Improving Shovel-Truck Productivity through Operational Efficiencies at Gold Fields Ghana Limited, Tarkwa Mine

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Apraku, E. and Temeng, V.A. (2020), "Improving Shovel-Truck Productivity through Operational Efficiencies at Gold Fields Ghana Limited, Tarkwa Mine", *Proceedings of 6th UMaT Biennial International Mining and Mineral Conference*, Tarkwa, Ghana, pp. 116-126.

Abstract

Shovel-truck combination for loading and hauling operations remains the most widely used materials handling system in many surface mining operations worldwide, constituting 50-60% of mining operation costs. The ability to move more material (waste and ore) within a time frame, considering the available resources and constraints, has direct effect on productivity. Numerous challenges are often associated with the loading and hauling operations of the materials handling chain. These include but not limited to truck bunching, material spillages on haul roads, equipment mismatching, operator boredom and payload deficiencies. There have been many researches aimed at improving the shovel-truck materials handling chain but with little or no focus on the aforementioned challenges. This paper presents a research on the effects of truck bunching in haulage, material spillage on productivity and also to determine the effective shovel-truck matching for improving productivity. This was achieved using relevant records from the real time Fleet Management System (FMS) and time and motion studies data on Liebherr hydraulic excavators and Caterpillar/Komatsu rear dump trucks at Gold Fields Ghana Limited, Tarkwa Mine, a major gold producing company in the Tarkwa-Nsuaem Municipality of the Western Region, Ghana. Using time and motion studies, colour coding, field tests coupled with mathematical and statistical analysis, results showed that, the major cause of truck bunching is inadequate tonne kilometre per hour (TKPH) ratings of trucks' tyres contributing about 62%. The truck bunching accounted for a monthly production loss of 101 000 tonnes, which is equivalent to 1.3%. The production loss through material spillage during haulage was about 618 tonnes of ore and waste, over one month period, which was very low. The best parings of shovels matching to trucks were also recommended.

Keywords: Shovel-truck mismatch, Productivity, Bunching, Spillage, TKPH

1 Introduction

The use of shovel-truck combinations for loading and hauling of material in surface mining is highly capital intensive and hence, the need to put proper measures in place to improve efficiencies. Shovel-truck systems constitute about 50% to 60% of total operating costs in surface mining (Nel *et al.*, (2011). Bagherpour (2007) shows that loading and haulage is a major share of direct cost of mining operations constituting about 70%. Choudhary, (2015) and Schexnayder *et al.*, (1999) underscore the need to use shovel-truck combination efficiently for improving economy in the mining operation. Torkamani (2013) explains that any deviation from the production targets because of operational uncertainties and inefficiencies increases the overall cost of operations. Improving the efficiency of haulage systems is one of the greatest challenges in mining operations and the subject of many research projects undertaken in the mining industry (Erçelebi and Basceti, 2009). Most of the researches for improving the efficiency of shovel-truck haulage systems have focused on truck dispatch modeling and/or simulation approach (Mendes *et al*., 2016; Tan and Takakuwa, 2016; Hashemi and Sattarvand, 2015; Osanloo and Frimpong, 2015; Subtil *et al*., 2011; Temeng *et al*., 1998; Xi and Yegulap, 1994; White *et al*., 1993; Zhang *et al.*, 1990; Lizotte *et al*., 1989). This approach to improving shovel-truck system efficiencies has been based on factors such as the production plans, blending requirements at crushers, stripping ratios, minimum and maximum capacity constraints at shovels, truck fleet characteristics and layout of mine. Almost no emphasis has been placed on factors like truck bunching, material spillage on haul road, shovel-truck mismatch operator boredom and payload discrepancies which are significant in improving shovel-truck system efficiencies.

Smith (2000) indicates that truck bunching can severely affect shovel-truck productivity. It is known to reduce a fleet's ability to meet its maximum capacity (Burt *et al.*, 2008). Koryagin *et al.* (2017) recommend the use of the same type of trucks in a shovel-truck system, as this minimises their idle time while waiting for loading. However, many surface mining companies typically run a heterogeneous shovel-truck system, partly because of mineral formation and selective mining method available. A discreet-event simulation model conducted by Zeng *et al*. (2016) shows that mixed truck fleets with varying performance can cause significant bunching effect if the hauling trucks are from multiple loading sites or dumps. For a truck cycle time scenario, under-trucking restricts the efficiency of the loader whilst over-trucking restricts the efficiency of the trucks partly due to queuing and bunching (Burt, 2008). Minimising truck bunching in shovel-truck operations reduces production and time losses and this can be a great plus for the mining company.

Material spillage calls for the introduction of clearing equipment such as a backhoe or sometimes motor graders to clear such spillages on the haul roads for the trucks to run smoothly. These spillages (ore or waste) are not accounted for in the already captured tonnage in the truck bucket. Tonnage lost through spillage goes a long way in accounting for truck payload variance. However, large tonnes of material lost through spillages are not normally accounted for during the entire period of production. Data collected on tonnes lost through spillages is significant and must be considered in analysing the mine productivity (Fricke, 2006).

Shovel-truck mismatch between loading and hauling units causes productivity to reduce below expectation. This emanates from the fact that the loading unit will have to wait for trucks to serve them and vice versa. Adams and Bansah (2016) identify a mismatch in shovel-truck system as one of the factors that can contribute to operational delays. A mismatch between sizes of shovel and trucks can lead to increased truck and shovel idle times and eventually lead to production losses (Koryagin and Voronov, 2017). Many open-pit mining companies of late, use the dispatch system to assign trucks to excavators primarily to minimise hanging or queuing. When the system is allowed to run on automatic or unlocking mode, any range of trucks can be assigned to any excavator or shovel without necessarily considering their sizes. However, the implications on shovel-truck optimisation is worrying, since many a time the shovels will load a truck quickly and hang or queue depending on the sizes of truck assigned to them. Clearly, a mismatch of shovel-truck combination is at play here principally because of varying equipment sizes. Choudhary (2015) suggests that when trucks are not optimally assigned and matched to loading units, excessive truck queuing times at the loading unit, excessive shovel wait on truck, abnormal queue time at the dump and truck bunching (typically observed with mixed fleet haulage) occur.

A small improvement in operation efficiency translates into substantial savings over the life of the mine due to the scale of operations associated (Burt *et al.*, 2008). Based on this, many surface mining companies vary their fleet systems and sizes as and when necessary in order to meet the demands of the global market. For this to be achieved however, the identified factors such as truck bunching on haul roads, material spillage during haulage and equipment mismatching should be given greater attention. This paper therefore focuses on the effects of truck bunching, material spillage on haul road and shovel-truck mismatching on productivity of the system.

2 Truck Bunching, Material Spillage and Shovel-Truck Mismatch

2.1 Truck Bunching

Truck bunching on haul roads is a phenomenon which occurs when faster trucks on ramps are forced to slow down by slow moving trucks which are in the lead. Burt (2008) defines it as the jamming effect that occurs when equipment travel along the same route. Bunching in off-road trucks is not well studied, and typically, reducing factors are used to shrink the efficiency to account for bunching (Smith *et al.*, 2000). Researchers suggest that the effects of bunching can be curbed by providing accurate equipment speeds before selecting the equipment and fleet sizes. Trucks are run on expensive rubber tyres and as such must be effectively utilized. Conversely, these trucks are forced to slow down when such tyres reach their tonne kilometre per hour (TKPH) thresholds. Truck bunching is prevalent in both homogeneous and heterogeneous situations of shovel-truck systems in loading and hauling. 'Bunching' and 'queuing' are terms commonly used with overlapping meanings and sometimes for the same condition in load and haul systems (Hardy, 2007). Hardy (2007) postulates that bunching of mining trucks manifests as a queuing effect - a loss of effective truck hours. The payload variance in surface mine fleet can influence productivity greatly due to truck bunching phenomena in large surface mines (Knights and Paton, 2010). Also, studies conducted by Soofastaei *et al.* (2015) indicate that payload variance in loading and hauling has effects on truck bunching. Paton (2009) suggests that reducing truck payload variance in surface mining operations improves productivity by reducing bunching effects and machine wear from overloaded trucks. Choudhary (2015) suggests that bunching is likely to occur when trucks are not optimally assigned and matched to the loading units.

Fleet matching principle holds that the loading unit's capacity in relation to the number of trucks loaded per unit of time should match exactly the number of trucks in the fleet. The situation is described as being a 'perfect match'. Fleet matching can be expressed mathematically in terms of mean values of operating parameters and treated deterministically using Equation 1 or other related linear relationships that include cost considerations (Hardy, 2007).

Equation 1:

$$M_F = (\frac{T_L + T_S) \times N}{T_T}$$

M_F = Fleet match, i.e. number of trucks per loading unit, where;

M_F = 1, the state is described as a perfect match;

$M_F > 1$, it means there are excess trucks, i.e. overtrucking. The loading unit is fully utilised with trucks decreasingly utilised as M_F increases; and

$M_F < 1$, it means there are insufficient trucks that are fully utilised but loading unit is increasingly underutilised as M_F decreases.

2.2 Material Spillage

Material spillage during haulage usually occurs where a fully loaded dump truck travels along the haul road. Material spillage handling is important in haulage especially in the conveyor belt and shovel-truck systems. Radlowski (1988) suggests that a standard hauler conveyor belt or truck should be selected to carry the material in order to minimise spillage. Salama (2014) on the other hand recommends good material size distribution in order to minimise material spillage during loading and hauling. Clifton (2006), a Caterpillar application consultant explains that cuts and impacts are mostly caused by material spillage on haul roads. Krzyzanowska (2007) also explains tyre damage occurs frequently on mines due to cutting of rubber by rocks, hence, spillage must be controlled.

2.3 Shovel-Truck Mismatch

Shovel-truck mismatch is common in loading and hauling and it is a great worry to load and haul handlers. Where there is a mismatch between loading and hauling units, productivity is reduced below expectation. This emanates from the fact that the loading unit will have to wait for trucks to serve them. Shovel-truck productivity estimation methods incorporate both match factor and bunching ideas into optimisation solutions (Burt *et al.*, 2008). Choudhary (2015) identifies shovel-truck mismatching as one of the major factors which affect shovel-truck productivity in loading and hauling. In mining and construction, it is very important to predict the productivity of a truck and a loading fleet as the productivity is intrinsic to equipment selection (Burt, 2008). Better shovel-truck matching helps to lower cost per tonne (Paterson, 2001). Bagherpour (2007) writes that proper matching of shovel-truck implies choosing the type of equipment, the size of the equipment and the number of units required to meet a selected production rate. Queuing theory, bunching theory, linear programming and genetic algorithms are a variety of models applied in selecting shovel-truck matching and productivity. Torkamani (2013) explains that in an open-pit mine, for truck-and-shovel haulage systems, the production capacity of the truck should match that of the loading unit. If the production capacity of the set of loading units is bigger than that of the set of trucks, it has to wait for the trucks to become available and vice versa. Either way, the system is inefficient, with mismatched capabilities (Castillo and Cochran, 1987). Differing performance of loading equipment and trucks is increased by mismatch between loading-equipment bucket capacity and truck payload (Hardy, 2007). Paterson (2001) explains that typically, the best match is one where the shovel, loading its maximum payload is able to fill a truck to its maximum payload in three or four even passes.

Shovel-truck mismatch and bunching are two phenomena when poorly handled, can affect productivity and increase cost per tonne in any loading and hauling operations. Some authors have treated fleet matching and bunching concurrently or in close succession with the inference of interrelationship or firm connection (Hardy, 2007). When a loading unit is being underutilised, waiting time (hanging) increases and this is partly attributable to bunching.

3 Materials and Methods Used

3.1 Materials Used

The materials used in this research are four (4) R984C, five (5) R9250, four (4) R9350 and one (1) R994B Liebherr loading units, thirty-nine (39) CAT 785C, eight (8) 793D, three (3) CAT 777F and thirteen (13) Komatsu HD 785 trucks respectively. For the material spillage data collection field studies, six (6) CAT 432F backhoes with 1 m^3 bucket capacity were used. Digital stop watches were used to conduct time and motion studies and the Mine’s Dispatch system was the source of data for the truck bunching studies.

3.2 Methods Used

The methods used in this research include material spillage measurements, time and motion studies for truck bunching measurements and shovel-truck matching assessments.

3.2.1 Spillage Measurements with CAT 432F Backhoe

The bucket of the backhoe used for cleaning spillage, by observation, was carefully and manually divided into four equal parts (Fig. 1). The material spilled (both waste and ore) on the ramp was scooped into the backhoe bucket and recorded by the operator based on the level of measurement observed in the backhoe bucket. The results were recorded onto the data sheets provided for that purpose. The total amount of material spilled and cleared by the CAT 432F backhoe for that period was summed up and recorded in the sample sheet.

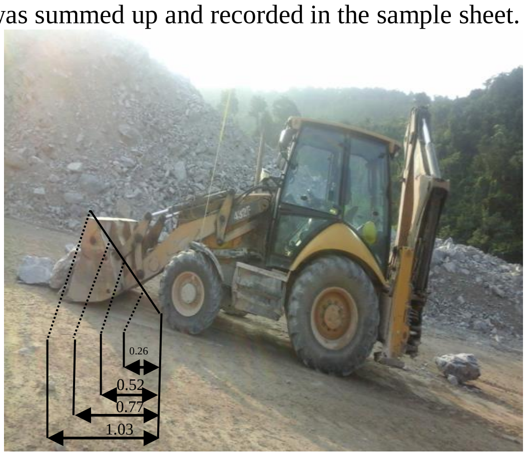

Fig. 1 Direct Observation and Measurement (m^3) with CAT 432F Backhoe

3.2.2 Truck Bunching Measurements

The truck bunching measurements were done through time and motion studies. The number of minutes a truck travelling slowly at, 20 km/hr or less, for instance, from a loading unit to its final destination is recorded. Since trucks are not allowed to overtake, the trucks following a slow moving truck are forced to slow down, resulting in bunching, hence taking longer times to reach their destinations. The delayed minutes were recorded and captured using the stop watch. In addition, the delayed minutes captured by the Dispatch system were recorded, over a two week period. The operational areas of the mine are mapped and integrated with the Dispatch software system. Trucks running on these areas are fitted with both GPS and the Dispatch system. The number of minutes both slow and normal moving trucks (empty or full) use to travel from loading units to their final destinations and vice versa, is transmitted and captured by the main Dispatch integrated software system in real time. Again, at the moment that such slow and normal moving trucks travel from loading units to their final destination and vice versa, the stop watch reading is synchronised to record the time – whether fully loaded or empty. These two concurrent processes are done in both bunching and normal situations. The time differences (time lost) for the normal travel time (full and empty) and bunching travel time (full and empty) in both situations are recorded. Both methods of recording (stop watch and Dispatch system) served as checks on each other.

3.2.3 Shovel-truck Mismatch

When a loading unit fails to achieve its expected dig rate (tonnes/hour) then productivity is not optimized. Optimizing productivity requires that right pairings are done in both situations where homogeneous (one truck type to a loading unit) and heterogeneous (two or more truck types to a loading unit) pairings occur. The colour coding was therefore used to categorise the dump trucks (Komatsu HD 785, CAT 777F, CAT 785C and CAT 793D) with varying bucket sizes assigned to the various loading units (Liebherr R984C, R9350 and R994B excavators). Homogeneous CAT 785C trucks pairing is coded as red, heterogeneous CAT 777F/ Komatsu HD 785 trucks pairing is coded blue, homogeneous CAT 793D trucks pairing is coded green, heterogeneous CAT 785C/ Komatsu HD 785 trucks pairing is coded purple and heterogeneous CAT 785C/ CAT 793D pairing is coded orange. For each of the loading units (EX05, EX06, EX07, EX08, EX15, EX16, EX18, EX19, EX24, EX25, EX26, EX27 and EX23) matching results were generated to ascertain the actual dig rates (tonnes/hour) achieved when particular set of trucks are assigned to them.

4 Results and Discussions

4.1 Material Spillage

To calculate the total amount of material spilled for the period, the recorded individual spillages were summed up for the waste material and the ore material respectively.
For instance (with reference to Table 1), on the date 13th December, 2017 the total waste material spilled (A1 (waste)) and cleared by a CAT 432F

Backhoe (labeled BH 13) with bucket size of 1.03 m^3, is calculated as:

$$A1(\text{waste}) = \frac{1}{2} + \frac{1}{2} + \frac{3}{4} + \frac{3}{4}$$

$$= 2.5\text{m}^3 \times 1.03\text{m}^3$$

$$= 2.575\text{m}^3$$

For the ore on the same date (A1 (rom)) is given as:

$$A1(\text{rom}) = \frac{1}{2} + \frac{1}{2}$$

$$= 1\text{m}^3 \times 1.03\text{m}^3$$

$$= 1.03\text{m}^3$$

The calculations were repeated for all the period and results were recorded on sample sheet A (Table 1). In a situation where there is no recording on a sample sheet column, it means no spillage occurred for that particular material - waste or ore and Nil is indicated

Table 1 Material Spillage Results Sheet

Sample Sheet	Date	Actual Production (Tonnes)	Total Waste Spilled (TWS) (m^3)	Total Ore Spilled (TRS) (m^3)	Total Material Spilled (TMS) (m^3)	Material Spilled in Tonnes (waste + ore)	Percentage of Actual Production Spilled
A1	13-12-17	121 905	2.575	1.030	3.575	9.474	0.0078
A2	14-12-17	121 570	1.030	1.030	2.060	5.459	0.0045
A3	15-12-17	140 480	2.575	Nil	2.575	6.824	0.0049
A4	16-12-17	130 135	1.545	Nil	1.545	4.044	0.0031
A5	17-12-17	130 365	3.605	4.635	8.240	21.836	0.0167
A6	18-12-17	134 625	12.618	3.605	16.223	42.991	0.0319
A7	19-12-17	120 215	6.695	3.863	10.558	27.979	0.0233
A8	23-12-17	124 801	1.030	2.575	3.605	9.553	0.0077
A9	24-12-17	135 173	1.545	0.258	1.803	4.778	0.0035
A10	25-12-17	137 710	7.468	1.545	9.013	23.884	0.0200
A11	26-12-17	148 385	14.163	Nil	14.163	37.532	0.0253
A12	27-12-17	148 531	1.030	5.408	6.438	17.061	0.0115
A13	28-12-17	135 358	6.180	0.258	6.438	17.061	0.0126
A14	29-12-17	132 005	1.288	0.515	1.803	4.778	0.0036
A15	30-12-17	149 015	1.803	1.545	3.348	8.872	0.0060
A16	01-01-18	114 785	6.953	3.863	10.816	28.662	0.0250
A17	02-01-18	137 099	4.893	0.773	5.666	15.015	0.0110
A18	03-01-18	124 537	4.120	9.785	13.905	36.848	0.0296
A19	04-01-18	145 372	10.043	7.468	17.511	46.404	0.0319
A20	05-01-18	145 295	4.120	1.030	5.150	13.648	0.0094
A21	06-01-18	147 389	8.498	2.060	10.558	27.979	0.0188
A22	10-01-18	136 102	5.923	Nil	5.923	15.696	0.0200
A23	11-01-18	123 078	1.288	5.923	7.211	19.109	0.0155
A24	12-01-18	137 286	4.120	3.863	7.983	21.155	0.0154
A25	13-01-18	136 260	5.665	8.240	13.905	36.848	0.0270
A26	14-018	152 766	5.150	2.575	7.725	20.471	0.0134
A27	15-01-18	145 503	10.043	0.515	10.558	27.979	0.0192
A28	19-01-18	147 715	4.635	2.833	7.468	19.790	0.0134
A29	20-01-18	155 957	10.558	1.545	12.103	32.073	0.0206
A30	21-01-18	145 666	2.833	Nil	2.833	7.507	0.0052
A31	22-01-18	156 160	2.833	2.833	5.666	15.015	0.0096
A32	23-01-18	140 654	6.180	Nil	6.180	16.377	0.0116
A33	24-01-18	145 650	13.905	0.258	14.163	37.531	0.0258
Total = 33		**Total = 4 547 547 tonnes**	**∑ (TWS) = 176.91 m^3**	**∑ (TRS) = 79.83 m^3**	**∑(TMS) = 256.71 m^3**	**Total = 679.95 tonnes**	

4.1.1 Resultant Effect of Material Spillage

The total amount of waste spilled in the 33 days between 13th December, 2017 to 24th January, 2018 is estimated to be 176.91 m^3. The average material density of the mine for both ore and waste is 2.65 g/cc (t/m^3). The estimated volume of the waste spilled is calculated as:

$$2.65\ t/m^3 \times 176.91 m^3 = 468.81\ tonnes$$

The total amount of ore spilled for the period is estimated to be 77.5 m^3. Applying the material density of 2.65 g/cc (t/m^3) to the estimated volume, the ore lost is given as:

$$2.65\ t/m^3 \times 79.83\ m^3 = 211.55\ tonnes$$

The total amount of material spilled between 13th December, 2017 to 24th January, 2018 is 256.59 m^3 or 679.95 tonnes. For a period of one month, a total of 618 tonnes was lost through spillage. Highest amount of material spilled occurred on 4th January, 2018 with an amount of 145 372 tonnes produced (Fig. 2). The average daily spillage is 20.60 tonnes.

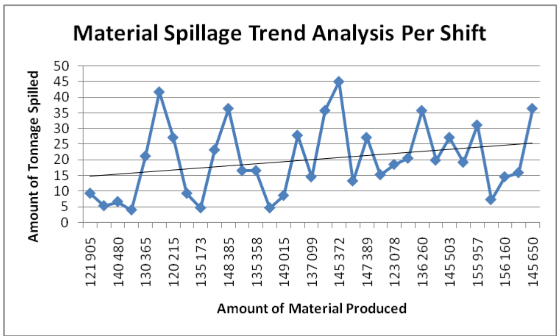

Fig. 2 Material Spillage Trend Analysis Per Shift

Studying the trend carefully reveals that, material spillage is not absolutely dependent on the amount of material produced. Indeed, lower amounts of material produced on 01-01-18, 19-12-17 and 03-01-18, for instance, had corresponding spillages of 28.66, 27.98 and 36.85 which are higher as compared to spillages from higher amount of material produced on 15-12-17, 24-12-17 and 21-01-18 respectively.

Most of the material spillages are caused by improper gear selection (accounting for about 50%), poor ramp designs (30%), poor loading practices (14%) and truck bucket defects (6%).

4.1.2 Estimated Gold lost through spillage

The following is an estimate of gold lost in 33 days, from the period of 13th December, 2017 to 24th January, 2018:

Total ore spilled (lost) = 211.55 tonnes

Average grade for the Mine = 1.24 g/t

Hence,

Metal content = $211.55\ tonnes\ \times 1.24\ g/t$

$$= 262.32\ grammes$$

Applying ounces factor of 31.10348 grammes, the mined ounces is estimated as

$$\frac{262.32\ grammes}{31.10348\ grammes} = 8.4$$

Based on the Mine Call Factor (97%) and the Recovery Factor (96.8%) of the Mine, the recovered ounces are estimated to be 7.9 ounces.

Therefore, the quantity of gold lost through spillage from 13th December, 2017 to 24th January, 2018 is estimated to be 7.9 ounces. Based on the average market value of gold price per ounce which is \$ 1 292.05 (as at 17th May, 2018), then a revenue lost of \$ 10 207.20 is recorded. Supposing the project is extended to cover the entire year (12 months), then revenue lost through material spillage for ore is estimated to be \$ 122 486.34. It must be noted that this revenue shortfall excludes costs of cleaning the spillage and the possible damage the spillage can cause to tyres.

4.2 Truck Bunching

The travelling time for both normal travel and when trucks are bunching were recorded for all the trucks observed. The time difference between the designated normal travel time and the time when trucks are bunching were recorded (Table 2) in order to analyse the time lost on productivity due to bunching.

For instance, on 20-01-2018, for DT 38 and DT09, during day shift:

The designated normal travel time $(travel\ loaded + travel\ empty)$ is given as:

$$8\ minutes\ 55\ seconds + 7\ minutes\ 42\ seconds = 16\ minutes\ 37\ seconds$$

and

$$9\ minutes\ 35\ seconds + 7\ minutes\ 27\ seconds = 17\ minutes\ 2\ seconds$$

The total normal travel time $(travel\ loaded + travel\ empty)$ *for two weeks* is:

$$16\ minutes\ 37\ seconds + 17\ minutes\ 2\ seconds = 33\ minutes\ 39\ seconds$$

On the same 20-01-2018, for DT 38 and DT 09, during day shift:

The bunching travel time $(travel\ loaded + travel\ empty)$ is given as:

$$13\ minutes\ 8\ seconds + 8\ minutes\ 5\ seconds = 21\ minutes\ 13\ seconds$$

and

$$11\ minutes\ 55\ seconds + 7\ minutes\ 41\ seconds = 19\ minutes\ 36\ seconds$$,

respectively

The total bunching travel time (travel loaded + travel empty) for two weeks is:

$$21\ minutes\ 13\ seconds + 19\ minutes\ 36\ seconds = 40\ minutes\ 49\ seconds$$

Hence, the time difference between normal and bunching, that is, *time lost* on productivity is given as:

$$40\ minutes\ 49\ seconds - 33\ minutes\ 39\ seconds = 7\ minutes\ 10\ seconds$$

The calculations were repeated for all the other trucks for the dates on which such observations were taken (Table 2). It must be noted that these normal travel times and travel times due to bunching are recorded per cycle.

Table 2: Lost Time on Shovel-Truck Productivity through Bunching

Date	Normal Travel Time *Travel loaded + travel empty*	Bunching Travel Time *travel loaded + travel empty*	Time Difference between *normal* and *bunching*
20-01-18	33 minutes 39 seconds	40 minutes 49 seconds	7 minutes 10 seconds
21-01-18	141 minutes 47 seconds	171 minutes 47 seconds	30 minutes 0 second
22-01-18	33 minutes 18 seconds	44 minutes 47 seconds	11 minutes 29 seconds
23-01-18	103 minutes 5 seconds	144 minutes 9 seconds	41 minutes 4 seconds
24-01-18	66 minutes 28 seconds	91 minutes 36 seconds	25 minutes 8 seconds
25-01-18	76 minutes 31 seconds	98 minutes 22 seconds	21 minutes 51 seconds
26-01-18	28 minutes 46 seconds	38 minutes 50 seconds	10 minutes 4 seconds
31-01-18	36 minutes 57 seconds	42 minutes 11 seconds	5 minutes 4 seconds
02-02-18	31 minutes 12 seconds	36 minutes 23 seconds	5 minutes 11 seconds
03-02-18	30 minutes 9 seconds	37 minutes 14 seconds	7 minutes 5 seconds
04-02-18	138 minutes 10 seconds	176 minutes 4 seconds	37 minutes 54 seconds
Total(Time Difference)= 3 hrs 22 minutes (3.367 hrs)			

4.2.1 Causes of Truck Bunching

The research identified the tonne kilometre per hour (TKPH) rating of trucks tyres as the major contributing factor for truck bunching, accounting for 62%. TKPH is an expression of the working capacity of a tyre and a function of the maximum allowable internal operating temperature (Anon, 2010). Tyres should be selected on the basis of the tyre TKPH rating being higher than the real site TKPH of the tyre operating in the mine environment. The real site TKPH of a tyre depends on the load it carries, the cycle speed of the truck and the ambient temperature. If the real site TKPH of a tyre operating in the mine environment happens to be higher than the rated tyre TKPH threshold the tyre will fail due to overheating. Some 62% of the total time lost due to bunching was due to tyres heating up and reaching their TKPH thresholds. Truck tyres reaching their TKPH thresholds were made to slow down to prevent tyres from failing. Other factors causing bunching include overloading of trucks (14% of the time lost to bunching), low engine power of trucks (19% of the time lost to bunching) and mismatching of trucks (5% of time lost due to bunching).

4.2.2 Effect of Truck Bunching: Time Lost on Production

From the Table 2, the total time lost due to bunching is estimated to be 3 hours 22 minutes for the two weeks of observation. On a typical hour within a shift, an amount of 15 000 tonnes of material can be hauled by trucks, considering the resources available. Translating this time lost into tonnage between 20th January, 2018 to 4th February, 2018, the estimated tonnage lost is given as:

$$15\ 000\ \text{tonnes/hr} \times 3.367\text{hr}$$
$$= 50\ 500\ \text{tonnes}$$

The tonnage lost due to bunching in 15 days (20th January to 4th February, 2018) is 50 500. This translates to 101 000 tonnes per month. Compared to the mine's expected average monthly production of 8 000 000 tonnes, the percentage of monthly production lost due to bunching is 1.3%.

4.3 Shovel-Truck Mismatch

Matching results were generated to ascertain the actual dig rates achieved when particular set of trucks are assigned to shovels. The best matching of trucks to excavators were the ones with high dig rates above the set targets. The average dig rates of the truck pairing are presented together with the loading unit categories (Table 3).

Table 3 Loading Units and Truck Matching Results

Loading Unit Category	Truck Category Assigned to Loading Unit	Colour Code Summary	Average Dig Rate (tonnes/hr)		Percentage Variance
			Target	Actual	
Liebherr R984C	CAT 785C & Kom. HD 785		950	1 001	+ 5.4%
	CAT 785C		950	977	+ 2.8%
	CAT 777/Kom. HD 785		950	824	-13.3%
Liebherr R9250	CAT 785C		1400	1 405	+0.4%
	CAT 777/Kom HD 785		1 400	1 000	+28.6%
	CAT 793D		1 400	1 655	+18.2%
	CAT 785 & Kom. HD 785		1 400	1 201	-14.2%
	CAT 785 & CAT 793		1 400	1 483	+5.9%
Liebherr R9350	CAT 785C		1 900	1 549	-18.5%
	CAT 793D		1 900	2 089	+9.9%
	CAT 785C & CAT 793D		1 900	1 900	+0%
Liebherr R994B	CAT 785C		1 600	1 737	+8.6%
	CAT 785C & CAT 793D		1 600	1 760	+10%

Based on the results presented in Table 3, the best excavator truck matching was determined. A summary of the excavator and truck matching has been provided in Table 4.

Table 4 Summary of Recommended Matching

Truck Types	Loading Units and Recommendation			
	Liebherr R984C	Liebherr R9250	Liebherr R9350	Liebherr R994B
Komatsu HD 785 only	Recommended	Not recommended	Not recommended	Not recommended
CAT 785C only	Highly recommended	Highly recommended	Recommended	Recommended
Komatsu HD 785 and CAT 785C paired	Highly recommended	Not recommended	Not recommended	Not recommended
CAT 793D only	Not recommended	Highly recommended	Highly recommended	Highly recommended
CAT 793D and CAT 785C paired	Not recommended	Highly recommended	Highly recommended	Highly recommended

5 Conclusions and Recommendations

5.1 Conclusions

This research focused on the effect of truck bunching, material spillage on haul road and shovel-truck mismatching on the productivity of shovel-truck haulage system in open pit operations at Gold Fields Ghana Ltd, Tarkwa Mine. The analysis was based on field studies, data from time and motion studies and data recorded from automated truck dispatching system and colour coding. The following conclusions were made from the results and analysis.

i. The major effect of truck bunching is a time loss of 3 hours 22 minutes in two weeks, translating into an estimated lost production of 101,000 tonnes per month. The percentage production lost through bunching is estimated to be 1.3% of total monthly production. Slowing down of trucks to prevent tyres from reaching TKPH thresholds was a major cause of bunching, accounting for about 62%. This was followed by low engine power (19%), overloading of trucks (14%), and truck mismatch (5%);

ii. Production loss through material spillage during haulage was 468.81 tonnes of waste and 211.55 tonnes of ore, totaling 679.95 tonnes over the thirty-three (33) days period. This amounted about 0.015% of production; and

iii. It was established that not all the current shovel-truck matching being practised at the Mine are efficient enough to achieve set targets. More efficient shovel-truck matching that meet production targets has been proposed (Table 4).

5.2 Recommendations

From the foregoing analysis and conclusions the following are recommended:

i. Minimising truck bunching on ramps requires that:
   a. Maintenance crew should ensure that ageing trucks are overhauled to improve engine power and truck speeds;
   b. A second look should be taken at tyre selection to ensure that tyres of the correct TKPH ratings are selected to minimise tyre heating problems; and
   c. Overloading of the truck must be avoided to ensure that truck drivers move at the right speeds on ramps.

ii. Minimising material spillage requires that:
   a. Operators adhere to the correct operating techniques for the trucks, especially when fully loaded and in motion to minimise jerking of trucks;
   b. Ramps with optimum gradient (at most 10%) and even surface must be constructed for the trucks, especially when fully loaded in accordance with ramp design standards;
   c. There should be closer supervision to ensure proper loading of trucks to minimise overloading which causes material spillage on ramps; and
   d. Defective truck buckets should be rectified in order to prevent material spillage from these defects.

Acknowledgements

Gold Fields Ghana Ltd, Tarkwa Mine is acknowledged for making the open pit operations, mine equipment and facilities available for this research.

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