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SMART TRUCK DISTRIBUTION IN AN OPEN-PIT MINE

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Abstract- Permanent integration of intelligent approaches within Open Pit Mine (OPM) dispatch systems has been a major advancement. The introduction of autonomous trucks has led to a production raise. The entire transportation system needs to be maintained in order to lower the operating expenses. The aim of this work is to expose in details the real-time fleet management difficulties, their features, and provide a Mixed Linear Programming (MLP) model of shovel truck dispatch aiming to find out the optimal number of trucks needed to move material from the loading site to the unloading point during a shift. The right excavator will be assigned to the right trucks in this model. A case study is discussed and analyzed for validation in a mining company within Moroccan context.

Keywords: Fleet Management System (FMS), Truck-Shovel Dispatching, Truck Routing.

1. INTRODUCTION

A mining operation is very extensive process since it contains several manuals, physical, mechanical, and logistical actions with different interfaces and human decisions. Mining is considered as a basic industry with difficult and dangerous working conditions, as well as it has many negative effects on the environment and used low levels of high technology, and automation [1].

Digital transformation is emerging as a driver of radical change in the world across many traditional industries [2]. Digitalization has become a force inside the mining sector that is altering how businesses interact with their workforces [3], communities, governments, and the environment at every point along the supply chain. Through data visualization to across supply chain, mining businesses can use digital transformation to boost efficiency, cut costs, and quickly improve production and safety. Stakeholders along an integrated production chain can make better decisions if they have access to the proper information. Additionally, mining companies can acquire strategic insights into their operations with the assistance of analytics and machine learning algorithms. Future insights on mineral performance, health, and features can be gained by feeding and implementing the aforementioned algorithms with real-time data and then analyzing the historical data.

Reducing material transport costs will result in significant savings since they are evaluated between 50 and 60 percent of the total operational cost in Open Pit Mines (OPM) [2]. In open pit mining, the shovel truck system is essential for moving the material from the mine sites to the landfills for additional processing. Every time a vehicle left a mine site, the following question is required: "Where should this truck go next?" This is the difficulty with dispatching trucks in OPM. In order to meet production needs and reduce vehicle running expenses, the fleet dispatcher must determine the optimal location where the truck should be sent.

This study models the truck dispatch problem as an Integer linear Programming (ILP) problem to achieve an optimal production with the minimum amount of resources and operational time. We will concentrate on resolving the top-level truck dispatching issue that establishes the number of trips made between shovel-loading sites and hopper-loading sites during a full shift. This study's findings are able to solve the planning problems for each truck in real time. In the following, we will give a shovel-trucks allocation overview in OPM. We will then discuss OPM allocation issues before proposing a dispatching modelling system with a real case study. Finally, we conclude and address further perspective research in the last section.

2. OPM SHOVEL ALLOCATION PROBLEM OVERVIEW

2.1. Real Time Approaches for Solving Fleet Management Problems

In order to decrease the high cost of transporting equipment, especially in OPM, researchers have proposed the integration of fleet management systems (FMS). An FMS is a real-time decision-making system that manages the fleet of devices [4], it receives the necessary information. Based on all these latter, the FMS makes its decisions. Then, the decisions are executed by concrete operations, and the FMS is called every time a new decision is required [5].

Sending trucks to the shovel is one of the main decisions taken by the FMS. The decision must meet the production requirements while also minimizing deviation and maximizing the productivity of the active equipment. Since the 1960s, various approaches and techniques have been employed to make the key decision regarding truck distribution, but none of them have been successful in achieving the goals at the same time [5]. In general, fleet management problem solving models are either fixed or dynamic models. Consequently, there are two types of truck assignments to the open pit mine: fixed and dynamic. In the following, we will discuss these two types in open-pit mines case.

2.1.1. Fixed Distribution

This static method assigns a trucks fleet to a shovel, which remains intact until the shift ends. This route will not be changed unless a shovel breaks down or a critical event occurs. The assigned trucks must work on the same route during the shift based on several criteria, such as production needs, availability of trucks in the fleet, etc. Classical methods based on queuing theory, and scheduling are some of the methods used for fixed truck assignment. All these methods aim to identify the optimal amount of trucks for each shovel [6].

2.1.2. Dynamic Distribution

According to research [6], the fixed allocation method is not efficient in transportation planning for large mines. In the dynamic allocation method, the available trucks in the fleet are allocated to a shovel at the beginning of the shift. Contrary to the static method, these trucks will be updated every time they load and unload at the hoppers by receiving a new assignment from the distribution system [7].

Many research results revealed that loading and transportation capacity has increased by using the dynamic allocation method. Olson et al [8] showed that the use of dynamic distribution of trucks in several mines improved productivity with different rates. table 1 shows these results.

Table 1. Productivity improvement rate in different mines using dynamic distribution method

Mine	Percentage rate
Bougainville copper	13%
Barrick Goldstrike mine	10-15%
LTV iron mine	10%
Quintette mine	10%

A comparative study by Kolonja and Mutmansky [9] on the difference between the two aforementioned methods demonstrated that the use of a variable allocation provides a significant improvement in the productivity of mining operations.

2.2. Fleet Management Approaches to Open Pit Mining: Truck Distribution

There are two types of methods used for the allocation of truck loaders in OPM: single-stage and multi-stage methods. [10].

A single-stage FMS system finds the shortest routes between the trucks and their destinations, and calculates the optimal number of truck trips for each usable route.

The one-step approach was replaced by a multi-step one. Three sub-problems are solved using the multi-step approach, and the solution of each step is used as an input for the next sub-problem. The three sequential sub-problems are: determining the shortest paths from all sources to destinations, determining the best amount of material to produce for each path, and sending trucks to shovels in real time [7].

2.2.1. Shovel-Trucks Distribution Criteria in OPM

The ideal path for a transport truck is one that seeks to maximize the satisfaction of one or more distribution objectives. In order to increase productivity and reduce vehicle inactiveness, many variables are utilized to allocate transport trucks, either directly or indirectly.

The various methods proposed for transport truck distribution in OPM can be found in the existing scientific literature. The concept of multi-criteria optimization implies a multi-objective modelization. Multi-criteria optimization is used to find the best truck allocation combination while avoiding side effects caused by the omission of certain criteria [10].

2.2.2. Shortest Path (SP)

The SP between the loading and unloading point is defined in the literature as a problem in open-pit mining. Elbrond and Soumis [11] used a cost flow model and defined upper floors as the used network to find the SP between the loading and unloading points [12]. The Dijkstra algorithm [13] is used to find the SP between the source and the destination in most of the Linear Programming (LP) algorithms developed so far.

2.2.3. Optimization of Production and Allocation of Trucks

The production optimization phase is the term referring to the second subproblem. In the past, NLP, LP, and full mixed linear programming (MILP) algorithms have all been used to provide solutions for the production optimization. The implementation of the existing techniques reveals either the number of truck trips required to reach the desired production rate for each trajectory over a given time period, or the total tonnage to be moved from various loading points from the mine to the destinations[7].

2.2.4. Real-Time Distribution

Real-time decision-making on the location of the truck was first used in the early 1960s with the integration of radio communication capabilities. The main objective was to create communication between the dispatcher and truck drivers in a fixed truck distribution mine. There are three major categories for real-time FMS in mining systems based on the use of modern computers [10]:

- Fixed or Locked allocation systems
- Semi-automated
- Fully automated

There is no effort to load the transport units in the locked method. The rise of computer in the mining industry has led to two types of semi-automatic dispatch: passive and active. The computer played no role in decision-making in the aforementioned class. In the fully automated class, computers use current mine condition information as inputs, process it using models, and recommend a list of assignments to the dispatch. A central server gathers information on the present status of the mine, as well as the condition and positioning of the equipment inside the operation, and provides the assignment to the trucks.

The assignment problem and the transport problem approach are the main approaches that govern the dispatch procedure:

➢ The assignment problem was mostly used to assign trucks to a location. The assignment model suggests that mining trucks should be assigned to minimize waiting time: time between trucks, and excavator inactive time.

➢ One of the reliable methods for real-time truck distribution in an OPM is the model developed by Temeng, et al. [12].

2.3. Bucket truck Distribution Strategies

The goal of the distribution system is to increase productivity. Reducing the waiting time for trucks near used shovels is a part of the distribution methods considered in the literature. Truck use will increase if the waiting time is reduced. Real-time management is the concept of which the FMS problems are based [10] [14].

2.3.1. The Approach of 1 Truck for *n* Pellets

The 1 truck for n pellets approach is the most common strategy used in mining. The truck is one of several heavy equipment that could be sent after the truck operator requested a new position. The pellet to which is assigned to the truck is determined by the dispatch's expertise or logical operating procedure. The truck is directed towards the shovel. This strategy is implemented in a single step.

2.3.2. The m Methods -Trucks-for-1-Excavator

The m-trucks-for-1-shovel strategy is based on a multi-step approach; truck allocation choices will take into account the m trucks being shipped, one shovel at a time. To be more precise, the heavy machinery is given priority first according to how late it is in relation to the production schedule. Next, the dispatcher places the shovel at the top of list of priorities on the nearest truck.

2.3.3. The *m*-Trucks to the Act n Methods - Shovel

According to the estimated availability of trucks and shovels, the dispatcher takes into account m trucks and n shovels at once and assigns the soliciting truck to the best loader. Only the truck that answers the call is involved. In this technique the following equation must be validated as $m \geq n$.

3. PROBLEMATIC

The term "FMS" is used to describe a number of approaches to fleet management issues. It comprises strategic planning coupled with fleet operation supervision and management based on the accessibility of transportation resources. Some of FMS's objectives include lowering risks, enhancing service quality, and increasing operational effectiveness.

Dynamic transportation problems include real-time fleet management issues. The definition of a dynamic problem is given by Powell, et al. [15]:

"A problem is dynamic if decisions must be made before all information is known and be modified when new information is denied".

The real-time FMS aims to:

• The dispatcher must assign a new requirement or service request that needs at least one vehicle in the fleet to respond while the previous cycles are executing.

• The cycles must operate efficiently to complete the planned missions.

The integration of the FMS in mines aims to maximize mine production and efficiency [16]. The goal of the FMS is to maximize mine output while minimizing inventory handling feeding the processing plant at the planned rate and meeting grade constraints.

The mining operations involve different equipment such as drills, draglines, bulldozers, shovels and trucks, as shown in Figure 1.

Figure 1. Mining operations in an open pit

The transport operation is where the shovels load the trucks with the extracted materials to transport them to different destinations in the mine. There are either the Hoppers or the stockpiles. The truck is used to transport material from a loading point to an unloading point. The cycle is a sequence of operations performed by each truck, which is repeated till the end of the shift as shown in Figure 2.

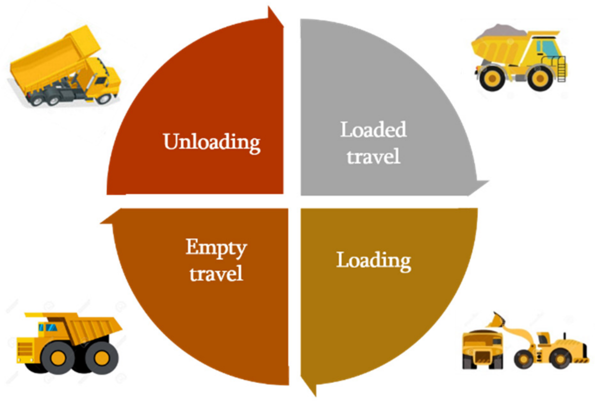

Figure 2. Truck cycle

There is a truck allocation problem in OPM. In the case of a mining fleet, trucks must go from a loading point to an unloading point multiple time. A truck can visit a point more than once. The travel times between points are short and the number of points is too small. An extra waiting time was created at the loading point. The application of a classical model for solving vehicle assignment problems is more difficult because of these differences.

FMS have been utilized in OPM since the 1960s [5] as a result of the deployment of operations research methodologies as a key method of addressing the high cost of material transportation, particularly in OPM. To make the crucial decision of truck allocation, various approaches and techniques based on simulation, heuristic procedures, and mathematical programming have been used.

These methods have a well-known implementation. Since weaknesses can be observed with respect to the dynamics and heterogeneity [17] of a mine, the proposed solutions are not accurate [18], and the information used in the calculations is just estimated [19], none of them are able to simultaneously achieve all the objectives and constraints of the mine. According to the study of Ali Moradi Afrapoli and Hooman Askari-Nasab [7], there are limitations to the methods used:

- Both short- and long-term goals are not achieved by the proposed FMS
- Most models assume a constant average grade for each size front and don't cover the entire life of the mine
- One of the major factors in the deviation of the production rate is the loss of tons associated with the movement of shovels from one level to another
- The models must fully represent the mining activity and account for the variety of the vehicles,
- Real-time data should be used to determine the shortest path.
- Transport or assignment approaches are not recommended in the dispatch procedure. There are transshipment points through which materials are transported from suppliers to demand points as well as delivery and demand points. Transshipment points can be defined as system inventories or network intersection points.
- Trucks and shovels don't perform well together, which causes a truck line to form near the shovels and Hoppers, and shovel operating periods are excessive.

The challenge is figuring out how to enhance the execution of one or more dispatch targets while minimizing the idleness of the vehicles in the mine by choosing the best location for a transport truck. This will increase the effectiveness of the material handling operation.

4. MODELING

A mathematical model is formulated to solve the problem based on recently developed models in the literature [20] [21] [22] [23] [24] [18] [25]. The model takes into account the objectives and constraints of the production plan in an OPM and uses a MILP to minimize the transportation cost in terms of time.

Any shovel in our model can be assigned one of the different trucks. Throughout the shift, the material must be moved from the pit to which the shovel is allocated to. Shovels can be loaded into a truck one at a time. While one vehicle can unload at a time in a hopper, multiple trucks can unload at once in a stockpile.

The number of trucks required to allow the realization of the transport of phosphates is determined by the cycle time of the truck. The objective function is to minimize the cost that shovels and trucks take to perform the operations, and the variables used in the model are presented in Table 2.

Our problem considers a set of truck categories noted D, for each truck category $d \in D$ there are N^d trucks of capacity Q^d. A truck starts its cycle at the loading point $i \in I$ corresponding to a loader $l \in L$, with the quantity to be loaded Q^i and ends its journey at the unloading point $j \in J$ corresponding to a given hopper or stockpile $h \in H$, denoting d_{ij}, the distance between the loading and unloading points.

The objective is to maximize the profiles in the mine for one shift. This is done by minimizing the cost of transportation between the different loading points and the different unloading points. As the truck fleet is heterogeneous, the profit associated with a defined trip depends on the type of truck used. For this reason, we will define C_{ijd} as the profit of the trip between loading point i and the hopper with a truck of type d.

The objective function (1) is:

$$\min z = \sum_{i \in I} \sum_{j \in J} \sum_{d \in D} C_{ijd} X_{ijd} \tag{1}$$

Table 1. The model's decision variables and parameters

Parameters	
Q_i	Quantity demanded of the extracted layer from the point of origin *i*
K_i	Quantity prepared by the Preparatory Works Service at point *i* and ready to be transported
d_{ij}	Distance between distance between hopper *j* and origin *i*
a_d	Average transportation cost of truck type *d* (in DH/h)
V_{ld}	Speed of the truck of type *d* from the origin *i* to the hopper
V_{rd}	Return speed of truck type *d* from hopper to point *i*
Cap_d	Capacity of the truck of type *d*
T_{ld}	Loading time of the truck of type *d*
T_{unld}	Unloading time of the truck type *d*
T_d	Average time of use of the truck of type *d*
N_d	Number of available trucks of type *d*
The decision variables	
X_{ijd}	Number of total trips of truck type *d* from point *i* to the hopper *j* during a shift.

The parameter C_{ijd} can take into account the transport cost on the route *ij*, the quality of the ore in *i*, the distance between *i* and *j*, the type of trucks, the tonnage, etc.

In our case, the transport profit is calculated by considering the average transport cost (DH/h) between the loading point and the unloading point considering the distance and the speed of transporting the ore using the available trucks:

$$C_{ijd} = \alpha_d\left(\frac{d_{ij}}{V_{id}} + \frac{d_{ij}}{V_{rd}}\right) \tag{2}$$

All of the constraints that control how the different trucks are used must be taken into account in order to model the issue accurately. The issue requires considering various site limits:

1) Resource capacity: Excavation and shovel loading capacity constraint.

$$\sum_{j\in J}\sum_{d\in D} Cap_d \times X_{ijd} \le K_i \;\; , \;\forall i \in I \tag{3}$$

2) Customer demand: Ensuring customer satisfaction.

$$\sum_{j\in I}\sum_{d\in D} Cap_d \times X_{ijd} \ge Q_i \;\; , \;\forall i \in I \tag{4}$$

3) The capacity of the truck fleet: the availability of trucks: Real total truck travel time does not exceed average truck travel time.

$$\sum_{j\in J}\sum_{i\in I} X_{ijd}\left(\frac{d_{ij}}{V_{ld}} + \frac{d_{ij}}{V_{rd}} + T_{ld} + T_{unld}\right) \le T_d N_d \;\; , \;\forall d \in D \tag{5}$$

4) Integrity and non-negativity: To have a functional model, we need to ensure integrity of the variables.

$$X_{ijd} \in N, \forall i \in I, \forall j \in J, \forall d \in D \tag{6}$$

5. CASE STUDY

5.1. Resolution Approach

Trying to find a realizable solution for MILP is equivalent to finding a point in the realizable solution. If a MILP has a feasible solution, it's an NP-complete problem. There are two methods for solving NP-hard problems. The best solution to a problem is sought by exact methods. Their time tends to grow larger with the size of the NP-hard problem instance. On the other hand, heuristics [26] aim at producing feasible, but not necessarily optimal, solutions to problems without requiring significant computation time.

Our transport problem is solved using two different methods MATLAB and CPLEX during 0.79 and 0.52 seconds, respectively, and for a node number equal to 10 and 14, respectively.

5.2. Results

We provide a real-world example based on information from a Moroccan mining company to test the proposed approach. The allocation takes place at the start of each shift in the Benguerir mine. One shovel is assigned to a number of trucks. Due to data confidentiality, we created virtual data based on the actual situation in the mine. The fixed allocation system employed in the mine to allocate trucks to various shovels is used as a model to show the advantages of the suggested strategy. The suggested models are evaluated using two distinct types of trucks with various payloads. Three 190T trucks and six 136T trucks are available. A number of three loading points (5254T, 6402T, and 4220T) and one unloading point are assumed to be accessible.

Tables 3 and 4 show the result of assignment trucks during a shift by changing the objective using CPLEX and MATLAB simultaneously resolution.

Table 3. The proposed model solution to the problem of allocation of truck shovels with CPLEX

Ore point	Trips 136T	Trips 190T	distance	dump site demand	Quantity available	Quantity transported
1	11	4	5.3	2256	5254	2256
2	13	2	5.9	2146	6402	2148
3	7	12	5.7	3220	4220	3232

Table 2. The proposed model solution to the problem of allocation of truck shovels with MATLAB

Ore point	Trips 136T	Trips 190T	distance	dump site demand	Quantity available	Quantity transported
1	11	4	5.3	2256	5254	2256
2	13	2	5.9	2146	6402	2148
3	14	7	5.7	3220	4220	3234

Based on the provided results, it is important to note that the CPLEX resolution is the most advantageous in respect to three criteria:

- Resolution time: with CPLEX resolution achieving less processing time.
- Resolution points.
- CPLEX proposes best rate of the affectated trucks in OPM with the minimal loss. In other words, the quantity demanded is more close dump site demand.

Our model achieved good results in satisfying the processing demand of the quantities available at each point with an overall transport cost and minimum time. They are used to maximize the number of trips while taking into account truck availability, capacity heterogeneity, and all of the constraints that govern the use of different trucks in the mine environment.

6. CONCLUSION

This article describes a method for allocating shovel trucks in OPM while taking into account the mining environment's constraints. The main advantages of such a model are its simplicity and precision. It provides a variety of benefits, including the ability to utilize shovels in a heterogeneous fleet and a variety of trucks with diverse capacities within the transport fleet.

Within the digital transformation project of the mining industry, the dispatching is only a part of the whole mapping of the mining processes that must be automated. We are working on the automation of the whole logistic process that manages the transport in a digital mine, namely the maintenance part and the dashboards. In the perspective of this work, we will develop the model of the second phase which will allow us to assign trucks in real time and we will develop a system of distribution of trucks in a heterogeneous environment by taking into consideration the queue and the quality of the transported product.

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