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HEURISTIC RULE-BASED TRUCK DISPATCHING SYSTEMS IN OPEN PIT MINES

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ABSTRACT

In this study, the existing truck dispatching criteria currently available are reviewed and their definitions, primary considerations and basic characteristics are presented. Small example problems are given for two shovel operations. Comparisons are made among the basic heuristic polices commonly applied in open pit mines.

Keywords: Heuristics, Truck Dispatch, Open Pit Mining, Haulage Systems

AÇIK-OCAK İŞLETMELERİNDE HÜRİSTİK TABANLI KAMYON SEVK SİSTEMLERİ

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ÖZET

Bu çalışma da, mevcut olan Hüristik kamyon sevk kriterleri incelenmiştir. Bu temel hüristik kriterlerin tanımları yapılmış ve ana özellikleri verilmiştir. İki ekskavatörlü küçük bir örnek problem sunulmuştur. Açık ocak işletmelerinde kullanımlarım alanları karşılaştırılmıştır.

Anahtar Kelimeler : Hüristik Kurallar, Kamyon Sevk Sistemi, Açık Ocak Madenciliği, Taşıma Sistemi

1. INTRODUCTION

A heuristic procedure or algorithm can be defined as a relatively simple formula or procedure applied to solve a problem. In mathematical terms, heuristic algorithm in most cases can solve a problem, but cannot guarantee an optimal solution. In general, heuristic procedures consider only current objectives without consideration of future events or long-term planning goals. Often, the solutions of heuristic procedures are based on local (i.e. individual elements and short time) optimization. The dispatching algorithms based on heuristic rules are easier to
implement and do not require much computation when making dispatching decisions in real-time. Typically, all heuristic rules are applied one-truck-at-a-time. That is, current truck assignment decision is made with indifference to the assignment of other trucks that will be made in the near future. Also, most heuristic rules ignore essential constraints or secondary goals of system operation such as maintaining product grade requirements by balancing production ratios among available loading sites.

In this study, the existing truck dispatching criteria currently available are reviewed and their definitions, primary considerations and basic characteristics are presented. The basic rules can be grouped into three categories as: criteria originated from consideration of optimizing equipment idle time measurements, criteria originated from maximizing truck productivity, and criteria originated from the optimization of the shovel production requirements. In the following sections, eight basic heuristic rules are explained.

2. BASIC TRUCK DISPATCHING HEURISTICS

2.1 Overview of Heuristics

Computerized truck dispatching systems require a procedure for assigning trucks to shovels in an open-pit truck/shovel haulage system. Each computerized system developed should employ a unique policy. In order to maximize fleet efficiencies, several methods ranging from simple heuristics to complex mathematical procedures can be applied in this decision-making process. The objective of any truck dispatching procedure is to increase the productivity of the system with the given fleet of trucks and shovels or a significant reduction in the number of trucks and shovels needed for a given production target subject to avariety of practical constraints. Reduction in truck and shovel waiting times contribute much to these goals. Dispatching policies consider different objectives in varying degrees of sophistication. For the heuristic rule-based dispatching systems, usually the dispatching decisions are taken when the truck reaches the dump site. They invoke a chosen heuristic rule; say minimizing truck waiting time, at the time of making a dispatching decision. The computer then checks the current status of the equipment in the mine and dispatches the trucks to the most appropriate shovel at that instant. The most appropriate shovel is determined as a function of the dispatching policy applied.

2.2 Fixed Truck Assignment (FTA)

In this strategy, each truck is assigned to a particular shovel and dump point at the beginning of the shift and remains in the same circuit for the entire duration of the shift. The number of trucks that are assigned to a particular shovel is a function of the performance variables of the shovel under question, the desired production level from that shovel, and the expected travel and waiting times for the trucks in the haulage network. There is no changing of assignment during the operation (i.e. locked-in dispatching). Only in the event of a change in the operational conditions such as shovel breakdowns, trucks are reassigned. Due to stochastic nature of haulage operations and random occurrence of down times, formation of long queues at a specific shovel occurs with some frequency. This strategy has been proven to be the most inefficient. This is mainly due to the fact that the equipment does not operate at constant rate. The reason for this is due to the variation of event times, along with the interactions between trucks at the road intersection points. Furthermore, both trucks and shovels are down for maintenance and servicing. The shovels may sometimes be required to move to new locations during the shift and unpredicted breakdowns may also occur. Under this policy, it is very common to find several trucks waiting in queue at one shovel for loading while another shovel may have been idle for a long time due to the unavailability of trucks. The highest productivity that this system can achieve is when all shovels operate continuously. If one truck is being loaded, the other trucks in the same circuit are either traveling empty or loaded, or are in the process of dumping. This implies efficient operation of the system when trucks are evenly spread out. It is assumed that the required number of trucks is always available. However, the system often suffers from a lack of trucks due to the high costs involved. The choice of fixed truck assignment strategy may be the result of the evaluation of the operating performance data, such as shovel load and delay times, truck cycle and wait times, production targets, equipment utilizations, etc. This strategy can serve as a baseline by which the effectiveness of other heuristic rules can be measured and it can also be used to validate the simulation model.

2.3 Minimizing Shovel Production Requirement (MSPR)

The objective of this criterion is to achieve the shovel target production, which has been optimized by linear programming or other approaches. When shovels have production targets, a simple heuristic rule is to assign the empty truck at the dispatching point to the shovel which is most behind in its production schedule, taking into account the total capacity of the trucks en route. This rule is most suitable for mines having quality control objectives such as blending requirements. Tan and Ramani (1992) used the following formula for identifying the most lagging shovel.

$$k{:}\arg\max_i\{(TNOW*PO_i / TSHIFT) - P_i\}$$

Where

k : shovel to which the truck is to be assigned

TNOW: time elapsed from the start of the shift

TSHIFT: total shift time (i.e. 480 minutes)

P_i : actual shovel production at current time

PO_i : shovel target production

2.4. Minimizing Truck Waiting Time (MTWT)

In this criterion, an empty truck at the dispatching point is assigned to the shovel which will result in the least truck waiting time for the truck to be loaded by the shovel. The objective of this criterion is to maximize the utilization of both trucks and the shovels. However, when the number trucks in the system is relatively low and the trucks do not wait at the shovel very often; this rule may result in underutilization of some shovels and, consequently, shovel idle times since several shovels may have zero truck waiting times at the same time. Secondary tie-breaking rules may be necessary for dispatching the trucks and these rules may dominate the overall dispatching decisions. This policy is recommended in mines where specific shovel production targets and grade requirements do not exist.

The decision-making criterion is as follows:

$$k{:}\ \arg\min_i\{\max\{SR_i - TR_i\}, 0\}$$

where
k : Shovel number to which the truck is assigned
SR_i : ready time of shovel for loading this truck
TR_i : ready time for the truck to be loaded by the shovel.

It should note that if ($SRi - TRi$) is greater than zero, then it corresponds the truck waiting time at the shovel. Truck ready time is defined as the predicted travel time from dispatching point to the shovel and it is determined from the summation of current time, and average truck travel time from dispatching point to the shovel. Shovel ready time is defined as the predicted ending time for the shovel to complete loading all the trucks in the queue at the shovel including the one being loaded and those that en route to this shovel, but have not reached yet.

2.5 Minimizing Shovel Waiting Time (MSWT)

In this policy, the empty truck at the dispatching point is assigned to the shovel which has been waiting (longest time) for a truck or is expected to be idle next. The objective of criterion is to maximize the utilization of shovel by minimizing its waiting time. One of the advantages of this criterion is that it tends to balance out shovel productions more evenly and give results closer to objectives. But, this causes a decrease in the overall production because of long cycle time required to reach the furthest shovel. This policy is recommended in mines having strict grade requirements and it works better in large open-pit mining operations. If the shovels rarely wait for trucks in the undertrucked systems, the secondary tie breaking rules may be necessary to make the dispatching decisions.

The decision-making criterion is as follows:

k: $\arg\min_i\{TR_i - SR_i\}$
where
k : Shovel number to which the truck is assigned
SR_i : ready time of shovel for loading this truck
TR_i : ready time for the truck to be loaded by the shovel.

2.6. Minimizing Truck Cycle Time (MTCT)

In this criterion, the empty truck at the dispatching point is assigned to the shovel which will provide the minimum value for the expected truck cycle time for this truck. The objective of this criterion is to maximize the number of truck cycles during the shift. The truck cycle time (TCT) is a function of mean travel time from dumping point to the shovel assigned, waiting time at the shovel after truck's arrival, mean loading time required by the shovel, mean travel time from shovel to the dump point, and the mean truck dumping time.
The decision-making criterion is as follows:

k: $\arg\min_i\{TCT_i\}$
where
k : Shovel number to which the truck is assigned
TCT_i: truck cycle time for shovel i.

Clearly, this criterion is strongly affected by the value of the truck cycle time and the overall resulting effect is that more trucks are assigned to the shovels closer to the dispatching point.

2.7 Minimizing Shovel Saturation or Coverage (MSC)

In this criterion, the empty truck at the dispatching point is assigned to the shovel which has the least degree of saturation among the available shovels. The objective of this rule is to assign the trucks to the shovels at equal time intervals to keep a shovel operating without waiting for trucks. The degree of saturation is defined as the ratio between the number of trucks that have been assigned and the desired number of trucks that should have been assigned to the shovel under consideration. The desired number, also referred to as the saturation number, is the number of trucks given by the ratio of the average travel time for the truck from the dispatching point to the shovel to the average shovel loading time for the truck.
The decision-making criterion is as follows:

k: $\arg\min_i\{(SR_i - TNOW)/TT_i\}$

where
k : Shovel number to which the truck is assigned
SRi : Ready time of shovel for loading this truck
TNOW: Time elapsed from the start of shift
TTi : Mean travel time from dispatching point to the shovel to be assigned.

This dispatching criterion attempts to utilize all the shovels in the system evenly and at the same time, keeps a balance between the truck requirements. This dispatching policy would be desirable in mines with a relatively sufficient number of available trucks to meet the shovel requirements.

2.8 Earliest Loading Shovel (ELS)

In this criterion, the empty truck at the dispatching point is assigned to the shovel where it is expected to be loaded at the earliest future point in time. This rule tends to reduce truck idle time and prevent long waiting lines. It might result in unbalanced production among the shovels since it encourages dispatching trucks to closer shovels. This might occur seriously if the system is undertrucked.

The decision-making criterion is as follows:

$$k: \mathrm{argmin}_i \{ \max \{ TR_i, SR_i \} \}$$

where

k : shovel number to which the truck is assigned
SRi : Ready time of shovel for loading this truck
TRi : Ready time for this truck to be loaded by the shovel.

In this dispatching criterion, the distances between the dispatching point and the shovels have significant effect over the dispatching results.

2.9 Longest Waiting Shovel (LWS)

In this criterion, the empty truck at the dispatching point is assigned to the shovel which has been waiting for a truck longest. The objective of this policy is to balance the production among the shovels.

The decision-making criterion is as follows:

$$k: \mathrm{argmax}_i \{ \max \{ TR_i - SR_i \}, 0 \}$$

where

k : shovel number to which the truck is assigned
SRi : Ready time of shovel for loading this truck
TRi : Ready time for this truck to be loaded by the shovel.

It must be noted that if $TR_i - SR_i$) is greater than zero, it corresponds to the shovel waiting time for this truck. This rule is generally preferred if the number of trucks in the system is small. If the number of trucks in the system is large, secondary rules will be required to make truck assignment decisions.

3. CONLUSIONS

The heuristic rule-based truck dispatching is very simple and do not require much computations. The economic feasibility of using a truck dispatching system in an open pit operation is very crucial. The selection of dispatching policies must be done according to the objectives of a particular operation, which may change with. The mine management should decide which dispatching procedure is to be used in a specific mine. The success of a dispatching procedure depends to a great extend upon the number of operating trucks in the mine from undertrucked to overtrucked situations. The major purpose of providing a dispatching system is to maximize productivity of the system. Also, heuristic rule-based truck dispatching provide truck assignments to the shovels only in a one-truck-at-a-time and myopic decisions are made. Finally, each mine is unique and should evaluate each policy separately according to its objectives. Implementing a truck dispatching system with a specific dispatching policy may not ensure the desired benefits for all situations.

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No	Arrival Time at Dispatch Point, TNOW, (min)	Travel Time to Shovel, (min)		Time Joining Shovel Queue		Waiting Time (min)		Time Shovel is Seized		Loading Time (min)		Time Shovel is Released		Shovel Ready Time, SR_i		Truck Ready Time, TR_i		Difference SR_i - TR_i		Max $\{SR_i-TR_i,0\}$		Min{ max{SR_i-TR_i,0}}	Assigned Shovel Number, k
		Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2		
1	0	5	6	5	6	-5	-6	5	6	2	3	7	9	0	0	5	6	-5	-6	0	0	0	1 or 2
2	5	5	6	10	11	-3	-2	10	11	2	3	12	14	7	9	10	11	-3	-2	0	0	0	1 or 2
3	6	5	6	11	12	1	2	12	14	2	3	14	17	12	14	11	12	1	2	1	2	1	1
4	8	5	6	13	14	1	3	14	17	2	3	16	20	14	17	13	14	1	3	1	3	1	1
5	9	5	6	14	15	2	5	16	20	2	3	18	23	16	20	14	15	2	5	2	5	2	1
6	18	5	6	23	24	-5	-1	23	24	2	3	25	27	18	23	23	24	-5	-1	0	0	0	1 or 2
7	26	5	6	31	32	-6	-5	31	32	2	3	33	35	25	27	31	32	-6	-5	0	0	0	1 or 2
8	32	5	6	37	38	-4	-3	37	38	2	3	39	41	33	35	37	38	-4	-3	0	0	0	1 or 2

Figure 2.1 An Example Problem for Minimizing Truck Waiting Time Rule (MTWT).

No	Arrival Time at Dispatch Point, TNOW, (min)	Travel Time to Shovel, (min)		Time Joining Shovel Queue		Waiting Time (min)		Time Shovel is Seized		Loading Time (min)		Time Shovel is Released		Shovel Ready Time, SR_j		Truck Ready Time, TR_j		Difference $TR_j - SR_j$		Min{$TR_j - SR_j$}	Assigned Shovel Number, k
		Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2		
1	0	5	6	5	6	-5	-6	5	6	2	3	7	9	0	0	5	6	5	6	5	1
2	5	5	6	10	11	-3	-2	10	11	2	3	12	14	7	9	10	11	3	2	2	2
3	6	5	6	11	12	1	2	12	14	2	3	14	17	12	14	11	12	-1	-2	-2	1 or 2
4	8	5	6	13	14	1	3	14	17	2	3	16	20	14	17	13	14	-1	-3	-3	1 or 2
5	9	5	6	14	15	2	5	16	20	2	3	18	23	16	20	14	15	-2	-5	-5	1 or 2
6	18	5	6	23	24	-5	-1	23	24	2	3	25	27	18	23	23	24	5	1	0	2
7	26	5	6	31	32	-6	-5	31	32	2	3	33	35	25	27	31	32	6	5	0	2
8	32	5	6	37	38	-4	-3	37	38	2	3	39	41	33	35	37	38	4	3	0	2
9	33	5	6	38	39	1	2	39	41	2	3	41	44	39	41	38	39	-1	-2	-2	1 or 2

Figure 2.2 An Example Problem for Minimizing Shovel Waiting Time Rule (STWT).

No	Arrival Time at Dispatch Point, TNOW, (min)	Travel Time to Shovel, TT_i (min)		Loading Time, LT_i (min)		Truck Return Time, $RT_{i,}$ (min)		Expected Truck Waiting Time, WT_i (min) (assumed)		Truck Cycle Time, TCT_i =TT+RT+LT+WT (min)		Min{TCT_i} (min)	Assigned Shovel Number, k
		Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2	Sh 1	Sh 2		
1	0	5	6	2	3	6	7	3	0	16	15	15	2
2	5	5	6	2	3	6	7	2	1	15	16	15	1
3	6	5	6	2	3	6	7	1	2	14	17	14	1
4	8	5	6	2	3	6	7	4	1	17	16	16	2
5	9	5	6	2	3	6	7	5	2	18	17	17	2
6	18	5	6	2	3	6	7	4	2	17	17	17	1 or 2
7	26	5	6	2	3	6	7	2	3	15	18	15	1
8	32	5	6	2	3	6	7	0	2	13	17	13	1
9	33	5	6	2	3	6	7	1	3	14	18	14	1

Figure 2.3 An Example Problem for Minimizing Truck Cycle Time Rule (MTCT).