A mathematical model to optimize allocation sequence in dispatching problem

Mohammad Ghobadi Samani¹, Masoud Monjezi²*, Jafar Khademi Hamidi³, and Amin Mousavinogholi⁴

1. Faculty of Engineering, Tarbiat Modares University, Iran. 2. Faculty of Engineering, Tarbiat Modares University, Iran. 3. Faculty of Engineering, Tarbiat Modares University, Iran. 4. Faculty of Engineering, Tarbiat Modares University, Iran.

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- Dispatch
- Dynamic allocation
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Abstract
Truck-Shovel fleet, as the most common transportation system in open-pit mines, has a significant part of mining costs, for which an optimal management can lead to a substantial cost reduction. Among the available dispatch mathematical models, a multi-stage approach is well-suited for allocating trucks to the respected shovels in a dynamic dispatching program. However, with this kind of modeling, sequencing the allocated trucks is not possible, though it is important to find out the best solution to get the minimum cost. To comply with the shortcoming of the traditional model, in this work, a new hybrid model is developed and applied to the Sungon Copper Mine in Iran, in which, for each truck, an allocation matrix is considered as the input to the genetic algorithm implemented to determine the best solution. According to the results obtained, the optimal sequencing of the trucks can result in a significant (31%) cost reduction in a shift.

1. Introduction
Transportation is a vast part of the operating costs in surface mining, which should be decreased as much as possible for getting higher benefits [1]. The truck-shovel system is the most adopted way of handling mined materials in open-pit mines. In order to reduce the operating costs, a proper dispatching method has to be taught for the available fleet. In the dispatch problem, it is determined that each truck should move to which possible point. Also using an appropriate dispatching strategy, the total transportation costs including the truck traveling time, fuel consumption, idle time, and depreciation can be significantly reduced. Various solutions to the dispatching problem have been developed by different researchers. Rafael et al. have developed a mathematical model to maximize production with a minimum number of trucks [2]. Zhang and Xia have used an integer algorithm to determine the number of trips of each truck for minimizing the operational costs [3]. Chang et al. have considered revenue maximization as the objective function for the homogeneous fleet [4]. Kaveh Ahangaran et al. have modeled the dispatch problem with the aim of minimizing the transportation cost for a heterogeneous fleet [5]. In evolution, Lutz has proposed a combined simulation and TS to deal with the transportation problem [6]. Fu and Healy have used the PA technique in the inventory models [7]. Faccenda and Tenga have presented an approach to incorporate the process of plant production operations into the design of a facility by combining simulation and genetic algorithm (GA) [8]. Morito et al. have applied a hybrid model simulation and simulated annealing (SA) to find an appropriate dispatching priority of operations [9]. Hill and Fu have applied simultaneous perturbation stochastic approximations (SPSAs) to a transportation problem [10]. By evaluation of the dynamic and fixed allocation, it proved that...
dynamic allocation is more efficient than fixed one [11-14].
In all of the above-mentioned models for dispatching a problem, the solving time is relatively high for which a multi-stage approach has been advised. Robert et al. have divided the dispatch problem into two stages of allocation and dispatching so that in the first stage, the maximum capacity of mine production and the optimal fleet are determined, and in the second stage, the simulation is applied to allocate trucks to shovels in a dynamic manner [15]. In the same way, Temeng and Otunye have solved the dispatch problem using a two-stage approach [15]. In a further research work, Gerrit and Subhash have employed a two-stage approach for solving a transportation problem. In the first stage, they determined the volume of rocks to be handled, and in the second stage, optimization was determined using integer programming [16].
In this work, a simulation-based mathematical model was developed for the heterogeneous fleet, in which an objective function of minimizing transportation cost was defined. A combination of the Zhang and Xia model with the proposed model could be used to perform the truck assignment in the form of a matrix. Since there are a huge number of alternatives for truck sequences, a heuristic method such as GA has to be applied to find out the optimum sequence. The aforesaid multi-stage approach was determined to determine the best dispatching sequence in a real case study.

2. Material and methods
The algorithm for solving the dispatching problem with the aim of determining the operating matrix is shown in Fig. 1. As shown in this figure, in the first step, according to the Zhang and Xia model, the dynamic allocation of the trucks is determined. Using this approach, the truck number of trips between the loading and dumping points is determined, and finally, a displacement matrix is generated for each individual truck. For each truck, this matrix represents the number of trips for a specific route but the sequence of the trips is not known. However, it is clear that the dispatch sequence is effective in the production and costs. Therefore, a way should be thought of to find the best sequence to get the maximum benefit.

![Flowchart of the development model](image_url)

For this purpose, in the second step, a new mathematical sequencing model was developed and considered as the cost function in GA. The developed model and its corresponding constraints are given in the Eqs. 1 to 8.
the fitness of each solution generated by GA. The following steps have to be determined:

Step I: Randomly generate the initial population of chromosomes based on the result of the first stage for the dispatch plan. The jth chromosomes in the initial population for ith truck can be shown by \( P_{j,0} \) as:

\[
p_{j,k}^0 = \begin{bmatrix}
a & \cdots & d \\
\vdots & \ddots & \vdots \\
c & \cdots & b \\
\end{bmatrix}_{s,i}
\]

Step II for each chromosome in the population, a simulation model is applied to determine the fitness function based on the objective function.

Step III If the stop condition is satisfied, stop and resume otherwise.

Step IV Create a new population by the operations of selection, crossover, and mutation.

Step V go to step II.

### 2.1. Procedure of GA

In order to make each chromosome from the first random generation, it is necessary to convert the assignment matrix of each truck to the operating matrix, which is done for each truck as below:

Step 1: Get an assignment matrix from the Zhang and Xia model.

Step 2: Define an empty displacement matrix.

Step 3: Finish the algorithm if there are no elements greater than zero in the assignment matrix.

Step 4: Randomly select an element greater than 0, which is considered as the next to the truck destination.

Step 5: Complete the primary displacement matrix by adding a new row, in which the first element is the row number of the selected intersection of the allocation matrix, and the second denotes the column number of the selected intersection of the allocation matrix, which is considered as a possible solution.

Step 6: The selected element is updated on the allocation matrix and is subtracted by one.

Step 7: Go to step three.

- Assume equal path lengths and zero discharge time and the following conditions:
  - Two shovels with normal distribution of \( N(4.2) \) and \( N(5.3) \) for loading
  - Two trucks with a normal distribution of \( N(10.1) \) and \( N(15.3) \) for a load capacity of one ton
  - Two drainage points

With the Zhang's model solution, we will have:

\[
\begin{align*}
\min & \sum_{i=1}^{N} \sum_{r=1}^{N} \sum_{s=1}^{N} C_{i} X'_{i} + C_{r} X_{r} \\
\sum_{i=1}^{N} \sum_{r=1}^{N} Y_{i,r} = 1 & \quad \forall k \\
\sum_{i=1}^{N} \sum_{s=1}^{N} Y_{i,s} = 1 & \quad \forall k, R \\
\sum_{i=1}^{N} \sum_{s=1}^{N} Y_{i,s} = 1 & \quad \forall k, R' \\
Y_{i,s} \geq \sum_{r=1}^{N} Y_{i,s} & \quad \forall k, R \\
Y_{i,s} = X_{i,s} & \quad \forall k, s, R \\
\end{align*}
\]
After creating the initial population, a simulation model is used to determine the fitness of each solution. The simulation technique is implemented for traveling and loading time in both the empty and full trucks. This generational process is repeated until a termination condition is reached. The common terminating conditions are as follow: a solution is found that satisfies the minimum criteria, a fixed number of generations is reached, allocated budget (computation time/money) is reached, the highest ranking solution fitness is reached, and successive iterations no longer produce better results.

In GA, the crossover operation is used to create the second generation. In this operation, the parents are randomly selected using the roulette cycle; thereafter, the new parents (solutions) are compared with the matching matrix. The mutation operator is used to maintain the genetic variation from one generation to the next. In order to determine the fitness of each one of the proposed solutions of GA, the simulation is repeated until the best answer is reached. The process of application of GA is shown in Figure 2.

**Figure 2. MAE approved with regard to appropriate iterations.**
2.2. Case study
The Songun Copper Mine is located in the East Azarbaijan Province, 130 km from Tabriz and 75 km from Ahar 30 km from Varzaghan. The mine operation takes place in three 8-hour shifts. A heterogeneous fleet with four different truck models including 12 Komatsu HD 785-5, 16 Komatsu HD 325-6, one truck KOM HD 325-5, two TEREX, and a total of 5 Shovels. Also, there are five operating shovels (i.e., two CAT 5090, one LIEBHERR-984, one LIEBHERR-992, and one Terex) in the mine. Note that in this work, there are 20 loading points for ore and 3 unloading points in the executive year. Accordingly, for waste materials, there are 20 loading points and 12 unloading points. The proposed approach is implemented to obtain the best operating truck sequence matrix.

3. Results
The dispatching problem has three stochastic parameters including the movement time, loading time, and unloading time. In order to find out the probability distribution function for each one of the random parameters, the Minitab software is used. Due to the multiplicity of routes and trucks, the distribution of the displacement time of each truck is not calculated; instead, the time of displacement of trucks in full and empty modes in all paths is clustered, and also instead of estimating the distribution of each truck’s travel time in each path, the distribution time of the displacement in the clusters is computed.

Estimates of the statistical distribution of the movement time for each truck from each shovel to the unloading point and reverse are:
- The estimated statistical distribution of the load time for each shovel
- The estimated statistical distribution of the discharge time for each truck group

Displacement distribution is estimated in four steps:
Step 1. At first, all records relating to the displacement time of each truck in each direction are collected in the full and empty modes.
Step 2. In each record, the time of displacement is divided by the route length so that the mean time of the unit length is obtained for each truck.
Step 3. Taking into account the average times of displacement of each truck in the full and empty parts for each route, the paths are clustered (using the k-means algorithm in the mini-tab software), as follows:
  a. First, the n cluster center is randomly determined.
  b. The distance between each record from the center of each cluster is determined.
  c. Each record is assigned to the closest center of the cluster.
  d. The cluster center is updated, and the average data for that cluster is replaced by the cluster.
In the clustering algorithm, steps c and d are repeated until no significant change is made in the center of the clusters.

Step 4. By considering the records for each cluster, the probability distribution function of the data is determined using the mini-tab software for each cluster.

After estimating the random parameters with GA and using the Zhang model results, the initial population is created, and then simulation based on the random parameters in accordance with the objective function of the model is determined. The fitness of each solution is calculated by repeating the process of making a new generation until the condition of stopping GA is reached; the optimal sequence of truck dispatch is determined. The results obtained are given in the next section.

3.2. Application of proposed model

3.1. Dynamic allocation of trucks

In the research literature, several articles have examined the optimization methods and have determined the optimal allocation of the truck and shovel matrix, one of them is the Zhang’s model, the result of which lead to the allocation matrix. In this model, the assignment matrix is evaluated by optimization of the model by an objective function that minimizes the movement cost in the two types of loaded and empty conditions. The result of the model is an assignment matrix for each truck whose entries (elements) show the number of truck trips between two specified points as Eq. 10

$$x^\dagger = \begin{bmatrix} 5 & 4 & \ldots & 3 \\ 0 & 0 & \ldots & 6 \\ 4 & 0 & \ldots & 0 \\ 0 & 0 & \ldots & 10 \end{bmatrix}$$

(10)

Based on Eq. 10, the 1st truck must be moved 5 times between the first loading point and the first unloading point and 4 times between the first loading point and the second loading point.

3.2. Determination of operating matrix using GA

By implementing the proposed model for extraction of minerals according to the planned level with the objective of minimizing the direct extraction costs, according to the results of the implementation of the model for 30 shifts, using the proposed model, the operational costs will be reduced by up to 31%.

![Figure 5. Comparing the cost of the real situation with the result of the proposed model.](image)

4. Conclusion

Fleet management is one of the most important issues in my planning, which is dealt with in the dispatch problem. In this work, it was tried to determine the sequencing of truck displacement at the surface level through a multi-stage problem solution, use of dynamic allocation, and consideration of random parameters in the model. On the other hand, in solving the dispatch problem, there are generally various goals that are sometimes contradictory. In this case, the dispatch problem was divided into two stages, the separation of the allocation process and the dispatch from one another such that in the first stage, the allocation process is followed, and in the second phase, using the simulation method, the optimal dispatch program for allocation of the first phase is done. According to the results obtained from the implementation of the model on the true data of the Songun mine, the results obtained from the implementation of the model are significantly better than the actual results. Given the results obtained from the implementation of the model that take into account various extraction policies, and that in all cases significant achievements can be made, it can be argued that the targeted simulations along with dynamic deployment in mines can always be used as an alternative to enhance capabilities. The
existing fleet can be considered by decision-makers in open-pit mines.

References


ارائه مدلى رياضی جهت بهینه‌سازی توالی گسل در مسئله دیسپچ

محمد قبادی سامانی ۱، مسعود منجزی ۲، جعفر خادی حمیدی ۳، امین موسوی نقی ۴

۱ دانشجوی دکتری، دانشگاه تربیت مدرس
۲ استاد گروه استخراج، بخش مهندسی معدن، دانشگاه تربیت مدرس
۳ استاد گروه استخراج، بخش مهندسی معدن، دانشگاه تربیت مدرس

ارسال ۱۱/۱۰۱۸، پذیرش ۱۲/۱۰۱۸

monjezi@modares.ac.ir

چکیده:
عملیات برگری و حمل ونقل به عنوان یک بخش مهم در استخراج مواد معدنی اکثریت معادن روابط نقش قابل توجهی در بهینه‌سازی تمام شده قبلاً قیمت محصولات معدنی دارد. تعین ترتیب و توالی حرکت تراکها که از جمله اساسی‌ترین و کاربردی‌ترین جنبه‌های مسئله گسل در معادن است تاکنون گردیده و درحقیقت میزان از تعداد تراکها، ماریس‌سی بویک و توالی حرکت آنها ارائه می‌گردد. بدین معنی که میزان مواد جابه‌جایی شده در هر روز و تعادل تراک نیز در هر شیفت تعیین، سبب می‌شود دفعات جاجایی، حرکات و تغییر توالی راک ترقیه شفافیت تعیینی بازی هر تراک، تعیین تحمل مشخص به در ترتیب، توالی مراحل راک، به شاخص مختلف تعیین می‌گردد. در منظور کاهش زمان جل و عدم توقف جمع‌آوری فضای جواب از انرژی‌های مختلفی در هر جواب باید اعمال ماهیت تصادفی تجهیز‌های زمانی از شیبی سازی استفاده شده است. به منظور اجرای عملیات برگری، مدلی مدل ارائه شده، با داده‌های یک سال عملیات برگری شهر سیروان از جرا شده و بنیادهای طی‌های سال و همچنین با نتایج بدست آمده از مدل راه‌شدن به شاخص توالی تعرضی و نزدیک شده است، نتایج بدست آمده از اجرایی مدل بیشتری در مقایسه با کامیونی، مدل توالی کاهش داشته‌اند. همچنین نتایج بدست‌آمده در مقایسه با جواب‌های بدست آمده بر اساس مدل جانگ نشان می‌دهد که در بخش‌هایی از مدل بیشتری، شده در این تحقیق منجر به کاهش ۸ درصدی می‌باشد که نشان می‌دهد عملکرد مدل مطلوب و قابل قبول است.

کلمات کلیدی: برگری، تراک، حمل و نقل، شاخص بُرس، پیش‌بینی و شبیه‌سازی