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Research Article

OPTIMIZATION OF LOAD–HAUL–DUMP MINING SYSTEM BY OEE AND MATCH FACTOR FOR SURFACE MINING

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ABSTRACT
The transport of material from production faces to dumping sites is accomplished by rail, truck, belt conveyor or hydraulic transport in mines. The most common transportation method in surface mining is classic truck and shovel combination. This operation almost consists about 50 to 60% of total operating costs in surface mining. It is necessary to use shovel truck combination efficiently for improving economy in the mining sector. Various techniques are available to analyze and optimize the combination. This paper describes and suggests the shovel and truck operation optimization approaches by applying Overall Equipment Effectiveness (OEE) and matching simultaneously.

Keywords: *Truck Dispatch System, Optimization, Productivity, OEE, Matching Factor*

INTRODUCTION
Mining is a very capital-intensive industry, and it is known fact that the equipment utilization and accurate estimation is very important. Presently in India 70-80% production of minerals comes from the surface mines. In a surface mining operation, materials handling system is composed of loading, hauling and dumping. Shovel-truck systems are most common in open pit mining.

Shovel-truck refers to a load-haul-dump mining system, involving any combination of loading units and trucks.

The most important factor in every operation is profitability. Overall Equipment Effectiveness (OEE) of equipment used is an important factor of profitability. Further profitability can be increased by optimization of the equipment combination by matching factor used (Ercelebi and Basceti, 2009).

Truck-shovel cycle optimizations are commonly performed to increase productivity (Figure 1), reduce costs and generally improve the profitability of the mobile assets at the mine.

Therefore the first goal of this paper to discuss the OEE to maximize productivity and hence increase production, which in turn will result in cost reduction. This task is most often performed by a fleet management system (Nel *et al.,* 2011).

The OEE technique is a well-known measurement method, which combines availability, performance and quality, for the evaluation of equipment effectiveness in manufacturing industry.

OEE identify causes of time losses for shovel and truck operations and introduces the procedure to record the time losses.

As a measurement index, it shows how equipment functions and measures the utilization of an asset's productive capacity in terms of three factors availability, performance and quality expressed as percentages of their ideal values (actual output divided by the theoretical maximum output) (JideMuili *et al.,* 2013; Williamson, 2012).

Truck – shovel operations can achieve operational efficiency by OEE and consequently reduces cost through fleet management.

If a truck shovel system is optimized, the gap between current production and potential capacity will become narrower, with further improvements only realizable through re-engineering.

Better shovel/truck matching, and optimizing the loading activity are important considerations. This paper provides an analysis of an option for truck-shovel fleet cycle optimization (Vemba, 2004; Nel *et al.*, 2011).

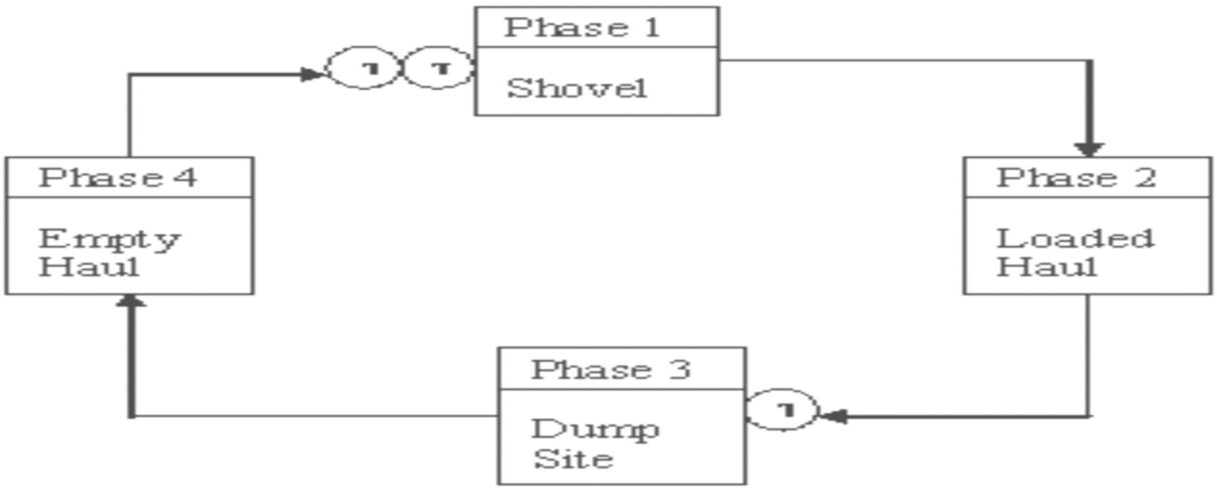

Figure 1: Phases of shovel-truck system (after Ercelebi and Bascetin, 2009)

Productivity

The productivity of a truck and loader fleet is an important problem for mining and construction. Productivity is a measure of the effectiveness in producing physical goods. The productivity is expressed by the ratio of output to input. This study focuses on predicting the travel times on the haul and return portions of the truck cycle and the prediction of the interaction between the shovel and truck at the loading point. Productivity is expressed as production (output), in tone or bank cubic meters (BCMs), per operating hour (input) (Burt, 2008; Nel *et al.*, 2011).

Shovel-truck productivity is determined by two methods:

- By the cycle time analysis
- By computer simulation

The mathematical expression of productivity is given by (Runge Mining (Australia) Pty Ltd, 1993)

$$\text{Productivity} = \frac{\text{Production}}{\text{Operating Time}}$$

There are various factors which influencing the shovel-truck productivity, the major factorsare shown in the figure 2.

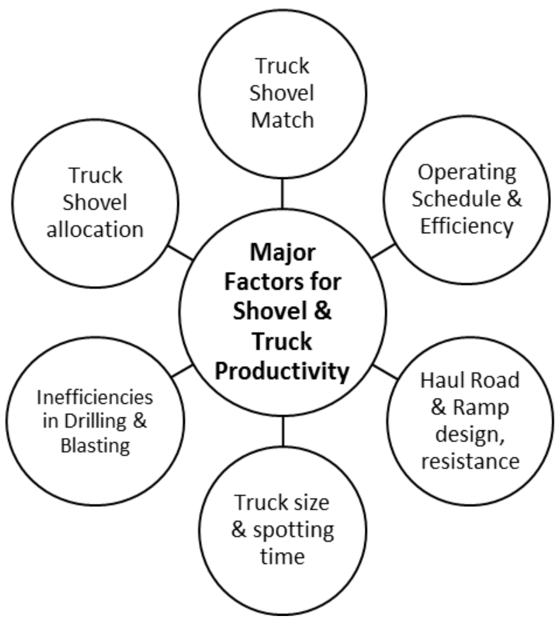

Figure 2: Major factors which affect the Shovel – Truck productivity

Productivity of the shovel truck fleet is mainly dependent on the working efficiency of truck and shovel that can be improved by OEE analysis of the combination and proper matching between truck and loader.

Overall Equipment Effectiveness (OEE)

OEE is a universally accepted method for measuring the improvement potential of a production process with one simple number. OEE is also referred to as Overall Equipment Efficiency (Impact, 2012) but for the purpose of this paper it will be referred as Overall Equipment Effectiveness (JideMuili *et al.*, 2013). OEE is a simple tool that will help manager to measure the effectiveness of their equipment. It takes the most common and important sources of productivity losses, which are called three losses and given in figure 3. These losses are quantified as availability, performance and quality in order to estimate OEE. Overall equipment effectiveness combines the availability, performance and quality for the evaluation of equipment effectiveness.

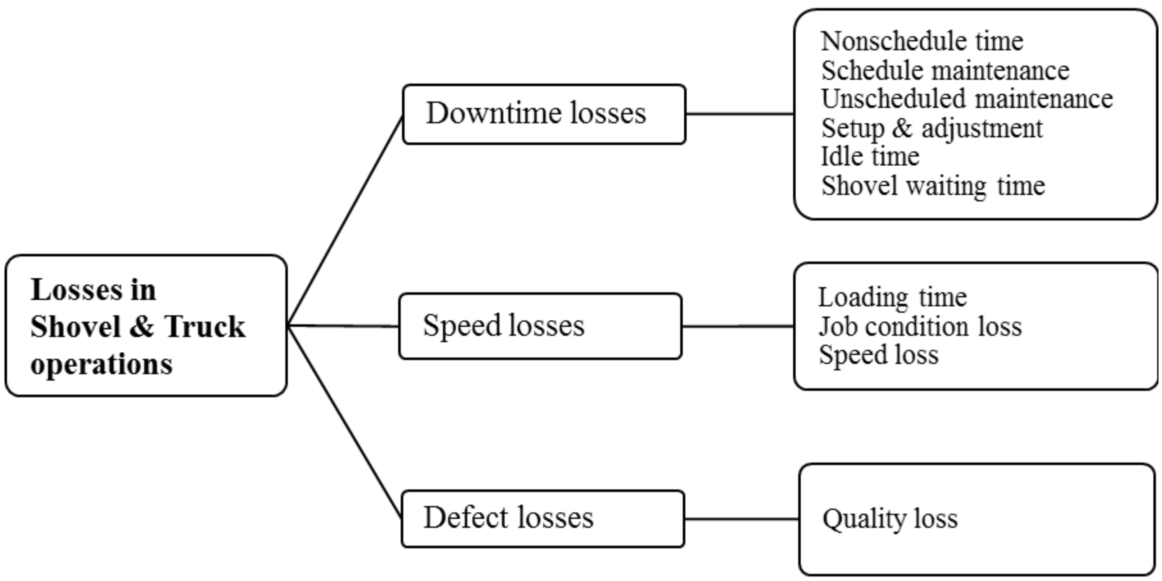

Figure 3: Losses in shovel and truck operations

It identifies the causes of time losses for shovel and truck operation and introduces procedure to record time losses. This gives the overall measure of how effectively an asset is being used and is given by the following formula.

Overall Equipment Effectiveness:

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality}$$

Availability is the proportion of time the equipment is able to be used for its intended purpose. Availability takes into account "lost time" which includes any events that stop planned production for an appreciable length of time. This is usually because of equipment failures, waiting times, and etc. Then, availability is determined as follows:

$$\text{Availability} = \frac{Net\ Available\ Time - Downtime\ Losses}{Net\ Available\ Time} \times 100$$

Performance takes into account "speed loss", which includes any factors that cause the equipment to operate at less than the maximum possible speed when running. Reasons for that can be substandard materials, operator inefficiency, and job conditions. Then performance is determined as follows:

$$\text{Performance} = \frac{Operating\ Time - Speed\ Losses}{Operating\ Time} \times 100$$

Quality takes into account "product loss", which is determined as follows (Elevli and Elevli, 2010):

$$\text{Quality} = \frac{Net\ Operating\ Time - Defect\ Losses}{Net\ Operating\ Time} \times 100$$

Successful computation of OEE depends on the ability to collect necessary data. Unreliable and inadequate data may not reflect real equipment utilization. After the estimation of the OEE, it should be compare with benchmark values. Accepted benchmark value for manufacturing industry is 85%. If the estimated value is below the benchmark value, then system should be evaluated for improvement.

Truck – Shovel Matching

Performance of a mixed truck/shovel fleet in surface mine is required to analyze the perfect matching between these two machines. For this three operating delays should be analyzed. Three delays are noteworthy; namely 'queue at loader', 'wait loading unit' and 'wait on truck'. The reason these are so significant can potentially be explained by an incorrect match between trucks and shovels and/or a less-than optimal truck-shovel assignment. When trucks are not optimally assigned and matched to loading unit, the following operational characteristics can be observed.

- Excessive truck queuing times at the loading unit,
- Excessive shovel wait on truck,
- Abnormal queue time at the dump, and
- Truck bunching (typically observed during with mixed fleet haulage).

Queue at Loader or Wait Loading Unit

When a truck is queuing at the shovel waiting to be serviced, it is still classed as being in an operational mode; operational but not productive. During these times, the operator is still getting paid while the trucks burn diesel fuel at an unforgiving rate. If this delay is a prominent one, it can mean that the truck-shovel fleet is generally over-trucked (too many trucks).

Wait on Truck

When a loader is waiting on trucks, it is a strong indication that there are an insufficient number of trucks assigned to it in the circuit, a phenomenon often referred to as under-trucking.

Total Cycle Time

For shovel = crowding (digging, loading, hoisting) time + swinging time towards truck +dumping time on truck + swinging back for crowding operations

For Truck = spotting time + loading time + travel time with load + spotting time to discharge+ discharge time + travel back time + waiting time for loading

Optimization

To optimize the materials handling such that the desired productivity is achieved and the overall cost is minimized. Optimizing a truck shovel operation might appear straightforward in theory; however, it is quite complex due to the interdependent nature of system. That is, the operation of loading units will affect the performance of the haulage unit and vice versa. Optimizing a truck and shovel fleet involves considerations of all the factor affecting the equipment's costs and productivity.

Three operating delays have a significant impact on fleet performance and productivity, namely: queue at loader; wait on truck; and wait on loader. Not only are the latter notable, these delays are potentially inter-related, stemming from a common problem-truck and shovel location. To make a truck and shovel fleet more optimum on the basis of productivity improvements and associated cost reduction, it was essential to calculate the best match factor and truck-shovel assignment (or fleet size) for the system. However, before that could be completed it was necessary to determine whether the fleet truck or shovel limited (Nel *et al.,* 2011).

Truck or Shovel Limited

There are occurrences of over and under trucking, meaning that sometimes there is an excess supply of trucks in the haul circuit and other times there are not enough trucks. This is more than likely due to allocation but can also mean that there are simply not enough trucks (truck limited) or not enough shovel (shovel limited) in the fleet.

Truck-shovel Match

In the truck and shovel operation, it is necessary that the capacities of a dig unit or shovels are compatible with the capacities of the truck fleet. Truck shovel match refers to the situation where the ideal capacity and number of haul truck is available for any given dig unit and how well they are suited to an each other.

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It usually refers to operating parameters such as truck height, shovel reach and truck capacity to name a few. Given that the mine uses a mixed truck fleet would perform better when serviced by certain shovels. One particular aspect that constitutes most of the loading time in a truck shovel cycle, is the time taken to complete each and all of the passes to fill the truck. The best match is one where the shovel, loading its maximum payload is able to fill a truck to its maximum payload in 3 or 4 even passes (Collins and Kizil, 2012).

Match Factor

The match factor itself provides a measure of productivity of the fleet. The ratio is so called because it can be used to match the truck arrival rate to loader service rate. This ratio removes itself from equipment capacities, and in this sense, potential productivity, by also including the loading times in the truck cycle times

$$MF = \frac{no.of\ trucks \times loader\ cycle\ time}{no.of\ loader \times truck\ cycle\ time}$$

The match factor ratio is an important productivity index in the mining industry. The match factor is simply the ratio of truck arrival rate to loader service time, and is used to determine a suitable truck fleet size claimed that operations with low match factors are inefficient". Such comments must be interpreted carefully. That is to say, fleets with a low match factor can be very cheap and satisfy the productivity requirements of the operation.

The use of the word efficient is used strictly in reference to the ability of both trucks and loaders to work to their maximum capacity. One must question why it is important for this to be so. When the match factor ratio is used to determine the suitability of a selected fleet, one must consider that the minimum cost fleet may not be the most productive or efficient fleet. In this way, a match factor of 1.0 should not be considered ideal for the mining industry, as this corresponds to a fleet of maximum productivity. That is, a loader operating at 50% capacity may be significantly cheaper to run than another loader that operates at 100% capacity under the same conditions.

Adopting the same concepts as the traditional match factor method, Gransberg (1996) described a heuristic method for determining the haulage fleet size (Collins and Kizil, 2012). Determine the cycle times, T, for haul and return routes

$$T = \frac{d}{2}\left(\frac{1}{vH} + \frac{1}{vR}\right)$$

WherevH and vR are haul and return velocities of the truck; d is the haul distance (metres), the divisor 2 averages the velocities.

1. Obtain loading time, L, from load growth curves.
2. Estimate delay time, D, along route.
3. Calculate “instantaneous" cycle time, C:

$$C = L + T + D:$$

5. Determine “optimum" fleet size

$$N = C/L$$

Note that no method for estimating delay times was provided by the authors. We can see that step 5 is using the truck arrival rate to truck loading rate ratio with a nominal match factor value of 1.0, and only one loader. When the match factor is 1.0, the truck arrival rate perfectly `matches' the loader service rate and the overall fleet is said to be efficient (with respect to wasted capacity). It is very restrictive to force the match factor to be any value, and is unlikely to result in an optimum solution with respect to fleet cost (Figure 4).

A low match factor suggest that the loader is not working that capacity, whereas a high match factor suggest the truck fleet is smaller than necessary to maintain a productivity balance between truck and loader fleet. Typically, if the ratio exceeds 1.0 this indicates that trucks are arriving faster than they are being served. For example, a high match factor (such as 1.5) indicates over-trucking. In this case the loader works to 100% efficiency, while the trucks must queue to be loaded (Burt and Caccetta, 2014).

A ratio below 1.0 indicates that the loaders can serve faster than the trucks are arriving. In this case we expect the loaders to wait for trucks to arrive. For example, a low match factor (such as 0.5) correlates with a low overall efficiency of the fleet, namely 50%, while the truck efficiency is 100%. This is a case of under-trucking; the loader's efficiency is reduced while it waits (Burt, 2008).

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. 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.

Production over a given time period of interest (typically one shift) can be calculated by the number of loads that trucks take to the dump:

$$\text{Production}=\frac{time\ period\ of\ intrest}{average\ cycle\ time} \times N \times Truck\ capacity$$

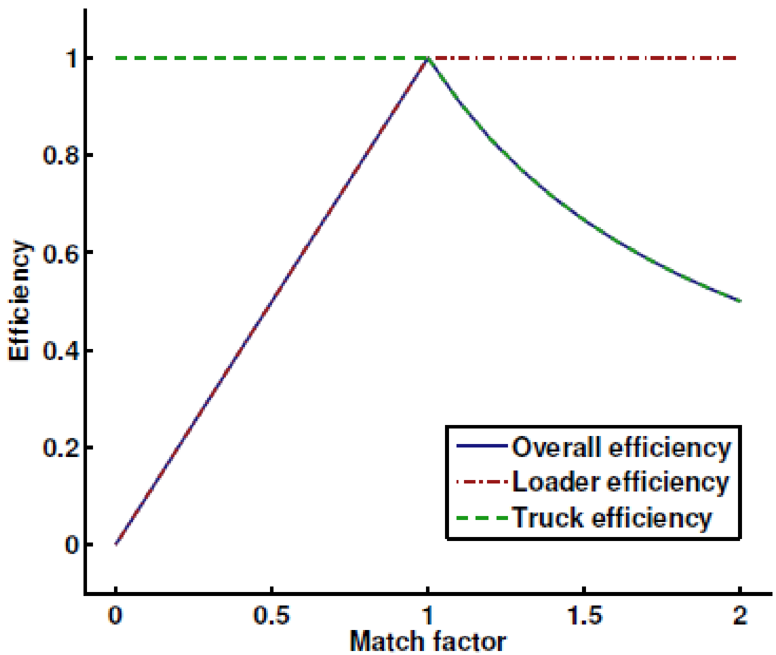

Figure 4: The match factor combines the relative efficiencies of the truck and loader fleets to create an optimistic efficiency for the overall fleet (after Burt and Caccetta, 2014)

Where– *N* is the number of trucks in the system. Also production may be calculated from:

$$\text{Production= time period of interest} \times \mu \times n$$

η is shovel utilization and μ is shovel loading rate.

The number of trucks that are assigned to a particular shovel is a function of the performance variables of the shovel, the desired production level from that shovel, and the expected travel and waiting times for the trucks in the haulage network. To obtain the appropriate and optimal number of trucks that can be assigned to a loader is rather complex, due to many variables such as haul distance, production target and material type. Some manual calculation and/or computer simulations can provide good estimates. Examining the cycle data, it was possible to deduce the average loading and haulage components of the total cycle time for each of the shovels (Nel *et al.*, 2011).

CONCLUSION

For shovel-truck type operations, the minimum unit cost of moved material is the main concern. OEE can minimize the unit cost of the truck and shovel operation. When the cost is of prime importance, a trade-off is sought between the cost of idle time of the shovel and the cost of providing extra trucks. This can be achieved by proper matching. The solution yields the optimum number of trucks of any given capacity that can be assigned to a shovel.

Truck-shovel operations typically have high operating costs. The factors which affected the performance of the truck-shovel fleet were ‘queue at loader’, ‘wait loading unit’ and ‘wait on truck’ and were more than likely attributable to the improper match between the loading and haulage unit. Focusing predominantly on productivity improvements through optimizing truck-shovel match and allocation, this paper determine the applicability of OEE and Match factor in fleet optimization. First, we have to analyze the OEE of different components of the system. Then, the match factor can maximize the combine potential of truck/shovel capacity.

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