DETERMINATION OF SHOVEL -TRUCK PRODUCTIVITIES IN OPEN -PIT MINES

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DETERMINATION OF SHOVEL - TRUCK PRODUCTIVITIES IN OPEN - PIT MINES

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Abstract: *In the open-pit mines, in order to improve productivity, they used to large numbers of heavy equipment. Due to the huge investments involved, no mine can afford to have invested then its equipment inefficient work, increased the idle time of equipment. Therefore, in during the selection process of equipment, consideration must be given to the proper matching of equipment. By comparing truck and shovel productivities, it can be seen whether they match or not. The paper deals with the productivity analysis of different shovel-truck combination conducted for two open pit coal mines and then will compare their productivities.*

Key words: *Equipment selection, Open pit mine, Matching of equipment, Shovel - truck productivity.*

1. INTRODUCTION

With the advent of larger machines capable of handling material at greater pace from deeper open pits, open pit mining has become of greater importance compared to underground methods. It also means the costs of capital is larger, the maintenance costs is higher, etc.

Based on the correct choice of capital equipment, probabilistic analysis of open pit haulage and loading gives an optimal grade for haulage, and an economic upper and lower bound for the truck fleet size and the productivity rate of a single shovel operation at each working site. The purpose of stochastic analysis of loading and haulage is to minimize the sum of the loading and haulage units cost at a given work site. This is accomplished by:

1. Choosing the best shovel and truck types for the mine conditions.
2. Selecting the corresponding optimal grade for the given truck type.
3. Selecting the correct economic range of truck fleet size, and productivity rate for the operating shovel at a given work site.

The improvement of mine productivity, by minimizing the idle time of equipment, creates the necessity of analyzing complex problems associated with the mining operations. The present study deals with the analysis of productivity field data for shovel-truck operations in two open pit mines and comparing their productivities.

2. THE CORNERSTONE OF SELECTION OF EQUIPMENT

Improved productivity can be achieved through the mechanization of all levels of productivity in open-pit mines. This requires must be selection of proper equipment (including operational cost and adaptability directly affects cost of productivity). Selecting proper equipment depends on: the size of project, the nature of material handled, the project size conditions, the lead for unloading excavated material, the type of equipment available on the market, and the comparative price of equipment.

In open-pit mines, the primarily equipment fleet used are shovel and truck, depending on the nature of the rock, overburden and working conditions. The size of the trucks will depend on shovel size, and the idle time of shovel and bunching of truck at the shovel is to be avoided base on selection of equipment fleet.

In selection process of a truck fleet, need to attention the following points:

1. The truck payload capacity should match with capacity of shovel.
2. The physical features of truck (ruggedness of construction, horse-power provided, grade ability, etc.) should suit the job conditions.
3. It should have reasonably high availability ratios.
4. The unit's price and operating costs should be the lowest.
5. The material characteristics (density, swell factor, size of fragmentation), as well as the climatic conditions (altitude and rainfall) should be taken into consideration.
6. The haul road characteristics (length, gradient, surface and type) should also be considered.

The suitability of an excavator to a hauling unit is based on the following points:

1. The minimum capacity of hauling unit should be approximately four times large than be bucket capacity.

2. The maximum capacity of hauling unit depends on the mine conditions (differs from mine to mine). In general, it should not exceed 6-8 times the bucket capacity.

An "efficient" mining operation is defined as: the moving of maximum amount of rock/overburden in shortest period of time, at the lowest possible cost. A number of factors contribute to mining efficiency and area related to the areas of machine activity (loading area, haul area, and dump area).

In order to increase efficiency in the loading area, can be achieved by: proper equipment selection (loader-truck combination), and properly equipped loading machines. For example, when loading material from a set stockpile, teeth mounted on the loader bucket can aid in penetration on the rock. Proper rock size will add to efficient operation of the loader. A smooth floor area will help to prevent premature loader and tire failures.

When transport the materials, the proper spotting of a hauling unit before loading will aid in optimizing productivity processing. Proper matching of the loader to the truck, with the loader having sufficient jump height and reach is important. The reaching back of the bucket to full jumping position before loader starts positioning should not be necessary. Bucket width-truck bed ratio should be correct to ensure a proper load distribution in the truck.

Improvements to the dumping area, should include finishing the haul road as far as possible into the dump area, to minimize the haul units travelling areas of high rolling resistance. The jumping point should be so located such that a minimum of maneuvering and waiting time is involved.

3. THE MATCH FACTORS OF EQUIPMENTS

Caterpillar's computer field analysis of a number of shovel-truck operations indicated that the primary cause for inefficiency is the mismatching and bunching of trucks at the loading points. From this analysis it is possible to predict the effect of mismatching and bunching. The term used in this theoretical prediction is called "Match Factor" and it is defined as:

$$Match\,Factor = \frac{\#loader\,x\,load\,cycle\,time}{\#haulers\,x\,hauler\,cycle\,time}$$

The perfect match point from the theoretical stand point is at 100 percent truck-shovel fleet efficiency, which occurs when the match factor equals 1. This requires the elimination of bottlenecks in the loading and dumping areas, and on the haul roads. This can be achieved by the spacing of trucks at the beginning of each shift. It also requires that the trucks have the weight appropriate to horsepower ratio to handle the haul road grades.

3.1. The mismatch of shovel-truck

When the truck productivity just matches the shovel productivity, this is generally known as the perfect match point and at this point match factor is equal to 1. If fewer trucks are used, then there will be an excess of loader capacity and the loader will have unnecessarily high idle times. If more trucks are used, then there will be an excess of truck capacity, which will cause one or more trucks to be shut down. An unutilized loader/hauler unit is due to what is called a mismatch.

3.2. The bunching of trucks

The irregular arrival of trucks at the loading point is known as bunching which causes reduction of the operating efficiency, and higher idle time for the truck fleet. The greater the bunching, the greater is the loss in efficiency. Some of the factors leading to bunching of hauling units includes: changes in the working conditions (rain, poor visibility, etc.), hauling units not uniformly spaced, hauling units of using different capacities, poor fragmentation or variations in the ore characteristics resulting to increased loading time, and clear the pit area time elements.

4. DETERMINING OF PRODUCTIVITY INDEX

The productivity Index (P.I) has been successfully utilized by modem management as a tool to indicate shift performance. It serves to control day-to-day and shift-to-shift operations in open-pit mines. The ratio of actual productivity to the potential productivity is termed as productivity index, and it is expressed through:

$$P.I = \frac{Actual\,Production}{Potential\,Production} x1000$$

5. SOME OF CASE STUDIES IN OPEN-PIT MINES

In the open-pit mines, the most of equipment to load and haul are excavator and truck, includes: EKG, KOMATSU, HD, CAT, VOLVO… etc. In this paper, the authors were survey at the two open-pit coal mines referred to in the text as Case I and Case II. The particulars are as given below:

Case I: [2], [3]

Excavator:	Type: Power Shovel
	Capacity: 4.6 m^3
Truck:	Type: HD785-3
	Capacity: 50 tons
	Number: 5
	Haul distance: 1.04 Km
	Grade: 1:16
Overburden:	soft rock and poorly fragmented

Case II: [2], [3]

Excavator:	Type: Power Shovel
	Capacity: 4.6 m^3
Truck:	Type: CAT – 769D
	Capacity: 35 tons
	Number: 3
	Haul distance: 0.6 Km
	Grade: 1:18
Overburden:	hard rock, and poorly fragmented

5.1. The cycle time of the shovel and truck in open-pit mines

Productivity is dependent both on the number of trucks in use and the number to trips they make per shift. The latter, it depends on time to complete one cycle of operation consisting of loading time, hauling time, dumping time, and time of back to the load point. This cycle time also continually changes as the face advances, since both hauling and return times will increase. When analysis productivity of shovel-truck fleet under a new set of conditions, requires time studies to be completed in order to find the time for each segment of cycle time. This data is required for the shovel as well as the trucks in each shift, so as to get representative data. This cycle time is input data for subsequent calculations including: matching truck productivity, effects of bunching, finding mismatch, predicting future cycle times, as well as compare of productivities under different sets of conditions.

Table 1. Average cycle time of each segment for shovel

	Case I (sec.)	Case II (sec.)
Bucket opening, unloading into truck	4.50	4.36
Finish unloading swing and touch soil	9.38	10.53
Digging and Filling bucket	7.67	11.65
Swing and take position to unload	8.39	10.06
Total cycle time	**29.96 = 0.49 min**	**36.62 = 0.61 min**

Table 2. Average cycle time of each segment for truck

	Case I (sec.)	Case II (sec.)
Reverser and take position	18.17	22.19
Wait for loading	103.20	224.28
Clear pit area	35.21	28.23
Load journey	137.61	113.94
Unloading	76.82	57.14
Empty journey	155.46	122.61
Total cycle time	**527.05 = 8.78 min**	**568.42 = 9.47 min**

Table 3. Average Loading and Truck cycle time

Case #	Shovel cycle time (sec.)	Shovel average loading time (min.)	Truck average cycle time (min.)
I	29.96	1.72	8.78
II	36.62	3.74	9.47

5.2. Determining of the matching Shovel-Truck Productivity

The potential truck productivity has been plotted against the number of truck as shown in Fig. 1 and Fig. 2 for case I and II respectively. Sample calculations are given below for Case I:

$$Truck\ Pr\ oductivity = \frac{Payload\,x\,60}{Cycle\,Time\,(min.)}(t/hr)$$

$$= \frac{45\,x\,60}{8.78}(t/hr) = 310\,t/hr$$

$$Shovel\,Pr\ oductivity = \frac{Payload\,x\,60}{Average\,Loading\,time\,(min.)}(t/hr)$$

$$= \frac{45d\ x\,60}{1.72} = 1570(t/hr)$$

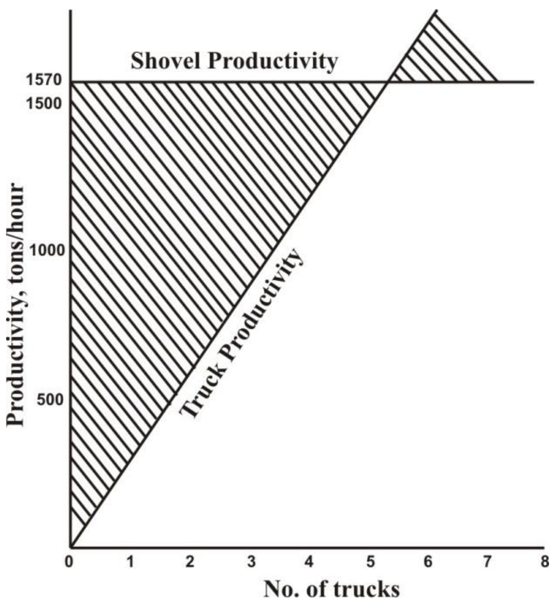

Fig. 1. Potential productivity rate, for Case I

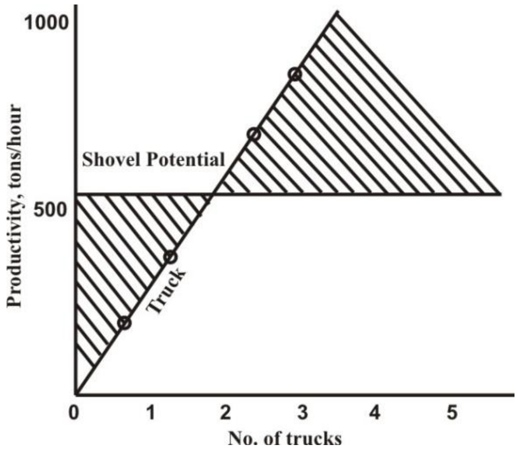

Fig. 2. Potential productivity rate, for Case II

From the figures, can be made the derivations following:

1. The potential truck productivity exceeds the shovel productivity when more than 5 trucks are used in Case I and more than 2.5 trucks in Case II.

2. The productivity of 5 trucks and 2.5 trucks in Case I and Case II respectively, just matches the shovel productivity.

3. If fewer trucks are used there will be an excess of shovel capacity as represented by the shaded area to the left of the match point.

4. If there are more trucks than required for a perfect match there is an excess of truck capacity which is represented by the shaded area to the right of the perfect match point.

The potential truck productivity will increase, but it cannot exceed the potential shovel productivity. This loss of productivity is due to mismatch. If more trucks are used and the shovel potential could not be attained, it would mean that addition loss of productivity is due to the bunching of trucks.

6. EFFECTS OF BUNCHING

The shovel and truck potential curves are as shown in Fig. 1 and Fig. 2, but the predicted actual curve is drawn as shown in Fig. 3 and Fig. 4 for Case I and Case II respectively. The relevant calculations are shown by equations below. The difference between the potential productivity of the fleet and the predicted productivity as represented by the shaded area is the losses due to the bunching of trucks.

Case I

It is observed that 20 trips are made by 5 trucks with the total productivity by these 5 trucks in an hour are:

= 30 x 34 = 1350 t/hr.

So the actual productivity per truck in an hour is:

= 1350/5 = 270 t/hr.

Case II

It is observed that 14 trips are made by 3 trucks with the total productivity by these 3 trucks in an hour are:

= 14 x 33 = 462 t/hr.

So the actual productivity per truck in an hour is:

= 462/3 = 154 t/hr.

6.1. The method to find a mismatch of equipment

The calculations made to get the match factor for trucks are given below for Case I:

Trucks (5 in number) = 50 tons capacity

The loading time = 1.72 min.

Average truck cycle time = 8.784 min.

Payload = 45 tons.

Shovel productivity = 30 trips of truck

$$Match\,Number = \frac{Average Truck\ Cycle\,time}{Average Shovel Load\ time}$$

$$= \frac{8.78}{1.72} = 5.11$$

$$Match\,Factor = \frac{Number\,of\ Trucks}{Match\,Number}$$

$$= \frac{5}{5.1069} = \ 0.979$$

Similar calculations for Case II, but the number of trucks are different Case I.

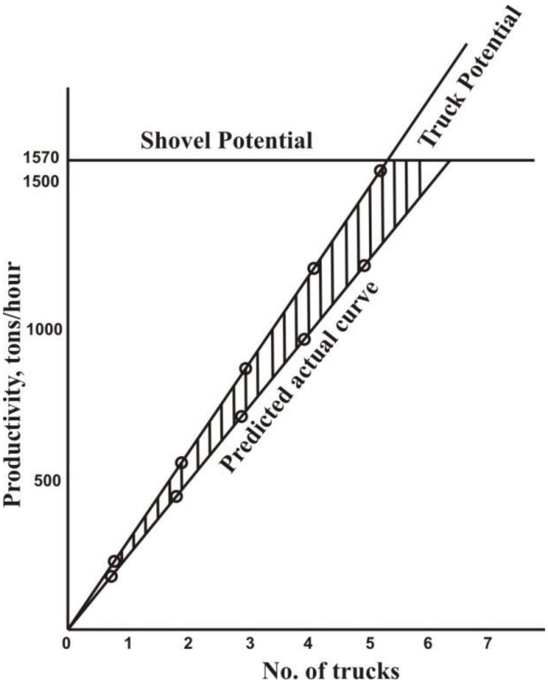

Fig. 3. Predicted actual curve, for Case I

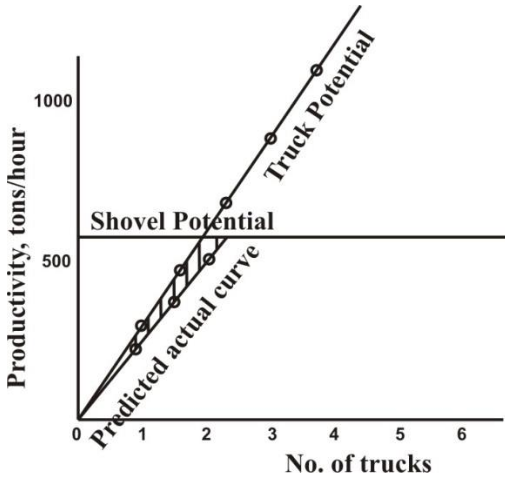

Fig. 4. Predicted actual curve, for Case II

From the fig. 3 and fig.4, the match factor 0.979 is match factor for 9 trucks in Case I. Similarly match factor for different number of truck can be calculated and is given in Tables 4 and 5. Tables 4 and 5 show the match factors for different numbers of trucks, for case I and case II respectively.

Table 4. Match factors for Case I

Number of trucks	Match factor	% Efficiency
1	0.196	19.58
2	0.392	39.16
3	0.587	58.74
4	0.783	78.32
5	0.979	97.90
6	1.174	82.52
7	1.371	62.94
8	1.566	43.36

Table 5. Match factors for Case II

Number of trucks	Match factor	% Efficiency
1	0.394	39.43
2	0.789	78.80
3	1.183	81.70
4	1.577	42.30
5	1.972	2.85

From the calculated values it is known that the productivity of the truck fleet can be varied by changing the number of trucks and using the above mentioned match factor. In this manner, the efficiency of various combinations can be predicted. Fig. 5 and Fig. 6 show the graph performed the match factor versus percent efficiency of the combined system, for case I and case II respectively.

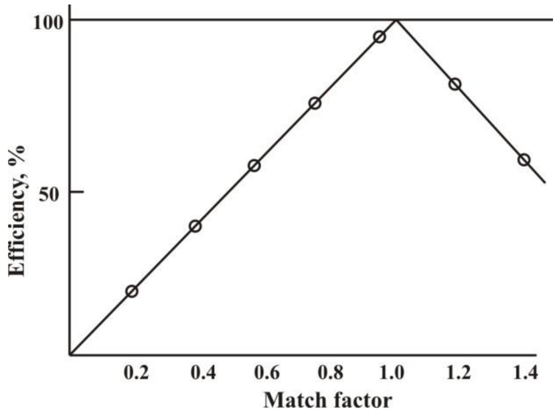

Fig. 5. Effect of mismatch, for Case I

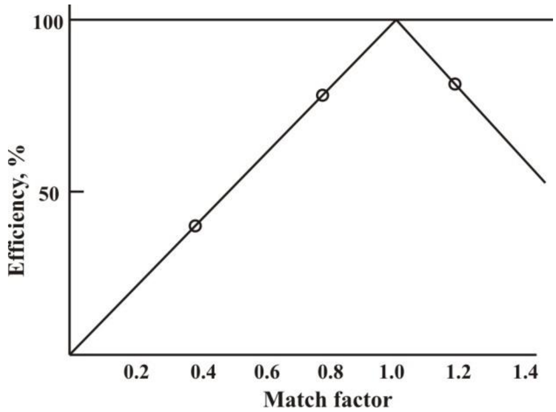

Fig. 6. Effect of mismatch, for Case II

From the figures, it is clear that percent efficiency of the system equals 100%, when the match factor equals 1 and called the perfect match. Anything greater or less than 1.0 is an indication of mismatch. From Fig. 5 and Fig. 6, when the match factor is less than 1.0, there is an excess of loader capacity indicating 100% efficiency of hauler and reduced efficiency of loader. On the other hand, with a match factor of greater than 1.0, the loader efficiency is 100% while the hauler efficiency drops off.

6.2. Prediction of future cycle time

Assuming that all segments of a truck cycle time remain the same, except loaded and empty travel times, we can predict the future cycle times for trucks in the new operating conditions.

Supposing face advances is ‘y’ meters/month hence the new haul distance will be the old distance, ‘x’ + the new distance, ‘y’ meters. Generally, trucks operate at 20 km/hr., therefore the haul and return times can be calculated and necessary corrections can be made, based on the above calculation and the practical average cycle time.

6.3. Comparative study of productivity in Case I and II

Case I consists of soft, well fragmented rock and case II consists of hard, poorly fragmented rock. A comparative study of productivities for case I and II is shown in Fig. 7.

Case I: 5 – 50 tons capacity trucks
1 – 4.6 m^3 electric shovel
Case II: 3 – 35 tons capacity trucks
1 – 4.6 m^3 electric shovel

Though the comparison is inconclusive because of differences in the characteristics of the overburden, it certainly reflects how poorly a combination can work in two different types of materials. It is thus very important to select proper equipment, so that the utilization of equipment is at a maximum and efficiency is optimized.

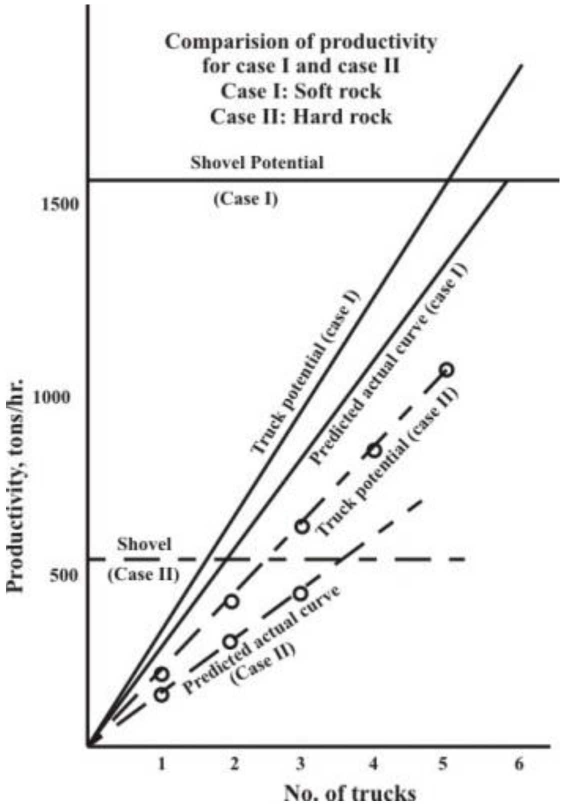

Fig. 7. Comparison of productivity curves

7. CONCLUSIONS

This study leads us to the conclusion that the productivity and efficiency of a shovel and truck combination can be achieved by the proper allocation and matching of trucks to a given shovel. This will also reduce losses in the potential productivity. The efficiency of the same shovel-truck system can also be affected by variations material properties of the overburden of the mine. A random increase in the number of trucks, in hopes of increasing the productivity may result in loss in productivity. Fig. 1 and Fig. 2 indicate the number of trucks that can be added or removed from the fleet to improve productivity, minimize idle time of equipment in open-pit mines.

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