the schedule of dispatching RMC trucks is presented. This systematic approach breaks down the dispatching model to four parts which are input parameters, decision variables, constraints, and system out.

4.1. Input parameters

From the aforementioned discussion, factors that impact the RMC delivery process include the traveling duration between the batch plant and different construction sites, the casting duration, and the number of RMC trucks required at different construction sites. The duration of mixing RMC and the duration of loading concrete to the RMC truck could also affect the process of dispatching RMC trucks. In addition, the duration of mixing RMC slightly varies with the grades of concrete required from different construction sites. However, the development of this dispatching model focuses on the process outside the batching plant. The durations of mixing concrete and loading concrete to the RMC trucks are considered as one parameter only and can be identified as a constant. Allowable buffer duration is also introduced in this model to provide the flexibility in determining the dispatching schedule. This allowable buffer duration presents the maximum duration that the construction site can wait for the arrival of RMC truck. In addition, the purpose of this study is to take a systematic approach to analyzing the process of dispatching RMC trucks. Although, the aforementioned factors, such as traveling duration and the casting duration, are usually uncertain in nature, for the purposes of establishing a systematic model, those factors are assumed to be deterministic and can be identified. Therefore, the input parameters include the number of RMC deliveries, traveling duration, casting duration, mixing duration and allowable buffer duration.

4.2. Decision variables

Since the RMC delivering requests are on-call and occur in certain peak working hours, the time span that requires RMC dispatching is defined as the close period of time which different construction sites request RMC deliveries. According to the required amount of the RMC, the minimum number of RMC trucks assigned to different construction sites can be determined and should be integer. For example, if a construction site calls for 28 m³ of RMC and the loading capacity of a truck is 6 m³, the minimum number of RMC deliveries required by this construction site is five trucks. As the number of RMC trucks required by different construction sites is identified, the dispatching schedule can be determined by deciding when each RMC truck is dispatched to which construction sites. Therefore, the variables for determining a dispatching schedule should include the departing time and the designated construction site of each truck. However, these two variables cannot be determined simultaneously since they are correlated. In this model, the sequence of assigning each RMC truck to the different construction sites is defined as "dispatching sequence". Only the dispatching sequence of RMC trucks is considered as the decision variable which decides the dispatching schedule in this model. The departing time of each truck is determined by simulating the delivering process. Different dispatching schedules result in various system performances in terms of efficiency. The evaluation of system performance is described in detail in the section of System output.

4.3. Constraints

Continuously casting RMC is usually required by the regulation to diminish the chance of having defects within the concrete. However, due to the fact that unexpected events, such as traffic jams, might interrupt the delivering process, the RMC batch plant usually provides the service that the RMC truck arrives the construction site within the allowable buffer duration. Therefore, in this study, the continuously casting requirement restricts the duration which the job site waits for the arrivals of the RMC truck is smaller than the allowable buffer duration. In addition, the number of RMC trucks that the Batch plant owns is limited. The dispatching process should be able to identify if there is at least one RMC truck available for dispatching. These two constraints are applied to eliminating the infeasible dispatching schedules.
4.4. System output

The ideal RMC delivery to the construction site is the process such that the arrival time of the RMC truck for casting concrete is the same as the time that the preceding one RMC truck just finishes casting concrete, a just-in-time delivery process. On the other hand, the maximum productivity process of the batch plant is a continuously dispatching process that RMC truck leaves the plant as soon as the RMC truck finishes loading concrete. However, the dispatching schedules that can simultaneously satisfy these two processes may be rarely found. Therefore, in this study, the goal of developing an efficient schedule of dispatching RMC trucks is to minimize the total waiting duration of RMC trucks at construction sites without breaking off the operations of casting concrete. In addition, a simulation process is developed to determine all necessary operating information which includes the departing time of each RMC truck, the leaving time of each truck from the construction site back to batch plant. Consequently, the total duration that the RMC trucks wait at the construction sites and the duration that construction sites are idle for the arrivals of RMC trucks can be identified. An example of simulation process is described in the next section.

From the development of the RMC dispatching model above, it is clear that the efficiency of the RMC dispatching schedule depends on the dispatching sequence of the RMC trucks. The dispatching sequence of the RMC trucks is the permutation of the RMC deliveries required by different construction sites, which is similar to the typical traveling salesman problem (TSP) except that the construction sites are visited more than once. As it can be expected, the solution space could be explosive if the designated construction sites and the required RMC deliveries increase. The total solution space of the dispatching schedules can be determined by Eq. (1).

\[ TS = \frac{\left(\sum_{j=1}^{m} k_j\right)!}{\prod_{j=1}^{m} (k_j)!} \]

where TS is the total solution space, \( k_j \) is the required number of RMC deliveries, \( m \) is the number of construction sites that request RMC deliveries.

For example, if there are only five construction sites and each site requires four-truck deliveries, the total solution space of dispatching schedules is about \( 3.05 \times 10^{11} \) (\( = (4 + 4 + 4 + 4 + 4)!/(4!4!4!4!4!) \)), which can not be efficiently solved by using traditional optimization techniques. Therefore, a GA is developed to find the best dispatching schedule of the RMC trucks because of its quick converge on the optimal or the sub-optimal solutions. In the following, the development of the GA for optimizing the schedule of dispatching RMC trucks is explained in details. Fig. 1 depicts the systematic model of the dispatching RMC deliveries.
5. Genetic algorithms for optimizing the schedule of dispatching RMC trucks

5.1. Introduction

Genetic Algorithms (GA) are search algorithms developed by Holland [2], which are based on the mechanics of natural selection and genetics to search through decision space for optimal solutions [3]. The metaphor underlying GA is natural selection. In evolution, the problem each species faces is to search for beneficial adaptations to the complicated and changing environment. In other words, each species has to change its chromosome combination to survive in the living world. In GA, a string represents a set of decisions (chromosome combination), a potential solution to a problem. Each string is evaluated on its performance with respect to the fitness function (objective function). The ones with better performance (fitness value) are more likely to survive than the ones with worse performance. Then the genetic information is exchanged between strings by crossover and perturbed by mutation. The result is a new generation with (usually) better survival abilities. This process is repeated until the strings in the new generation are identical, or certain termination conditions are met. Fig. 2 demonstrates the general structure of Genetic Algorithms. Goldberg [3] and Gen and Cheng [4] are good references for details regarding Genetic Algorithms.

GA has also been known for its flexibility in hybridizing with other methodologies to obtain better solutions [5]. The departing time of each truck assigned to different construction is obtained from

![Fig. 2. General structure of Genetic Algorithms (adopted from Ref. [4]).]
the simulated process; hence the GA is adopted to integrate with the simulation methodology to find the optimal solution. The following sections describe the components and process of the GA for optimizing RMC dispatching schedule in detail.

5.2. Components and process

5.2.1. Chromosome structure

The purpose of using GA is to find the most efficient and effective dispatching sequence of RMC trucks that are to be assigned to different construction sites. Since the required number of the RMC trucks can be also be determined, different dispatching sequences can be treated as the permutations of assigning RMC trucks to different construction sites. Therefore, the chromosome structure used in this study is designed so that all permutations can be represented and evaluated.

First, the length of the chromosome is defined as the total number of the RMC trucks that will be dispatched from the RMC plant. For example, if there are three construction sites that respectively require three, four and five trucks to deliver RMC in the close period of time, the total length of the string would be 12 genes, the sum of three, four and five. Secondly, the random key representation for the genes of the string is used in this study to avoid the infeasible and illegal solutions generated within the evolution process. Fig. 3 shows the process of decoding a string with random key representation. This string represents the dispatching sequence involved with job sites 1, 2 and 3, which respectively requires three, four and five trucks to delivery RMC. In Fig. 3, “Site ID” denotes each gene’s corresponding construction site. The dispatching sequence is determined according to each gene’s “Site ID” and its corresponding random number in ascending order. For example, the smallest random number of the genes is 0.07 and the corresponding “Site ID” is 3, which indicates the dispatching sequence starts with assigning the RMC truck to the job site 3. Consequently, the dispatching sequence of the string is decoded to 3, 3, 2, 3, 1, 3, 2, 1, 2, 2 and 1.

5.2.2. Fitness value

As described in the model development, an efficient dispatching schedule should balance the casting and dispatching processes at the construction sites and the batch plant, respectively. However, the number of RMC trucks that the batch plant owns is limited; it is possible that the batch plant cannot dispatch RMC truck because no trucks are back to the batch plant. In addition, the requirements of continuously casting concrete and avoiding solidification of concrete constrain the RMC trucks to arrive at the construction sites within the allowable buffer duration. Different dispatching sequences could result in that the construction sites wait for the arrivals of the RMC trucks or the RMC trucks wait in queue for casting concrete. Therefore, the fitness value of a dispatching schedule is determined by minimizing the total duration that the RMC trucks wait at the construction sites, which can be determined by the simulation process. The process of casting concrete at construction site could be interrupted if the duration that construction site waits for the arrival of the RMC truck is longer than the allowable buffer duration; hence a penalty function is used to represent the level of violation. A simple example of determining the fitness value of a dispatching schedule is described in the following.

The same example as described in chromosome structure is used for demonstration. In addition, the batch plant owns five RMC trucks and the duration of mixing concrete (MD) is 3 min. The information of dispatching operation is listed in Table 1.

Step 1: Determine the ideal departing time of each RMC truck. The ideal dispatching process of the batch plant is the process that RMC truck leaves the
Table 1  
Information of the dispatching operation

<table>
<thead>
<tr>
<th>Site</th>
<th>SCT, CD, TDG, TDB, ABD, k</th>
<th>Capacity of the Batch Plant</th>
<th>Mixing duration</th>
<th>Max. load of trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>08:00 20 30 25 30 3</td>
<td>5 trucks</td>
<td>3 min</td>
<td>6 M³</td>
</tr>
<tr>
<td>Site 2</td>
<td>08:00 30 25 20 20 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site 3</td>
<td>08:30 25 40 30 15 5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SDTj: Start casting time of the construction site j (in 24 h format).  
CDj: Casting duration of the construction site j (in min).  
TDGj: Traveling duration from the batch plant to the construction site j (in min).  
TDBj: Traveling duration from the construction site j to the batch plant (in min).  
ABDj: The allowable buffer duration of construction site j (in min).  
kj: The required RMC truck deliveries for the construction site j.  

Step 2: Simulate the process of dispatching RMC trucks. The ideal departing time of each RMC truck is determined by the simulation process according to the dispatching sequence generated by the GA. Table 3 shows an example of the dispatching sequence generated by the GA.

The simulation process starts with the first dispatched RMC truck which departs from the batch plant at 07:30 h. Table 4 records the process of the simulation according to Eqs. (4)–(11) and Table 5 shows the simulated result according to the dispatching sequence and simulation process.

Table 3  
Dispatching sequence generated by the GA

| 2 | 3 | 2 | 1 | 3 | 1 | 3 | 1 | 2 | 3 | 2 |

where SDTj is the simulated departing time of ith dispatched truck, TACji is the time that ith dispatched truck arrives at construction site j, PTFji is the start casting time of the construction j if ith dispatched truck is the first truck arrives at construction site j or the time that the (k – 1)th truck leaves the construction site j, if ith dispatched truck is the kth truck arrives at the construction site j.

Table 4  
Earliest departing times of RMC trucks

<table>
<thead>
<tr>
<th>FDT</th>
<th>min[08:00 – 00:30, 08:00 – 00:25, 08:30 – 00:40] = 07:30</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>1</td>
</tr>
<tr>
<td>IDT</td>
<td>07:30</td>
</tr>
</tbody>
</table>
struction site \( j \). \( WC_{ji} \geq 0 \) is the duration that \( i \)th dispatched truck waits at the construction site \( j \), \( WC_{ji} < 0 \) is the duration that construction site \( j \) waits for the arrival of the \( i \)th dispatched truck, \( LT_{ji} \) is the time that the \( i \)th RMC truck leaves construction site \( j \), \( TBB_i \) is the time that the \( i \)th dispatched RMC truck back to the batch plant, \( i \) is the dispatching order of the RMC trucks. \( i = 1–N \), \( j \) is the index of the designated construction site. \( j = 1–m \), \( k \) is the order of the RMC truck arrives at the respective construction site, \( k = 1–K_j \) for each construction site \( j \). \( l \) is the order of the truck that is back to the batch plant and has not been dispatched, \( c \) is the number of the RMC trucks that the batch plant owns.

Step 3: Determine the fitness value. From the Table 5, the total duration that RMC trucks wait at construction sites and total duration that construction sites wait for the arrival of RMC trucks are 84 and 209 min, respectively. The interruption of casting concrete occurs when the duration that the construction site waits for the arrival of the RMC truck is longer than the allowable buffer duration. As shown in Table 5, the number of interruptions marked as * in the Table 5 is 4. Since the interruptions of casting concrete should be avoided as could as possible, the penalty function is defined as Eq. (12).

\[
P = (\text{the number of interruptions}) \times 60 \times 24.
\]

The interim fitness value \((F')\) of a dispatched schedule is defined as \(F' = P + TWC\), where TWC is the total duration that RMC trucks wait at the construction sites. In this example, the interim fitness value of the dispatching schedule is equal to 5844 \((-4 \times 60 \times 24 + 84)\). The final fitness value \((F)\) is then justified by Eq. (13) because of the minimization.

\[
F = M - F'
\]

\(M\) is the maximum \(F'\) in the current population.

5.2.3. Selection

The proportional selection is used in this study to select the strings (dispatching schedules) that have better fitness value. According to the fitness generated by the above steps, the selection probability can be determined by using Eq. (14).

\[
P_i = \frac{F_i}{\sum_{i=1}^{\text{Pop\_size}} F_i}
\]

where, \(P_i\) is the selection probability of the string \(i\), \(F_i\) is the fitness value of string \(i\), \(\text{Pop\_size}\) is the population size.
5.2.4. Crossover

The two-point crossover mechanism is applied to the chromosomes used in this study. The process of the two-point crossover as shown in Fig. 4 is described as follows: at first, two parent strings, P1 and P2, are selected randomly. Then two randomly selected points are used as the separators that cut the each selected parent string into three sections. Combine Sections 1 and 3 of P1 to form the head of the first offspring (O1) and use Section 2 of P2 to form the tail of O1. In addition, the Section 2 of P1 is used as the head of the second offspring (O2). Combine Sections 1 and 3 of P2 to form the tail of O2.

5.3. Mutation

Self mutation [6] is used in this study. If a chromosome is selected for mutation, two genes are randomly selected for exchanging their values. An example of self mutation is shown in Fig. 5. P is the selected chromosome and O is the chromosome after self-mutation.

5.4. The computer program

A user-friendly computer implantation named “RMC Dispatching Schedule Optimizer” (RMCDiSO) is developed to help the batch plant manager quickly generate an efficient dispatching schedule. Fig. 6 shows the interface of RMCDiSO.

5.4.1. Input

There are three areas that require users to input data. The first area is the section of “Operation Data of Sites”, which contains the data related to
different construction sites that request RMC deliveries. The descriptions of these data are listed below:

<table>
<thead>
<tr>
<th>Description</th>
<th>Units/Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traveling duration (Go)</td>
<td>the duration that the RMC truck travels from the batch plant to the construction (in min)</td>
</tr>
<tr>
<td>Traveling duration (Back)</td>
<td>the duration that the RMC truck travels from the construction site to the batch plant (in min)</td>
</tr>
<tr>
<td>Required amount of RMC</td>
<td>the required amount of concrete needed for each construction site (M$^3$)</td>
</tr>
<tr>
<td>Casting duration</td>
<td>the duration of casting concrete at each construction site (in min)</td>
</tr>
<tr>
<td>Allowable buffer duration</td>
<td>the allowable buffer duration of each construction site (in min)</td>
</tr>
<tr>
<td>Starting time</td>
<td>the start time of casting concrete at each construction site (in 24 h format)</td>
</tr>
<tr>
<td>Required number of trucks</td>
<td>the required number of trucks for each construction site, which can be automatically generated by RMCDiSO</td>
</tr>
</tbody>
</table>

The second area is the section of “The Batch Plant”, which includes the data related to the batch plant operation. The descriptions of these data are listed below:

<table>
<thead>
<tr>
<th>Description</th>
<th>Units/Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sites</td>
<td>the number of construction sites that request RMC deliveries</td>
</tr>
<tr>
<td>Max. load of trucks</td>
<td>maximum RMC loading of the RMC truck (M$^3$)</td>
</tr>
<tr>
<td>Capacity of the plant</td>
<td>the number of operable RMC trucks the batch plant owns</td>
</tr>
<tr>
<td>Mixing duration</td>
<td>the duration of mixing concrete (in min)</td>
</tr>
</tbody>
</table>

The third area is the section of “GAs Parameters”, which includes “Generations”, “Population size”, “Crossover rate” and “Mutation rate”. After the data needed for these three areas are entered, the RMCDiSO will be ready to optimize the dispatching schedule.
5.4.2. Output

There are also three areas that report the results generated by RMCDiSO. “Population Status” indicates the performance of GA operation. Users can let RMCDiSO finish the whole GA operation or determine when he or she wants the GA operation to be terminated by clicking on “Interrupt”. “Dispatching Result” shows the simulated result of the dispatching schedule, which indicates the dispatching sequence, the simulated departing time of each truck, and the simulated leaving time of each truck. In addition, “Best 20” shows the result of the best 20 solutions found by RMCDiSO. Users can click any one of best 20 solutions and RMCDiSO will display the dispatching schedule of the solution in the section of “Dispatching Result”. As shown in Fig. 6, solutions are first ranked according to their values in “Times of Interrupts” first and then the “Trucks waiting duration” in ascending order. This is because the interruptions of casting operation should be eliminated as much as possible.

6. Results

Many examples are tested to verify the accuracy and efficiency of RMCDiSO. The test platform is a Pentium 4 2.0 GHz PC with 512 MB RAM. Three examples are presented in this paper to demonstrate the accuracy and efficiency of RMCDiSO. The first one is the same example as described in the section of Chromosome Structure. Table 1 shows the information related to this dispatching operation. There are 27720 (= 12!/(3!4!5!)) different dispatching schedules. With the population size of 200 and generations of 100, it takes RMCDiSO 10 seconds to complete the evolution process. From the results reported by RMCDiSO, the total waiting duration of the optimal dispatching schedule that does not interrupt casting operation is 95 min. As shown in Fig. 7, RMCDiSO searches through about 15% (= 21 × 200/27720) of the solution space by taking 21 generations to converge to the optimal solution. The result may not be significant in terms of searching efficiency. This phenomenon is typical in GA applications because the scale of the problem is small. However, an accurate optimal solution is

Table 6
Information of the dispatching operation

<table>
<thead>
<tr>
<th>Site</th>
<th>$SCT_j$</th>
<th>$CD_j$</th>
<th>$TDG_j$</th>
<th>$TDB_j$</th>
<th>$ABD_j$</th>
<th>$k_j$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>08:00</td>
<td>20</td>
<td>30</td>
<td>25</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
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<td>20</td>
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<td>2</td>
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<tr>
<td>Site 3</td>
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<td>30</td>
<td>15</td>
<td>4</td>
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<tr>
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<td>4</td>
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<td>Site 5</td>
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</tbody>
</table>

Capacity of the Batch Plant: 5 trucks
Mixing duration: 3 min
Max. load of trucks: 6 M³

Table 7
Optimal dispatching sequence of example 2

<table>
<thead>
<tr>
<th>Site</th>
<th>4</th>
<th>3</th>
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<th>4</th>
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</tbody>
</table>
found by RMCDiSO. In addition, the dispatching sequence of the optimal solution is 1, 2, 2, 1, 1, 3, 2, 3, 2, 3, 3, and 3. The result is also verified by exhaustively enumerating the total possible solutions, which takes 13 s to accomplish.

The second example is the dispatching operation involved with 5 construction sites. Table 6 shows the information related to the dispatching operation. There are 18918900 (=(2 + 2 + 4 + 4 + 2)!/(2!2!4!4!2!)) different dispatching schedules. With the population size of 200 and generations of 100, RMCDiSO takes 13 s to find the optimal solution. From the result reported by RMCDiSO, the total waiting duration of the optimal dispatching schedule that does not interrupt casting operation is 125 min. As shown in Fig. 8, it takes RMCDiSO only 34 generations to converge to the optimal dispatching schedule. The searching ratio is about 3.594 × 10^{-4} (=34 × 200/18918900) of the solution space. The duration to find the optimal solution by using exhaustive enumeration is 2 h 5 min and 18 s. Significant result in terms of searching efficiency is reported by using RMCDiSO. Table 7 shows the optimal dispatching schedule of example 2.

### Table 7

<table>
<thead>
<tr>
<th>Capacity of the Batch Plant</th>
<th>20 trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixing duration</td>
<td>3 min</td>
</tr>
<tr>
<td>Max. load of trucks</td>
<td>6 M³</td>
</tr>
</tbody>
</table>

The third example is a dispatching operation involved with 9 construction sites. The information related to this dispatching operation is listed in Table 8. As it can be examined, the total solution space of this example is about 2.09 × 10^{36}, which is almost impossible to solve by exhaustively enumerating all possible dispatching schedules. With the population size of 300 and generations of 100, RMCDiSO takes 64 s and 72 generations to converge to the solution that has total waiting duration of 91 min without interrupting casting operations. Fig. 9 shows the results reported by RMCDiSO. Although the solution found by RMCDiSO cannot be verified by using exhaustive enumeration in terms of optimality, a sub-optimal solution is reported. Consider the size of the total solution space, this result is very promising. Table 9 shows the optimal dispatching schedule of example 3.

### 7. Summary and future works

Efficiently delivering RMC to the construction site is an important issue to the RMC batch plant manager. The batch plant manager needs to quickly
generate a dispatching schedule that satisfies the requests from different construction sites. However, completing such an operation is not an easy task and mainly depends on the experiences of the batch plant manager in practice. This paper presents a systematic approach to modeling the process of dispatching RMC trucks. Results show that by applying the proposed RMC dispatching model to the mechanism which incorporates the GA and the simulation technique, the batch plant manager can quickly generate the efficient and flexible dispatching schedule of the RMC trucks, which not only improves the operations at the batch plant but also promotes the service of the RMC batch plant. In addition, the development of the computer implementation, RMCDiSO, simplifies the process of dispatching RMC trucks for batch plant managers.

As described in the model development, the input parameter values, such as traveling duration and the casting duration, are usually uncertain by nature. In the future research, those parameters are considered in terms of uncertainty. For example, these factors can be represented by using probability distributions or fuzzy sets. With simulation process proposed in this study, uncertain considerations of input parameters can be easily incorporated within the processes of GAs. In addition, for building a dynamic system that can synchronize with the real time dispatching operation, Global Positioning System (GPS) can be integrated with the RMCDiSO to provide the real time operation data. Furthermore, by expanding the single bath plant model, a dispatching-center-based approach could be developed to resolve the operation that includes multiple batch plants and construction sites.

Acknowledgements

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References