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Truck and Shovel Versus In-Pit Conveyor Systems: a Comparison Of The Valuable Operating Time

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TRUCK AND SHOVEL VERSUS IN-PIT CONVEYOR SYSTEMS: A COMPARISON OF THE VALUABLE OPERATING TIME

Isaac Dzakpata, Peter Knights, Mehmet Siddik Kizil, Micah Nehring and Saiied Mostafa Aminossadati

ABSTRACT: Shovels, haul trucks and conveyors are used in surface mines for material haulage of which trucks are have been most widely used. This paper presents a comprehensive comparison study in terms of the operating efficiency of trucks and conveyors as applied in surface mining operations. Three key time usage metrics are used to assess the efficiency of both haulage systems namely: Utilised Time, Operating Time and Valuable Operating Time. The notion that measurement of equipment performance should focus on a multi instead of a single- factor approach is proposed. Comparison of the two systems based on these measures indicates that although trucks lend themselves to high flexibility and lower upfront capital outlay, conveyor haulage offers a better measure of performance on all the three metrics of measuring equipment performance. This opportunity lies in the high Valuable Operating Time achievable with the conveyors compared to the trucks. The results of analysis on 308,912 load records and 12 months equipment usage indicates that while the truck fleet achieve much higher Available Time and Utilisation Time, the conveyors achieve a higher Valuable Operating Time (25% higher) compared to the truck fleet. The conveyors achieved an average of 3,509 hours in Valuable Operating Time compared to the average Valuable Operating Time of 2,638 hours for the truck fleet. The inference made from this observation is that, the higher effective utilisation of a continuous haulage system for example In-Pit Crusher Conveying (IPCC) could significantly improve the operating efficiency of the loading equipment.

INTRODUCTION

Surface mine material haulage costs constitutes nearly 50% of the total mining cost (Nel et al., 2011; Thompson 2005; Kennedy 1999 and Bozorgebrahimi 2004). Haul truck and conveyor haulage are a major part of surface mine material haulage over the years, of which trucks have been most widely used (Burt and Caccetta 2014 and Radlowski 1988). It has been argued that trucks and shovels are common to 95% of the global surface mining fleet due to their flexibility and large economy of scale (De Lemos Pires 2013). Over the last three decades, conveyor haulage has gathered a great deal of momentum in association with In-pit Crusher Conveying (IPCC), which is argued to be a cost-effective alternative to the truck and shovel material handling system. With current trends in global mining industry (e.g. fluctuating fuel prices, lower commodity prices, high operating cost) coupled with the maturing of many surface operations, the efficiency of mining equipment has come to the forefront of discussion regarding the sustainability of surface mining. In addition, many mine operators are demanding more from existing assets as capital expenditure stalls. This calls for the ability to measure the overall efficiency of mining equipment for the purposes of improving the operating efficiency of mining operations, effective asset utilisation, resource scheduling, operational planning and resource optimisation. Figure 1 shows a schematic of a typical truck-shovel operation from loading area to dump location (ore or waste).

This paper compares the performance of truck-shovel and conveyors as applied in surface mining operations. The science of measuring the performance (productivity and effectiveness) of mining equipment has evolved and matured particularly for trucks and shovels. Useful metrics have been developed by Original Equipment Manufacturers (OEMs), mine operators and academics. Consistent with the recent trends toward increased asset optimisation and productivity across the industry (Ernst et al., 2014 and 2015), this aims to draw on the experiences gained from truck haulage in comparison with
the performance of in-pit conveying haulage. This study examines the performance of truck-shovel and conveyor operations based on a combination of the following three key time usage metrics (indicators):

Utilised Time (UT),
Operating Time (OT)
Valuable Operating Time (VOT)
In this study, the overall emphasis is placed on the VOT for each operation.

Figure 1: Schematics of (a) Truck – Shovel Operation (adapted: www.oilsandstoday.ca) and (b) In-pit conveyor in used a Fully Mobile Crusher and Shovel (Humphrey et al., 2011)

CURRENT APPROACHES TO MEASURING MINING EQUIPMENT PERFORMANCE

Lord Kelvin was the first in 1883 to recognize that one cannot improve something which cannot be measured. A review of literature supports the view that measuring the performance of an asset must not only capture the physical productivity but also the financial productivity (United States Bureau of Labor Statistics, 1988). Productivity relates outputs to inputs while effectiveness is the ratio of actual output to rated (or best). Business improvement practitioners are often more focused on productivity. Efficiency is widely expressed as a percentage of actual output to the maximum achievable output which is therefore a strong measure of how well an asset (in this case equipment) is performing with respect to best practice. Figure 2 shows a Time Usage Model (TUM) commonly used across the mining industry.

A critical review of literature indicates that while there is a measure of VOT, it is mostly applied to fixed plant and not mobile equipment. In mining operations, trucks are classified as mobile equipment whereas conveyors are classified as fixed plant as they are comparatively less mobile than haul trucks. This would appear to suggest that while conveyors are subjected to efficiency measures that account for performance and quality losses, haul truck efficiency is assessed by accounting for losses only up to operating delays. Also the use of conveyors with, for example, a fully mobile in-pit crusher re-defines the definition of fixed plant. The reason for this exclusion may lie in the difficulty of measuring quality and performance losses associated with trucks since they consist of many units as opposed to conveyors that might have only a few flights or units.
Overall equipment effectiveness

One of the most commonly used measures of equipment efficiency is the Overall Equipment Effectiveness (or Efficiency) – OEE (Emery, 1998 and Mohammadi et al, 2015). OEE is defined by equation 1.

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

where:

- Availability = Operating Time / Planned Production Time;
- Performance = (Output / Operating Time) / (Rated Output / Design Cycle Time);
- Quality = Valuable Output / Total Output.

Equation (1) can be used for basic estimates of OEE without collecting all six loss categories. A review of literature indicates that further modifications of the OEE definition have evolved since Equation (1) first became commonly applied. Without discussing the details involved, a summary of various modifications to the OEE suggested by Pintelon and Muchiri, (2006) are listed as follows:

- Total Equipment Effectiveness Performance (TEEP)
- Production Equipment Effectiveness (PEE)
- Overall Factory Effectiveness (OFE)
- Overall Asset Effectiveness (OAE)
- Overall Production Effectiveness (OPE)

Pintelon and Muchiri (2006) advanced their argument by proposing a framework that treats the OEE at three levels:

- equipment level;
- operational level; and
- business level.

It is, however, the view of the authors that these approaches over-emphasise the losses rather than focusing on the Input – Output – Loss relationship. Furthermore, this approach fails to account for other key production factors like labour and energy requirement which is a function of the valuable operating time.

MINE PRODUCTION INDEX

Another suggested measure for equipment performance is the Mine Productivity Index (MPi). The proponents argue that the OEE including utilisation has limited application for mining in that, the quality rate cannot be used for the mining industry as per the original definition intended in the OEE equation (Lee and Johnson 2015 and Lanke et al., 2014). They defined MPi as follows:

$$\text{MPi} = Av^a \times PP^b \times U^c$$

Where:

- $Av$ = Availability,
- $PP$ = Performance and
- $U$ = Utilization and $0 < a, b, c <= 1$ and $\Sigma a, b, c=1$.

It can be seen that equation (2) essentially replaces Quality with Utilisation and applies a weighting to the various elements through the constants $a$, $b$, and $c$. This may answer the need to use a multi-dimensional measure to assess the overall efficiency of mining equipment.

DATA COLLECTION AND ANALYSIS

Table 1 provides a summary of the order of priority applied to the data collecting and analysis in this paper. The prioritization sought to minimise variations in material properties, data collection methodology, time usage definition and also potential effect of different maintenance practices. Where
unavoidable, data from different operations and time overlaps have been used. After the data was collated, a series of checks were conducted to establish the context of the data and then the data was reorganized, filtered and re-checked. This paper focuses on the measurement of efficiency at the fleet level using the three-fold metric previously discussed.

Table 1: Prioritisation of criteria for data collection and analysis

<table>
<thead>
<tr>
<th>Priority</th>
<th>Applied To</th>
<th>Criteria</th>
<th>Data Analysed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>All</td>
<td>Data from same site / deposit</td>
<td>3 Mining Operations</td>
</tr>
<tr>
<td>2</td>
<td>Trucks</td>
<td>Data from same mine operator/source</td>
<td>5 Rope shovels (44.5m³)</td>
</tr>
<tr>
<td>3</td>
<td>Conveyors</td>
<td>Data from mining application. e.g. IPCC</td>
<td>198 trucks (225t – 360t)</td>
</tr>
<tr>
<td>4</td>
<td>Shovels</td>
<td>Data from Same Type/ Make/Class</td>
<td>309, 000 Load Record</td>
</tr>
<tr>
<td>4</td>
<td>All</td>
<td>All other available sources</td>
<td></td>
</tr>
</tbody>
</table>

A total of 308,912 load records were analysed from three mines operating within Australia with a total of five electric rope shovels and nine different fleets of haul trucks grouped as Type 1(≤240 tonnes) and Type 2 (>240 tonnes). In total data from 198 trucks have been analysed and the results form the basis for discussion in this paper. The data collected covers a period of at least twelve months with an average of 29 days per month. Due to confidentiality issues the identities of the mines and equipment cannot be revealed. However, the data set used in this analysis is representative of similar class of operating equipment in industry.

LIMITATIONS OF DATA ANALYSIS

It is widely understood that the environment within which mining equipment operates has a significant impact on the performance of the equipment. It is recognised that comparing equipment data from different mining operations without recourse to explaining the unique operating or mine-specific conditions (e.g. different haul profiles, operating bench heights, material characteristics and strip ratios) that might have a bearing on the performance of the equipment could significantly affect the results discussed in this paper. Another issue observed from the data used is the fact that different computer systems or Fleet Management Systems (FMS) and data classification logic might have been used in gathering the data and therefore could also affect the results presented in this paper. Furthermore the above issue may have been compounded by the lack of full understanding of the context under which the data was collected, e.g weather issues and operational constraints. An issue identified was underlying error in the data which is difficult to explain without understanding the context of datasets and its impact on the data quality. Notwithstanding, an endeavour has been made to use acceptable statistical techniques and data filtering methods to ensure that the results are reflective of reality.

SHOVEL PERFORMANCE

While the word shovels in this paper refers to any of the following loading equipment types, there is an apparent emphasis on the electric rope shovel as the data collected relates to this category:

Electric Rope Shovels (ERS)
Hydraulic Face Shovels (FS)
Hydraulic Backhoe Excavators (BH)

The following discussions give a brief summary of some of the key issues at the heart of loading equipment performance. Figure 3 shows the working ranges of three examples of some of the largest shovels for digging and loading at the dig face. It is noted that the image is only for enhancing the discussions in this article and therefore does not have specific alignment with any particular OEM.
Figure 3: working ranges of three examples of some of the largest shovels for digging and loading [Komatsu 2012 and P&H 2003]

It can be observed from Figure 3 that all three classes of loading units have nearly the same working range in terms of height but have distinctly different reach and digging depth as a result of equipment sizing in general and front-end arrangement of the buckets, arms and digging mechanism. Table 2 provides a summary of some of the loader-specific characteristics that affect measuring mining equipment performance. These factors not only affect equipment erection costs, but also the operational efficiency in terms of bucket cycle times and maximum bench height used for mining and the capital efficiency. Table 3 shows indicative cycle times and reference Bench Heights (BH) for the three classes of shovels discussed previously. The indicative values show that for the same digging and loading conditions, the BH typically has the least cycle time per pass although bench height may impact these ranges significantly.

Table 2: Prioritisation of criteria for data collection and analysis

<table>
<thead>
<tr>
<th>Factor</th>
<th>BH/FS Description</th>
<th>ERS Description</th>
<th>Area of Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine Assembly Time</td>
<td>typically takes 10-20 days, with an eight-person crew working a 10-hour shift</td>
<td>It takes approximately 30-70 days to erect an ERS</td>
<td>Capital Productivity</td>
</tr>
<tr>
<td>Mobility</td>
<td>Higher manoeuvrability and mobility shown in faster travel speeds.</td>
<td>Lower manoeuvrability and mobility shown in Slower travel speeds.</td>
<td>Operational Efficiency</td>
</tr>
<tr>
<td>Bench Height</td>
<td>better suited for low – med-height benches. Able to dig below grade to depths up to 8m (BH)</td>
<td>better suited for high benches. Limited ability to dig below grade.</td>
<td>Operational Efficiency</td>
</tr>
</tbody>
</table>

Table 3: Indicative cycle times and reference bench heights (Fiscor 2007 and Berkhimer 2012)

<table>
<thead>
<tr>
<th>Cycle Times</th>
<th>Units</th>
<th>Rope Shovel</th>
<th>Hyd. Excavator</th>
<th>Face Shovel</th>
<th>Wheel Loader</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dump</td>
<td>s</td>
<td>3.0</td>
<td>3.0</td>
<td>4.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Swing Empty</td>
<td>s</td>
<td>8.3</td>
<td>7.5</td>
<td>6.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Time in Bank</td>
<td>s</td>
<td>11.0</td>
<td>12</td>
<td>13</td>
<td>14.0</td>
</tr>
<tr>
<td>Swing Loaded</td>
<td>s</td>
<td>11.5</td>
<td>7.0</td>
<td>8.0</td>
<td>11.0</td>
</tr>
<tr>
<td>1st Bucket Delay</td>
<td>s</td>
<td>4.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Cycle Time Per Pass</td>
<td>s</td>
<td>37.8</td>
<td>32.5</td>
<td>34.0</td>
<td>43.0</td>
</tr>
</tbody>
</table>
The difference in the cycle time for the ERS lies in the swing times as shown in Table 3. In the case of the FS, the difference in cycle time is due to the time in bank (dig cycle). These differences are supported by the argument that the FS is able to produce higher digging forces low in the bank but ends up with a relatively lower breakout force compared to the ERS. Conversely the ERS consistently generates higher digging forces throughout the bank aided by the hoist force from the ropes as shown in Figure 4 (P&H 2003).

![Figure 4: (a) Digging forces in bank (b) Net digging force profile for shovels (P&H, 2003)](image)

It has been argued that 79% of the shovel’s time is spent digging, with the remaining time spent waiting or idling (9%); clean-up work (5%), relocating to new digging position (3.1%), and 3.5% of the time is spent offline (Fiscor 2007). Three main loading approaches are used industry wide. These are double sided loading, single sided loading and single drive-by loading; a modification of the latter is often counted as the fourth method. Truck spotting and operator skill levels play a major role in how efficiently these loading methods are executed (Choudhary 2015). Figure 5 shows the spotting tolerance for the major mining shovels. The ERS has a relatively wider spotting tolerance due to the variable reach of the dipper arm as shown in Figure 5.

![Figure 5: Truck spotting tolerance for the major mining shovels (P&H 2003)](image)

While there are a number of arguments for double-sided loading aimed at reducing truck spotting time, counterarguments suggest that it does not improve the truck cycle time other than eliminating some of the truck queuing, thereby improving the truck exchange time (Bradley 2000). Figure 6 shows an observed trend of spotting time versus loading unit productivity. It shows that an increase of 20 seconds in spotting time could lead to a 500t/hr drop in the shovel productivity (Tegtmeier 2007). A critical review of literature suggests that shovel productivity is significantly affected by the truck spotting time (Fiscor 2007). While there have been a number of efforts to improve the spotting time by using the double sided loading method, it has been argued that double sided loading may marginally reduce the spotting time.
Truck and shovel performance is a function of the Match Factor (MF: ratio of loader productivity rate to truck productivity). Since the MF is essentially the ratio of loader service time to truck arrival rate, much of the effort in this system is focused on balancing the MF. An MF less than 1.0 is indicative of an underproductive or inadequately sized shovel whereas a MF greater than 1 suggests an inadequate truck fleet. The MF is therefore used as a measure to determine the correct truck fleet size (Burt et al., 2005).

Figure 6: Truck spotting tolerance for the major mining shovels (Tegtmeier, 2007)

Shovel performance – time usage

One of the key measures of shovel productivity is the annual Total Material Movement (TMM), which is a function of the average payload per shovel cycle and the number of load cycle per year. The TMM is also a function of the total Operating Time of the equipment. Figure 7 shows the total annual production generated by the five dig units discussed in this paper. Figure 7 shows that the 5 loading units across the three mines are on the average producing 13.5Mbcm with a maximum demonstrated output of 17.5Mbcm per annum. It is also evident from Figure 7 that, while Mine A is achieving average output, Mine B and C are well over the average output with Mine C emerging top with the highest production of 17.5 Mbcm per annum. Figure 8 shows a gap and opportunity result for the variance in worst case and best case production. The results indicate that changes or improvement in bucket fill factor (4%), operator efficiency (3%) and material characteristics (14%, including fragmentation quality) could significantly improve the output of the worst performing shovel. Poor bucket fill factor results in high variability in payload and also a reflection of the operator skill level. The quality of material fragmentation, which is influenced by drilling and blasting practices, has a significant impact on the bucket fill factor. Details of these operational analyses are not discussed further as they fall out of the scope for this paper.

Breakdown of utilised time

Figure 9 shows the breakdown of time usage for the five shovels including availability, operating time, operating delays and operating standby as defined earlier in Figure 2. The upper shading (Grey) is a combination of operating standby and operating delays; added to the OT give the utilised time. Figure 9 shows that the average utilised hours across the 5 shovels is around 6,457 hours as expected for this class of shovel. It is also shown in the figure that losses due to delays and standbys amounts to a third of the utilised time leaving an average OT of 4,514 hours across the 5 shovels. The results also show that
except for SH04 (availability of 78%), all the other shovels achieve an average of 87% availability which is an acceptable. The next sections look at a further breakdown of the OT into loading, spotting and non-loading tasks.

Figure 7: Total annual production generated by the five mining shovels

Figure 8: Gap and opportunity analysis of variance in and best shovel production

Figure 9: Breakdown of time usage for the five mining shovels
Breakdown of shovel operating time

Figure 10 shows the proportion of truck spotting (plus exchange) to load lime where between 40% and 50% of shovels’ Operating Time is spent spotting trucks (including truck exchange). At first glance, the results are surprising, however a closer look at Figure 11 showing the spotting time of trucks provides further weight to the analysis. Another premise for these results is that the loading method used is a 50% share of single and double sided loading method. Single side loading typically has higher truck queues and spot times compared to the double sided loading method. The key opportunity identified here is that, the use of a continuous mining system like the FM-IPCC may be a good alternative for reducing the shovel’s time lost due to spotting trucks and non-loading tasks within the OT.

A critical review of literature suggests that shovel productivity is significantly affected by the truck spotting time. While there has been a number of efforts to improve the spotting time by using the double-side loading method, it has been advanced that double sided loading may marginally improve the spotting time but has no significant impact on the cycle time of the truck. Figure 11 shows the spotting time of the various classes of truck fleet under the five loading shovels. A clear distinction is observed for Type 1 and Type 2 truck fleets in terms of face loading profiles (queue, spot and loading) of the truck-shovel load interaction.

Definition of truck queue, spot and loading times at the loading face

The truck queue, spot and loading time are defined with respect to a virtual perimeter (beacon) established around the shovel summarised as follows: **Queue Time** is when the truck has arrived within shovel beacon, <10km/h and another truck loading; **Spot Time** is the time from last truck full to first bucket or time from arrive to first bucket if no other trucks loading; **Loading Time** is the time from the first bucket trigger to truck full. Once the truck enters the beacon radius, its locations picked up by GPS and it attains arrive status. The definition of spot time therefore encompasses the combined time from the start of last ‘Full Truck” to the time of next “Load Start”. Spotting therefore includes truck exchange time, first bucket delay and truck positioning. Upon dumping the first bucket, the operator triggers a loading button and attains the “loading state”. Verbal advice from industry experts indicates that the time for a single shovel pass is a fair estimate of truck spot time.

![Figure 10: Proportion of Truck Spotting (plus exchange) to Load Time](image-url)
It is apparent from Figure 11 resulting from the 308,912 load records analysed that, the average truck queue time per load is approximately three times the spot and load times. Spot and load times appear to be 5-15% of the other. It is important to note that the load times (and cycle times) as shown in Figure 11, observed from the results are very good compared to indicative values discussed in Table 4. Spot time as used in this paper refers to the time from last truck full to first bucket which often has an overlap with the definition for truck exchange time. This explains why the spot time of the shovel seems high. There is often a lag between when truck spotting ends and when the truck operator actually triggers the status change. In such instance, the spot times may appear to be longer that they actually are. Figure 12 shows the overall shovel performance the truck fleet which align with observations made in Figure 7, through to Figure 11.

Table 4: Summary of average queue, spot and load times of truck fleet by class

<table>
<thead>
<tr>
<th>Average Of Queue, Spot &amp; Load Time</th>
<th>Queue Time</th>
<th>Spot Time</th>
<th>Load Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1 (≤240t)</td>
<td>2.94</td>
<td>0.86</td>
<td>0.63</td>
</tr>
<tr>
<td>Type 2 (&gt;240t)</td>
<td>3.61</td>
<td>1.16</td>
<td>1.31</td>
</tr>
</tbody>
</table>
The primary observation here is that the actual shovel output equates to only a fraction (55% - 60%) of the shovel OT which is a maximum of 17.5 Mbcm per annum as shown in these results. This implies that the shovel could produce an additional 20% - 25% which is equivalent to 4.37 – 4.80 Mbcm per annum based on the results discussed earlier in this paper. These figures leave a 15% - 20% leave a 10% room for other non-loading tasks which is still questionable for best practice performance. From the foregoing discussions, the follow conclusions are reached with regard to the shovel productivity efficiency:

- Between half (40% - 50%) of the shovels OT is spent spotting trucks, which shows the inherent losses associated with the Truck-Shovel mining combination.
- The use of an efficient continuous haulage system may improve the productivity of the shovel (Loading units in general) by up to 20% - 25% of current levels. It is acknowledged that the alternative use of FM-IPCC may not totally eliminate shovel production losses associated with truck spotting as the shovel-mobile crusher interaction may incur some production losses.
- The potential benefits accruable from efforts put into the above two opportunities far outweighs any benefits from efforts that may focus on improving the shovels operating hours or utilised hours particularly if the loading unit is already achieving between 4,500 – 5,200 hours OT (excludes operating delays and operating standbys).
- The average VOT of the five shovel across the three mines is 2,483 hours (55% X 4,514 hours) which essentially is the time when the shovel is doing “useful work”.

**TRUCK AND CONVEYOR PERFORMANCE**

Table 5 provides a summary of the time utilisation of the 198 truck units analysed over a 12 month period grouped by mine. The results show that the weighted average utilised time per truck is 5,300 hours with a range of 5,200 – 5,800 hours, which again is a fairly good achievement. Figures 13 and Figure 14 show a breakdown of the total truck fleet utilised time and OT respectively.

**Table 5: Prioritisation of criteria for data collection and analysis**

<table>
<thead>
<tr>
<th>Truck Fleet Size</th>
<th>Util. Time (hours)</th>
<th>Op. Time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine A</td>
<td>84</td>
<td>4,893</td>
</tr>
<tr>
<td>Mine B</td>
<td>44</td>
<td>5,294</td>
</tr>
<tr>
<td>Mine C</td>
<td>70</td>
<td>5,844</td>
</tr>
<tr>
<td>Weighted Avg.</td>
<td>198</td>
<td>5,318</td>
</tr>
</tbody>
</table>

**Figure 13: Breakdown of OT for the all truck fleet**
The focus of this paper is on the effectiveness of performing the objective(s) for acquiring the equipment and therefore the emphasis on truck performance will be on its OT. It can be seen from Figure 13 that 38% of the truck fleet’s OT is actually spent travelling empty - often described a carrying dead weight. From these results it can be estimated that the VOT of the entire truck fleet is 2,638 hours (Travelling Full + Spot Time + Loading Time + Dumping Time).

Arguments against this approach could be that since trucks first need to travel empty in order to get loaded, travelling empty must be counted as useful work. Conversely it can be argued that since the extent of dead weight carrying is mainly a function of the haul profile (Grade, rolling resistance and distance), travelling empty should be excluded from useful work particularly when the inbound travel distance differs significantly from the outbound haul distance. Figure 14 shows a breakdown of (a) UT and (b) OT for Conveyors as used in an IPCC configuration. It can be seen from the results presented Figure 14 (a) that the conveyors achieve an average of 4,639 hours in utilised time compared to the average truck utilised time of 5,318 hours (15% higher). The results in Figure 14 (a) also indicate that the conveyors achieve an average of 4,287 hours in Operating Time compared to the average truck Operating Time of 4,254 Hours.

Looking at the Figure 14 (b) it becomes apparent that the conveyors achieve an average of 3,509 Hours in VOT relative to the average truck’s VOT of 2,638 hours (25% lower). Table 6 provides a summary of results discussed so far including the time usage of shovels. It is noted that no SMU factors have been applied to these equipment hours.

Figure 14: Breakdown of (a) Utilised Time (UT) and (b) Operating Time (OT) of conveyor system

Table 6: Summary of shovel, trucks and conveyor time usage

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>UT (hours.)</th>
<th>OT (hours.)</th>
<th>VOT (hours.)</th>
<th>Output Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shovel</td>
<td>6,457</td>
<td>4,514</td>
<td>2,483</td>
<td>28.7 Loads /hour</td>
</tr>
<tr>
<td>Haul Trucks</td>
<td>5,318</td>
<td>4,254</td>
<td>2,638</td>
<td>1.9 Loads/hour</td>
</tr>
<tr>
<td>Conveyors</td>
<td>4,639</td>
<td>4,287</td>
<td>3,509</td>
<td>6,000 t/hour*</td>
</tr>
</tbody>
</table>

*Already crushed material measured in tonnes per hour.

CONCLUSIONS

The aim of this paper was to re-evaluate the performance of shovels, trucks and conveyor three key performance measures of: UT, OT and VOT. From the foregoing discussions, the following conclusions are reached with regards to the shovel, truck and conveyor performance:
1. Approximately half (45%) of the shovels OT is spent spotting trucks, which shows the inherent losses associated with Truck-Shovel mining arrangements. The average VOT of the shovel across the three mines was 2,483 hours (50% of the OT).

2. The potential benefits of improving Valuable Operating Time outweigh the benefits from efforts that improve shovel operating hours or utilised hours. Loading units already achieve between 4,500 – 5,200 Hours of Operating Time (excluding operating delays and operating standbys). The use of an efficient continuous haulage system such as an in-pit crusher and conveyor system has the potential to improve the productivity of the shovel (Loading units in general) by between 20%-25% of current levels.

3. While the truck fleet achieve much higher available time and utilisation time, the conveyors achieved higher Operating Time and Valuable Operating Time compared to the truck fleet. The conveyors achieve an average of 3,509 hours in Valuable Operating Time relative to the average truck’s Valuable Operating Time of 2,638 hours (25% lower). These estimates affect the calculation of the capital efficiency of IPCC systems. It is noted that no SMU factors have been applied to these equipment hours.

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