DEBASIS DEB
and
SREENIVASA RAO ISLAVATH

Time and motion study of dumpers and shovel deployed at a shallow depth mine

A friable chromite ore body in Sukinda valley, Odisha is being excavated by opencast mining method. Combination of shovel and dumper system is deployed to lift overburden rock and ore body to the dump yard and ore handling plant respectively. Dumpers carrying overburden rocks travel from loading points in the pit to dump yard and others carrying ore travel to ore handling plant for unloading the material and return. A time-and-motion study has been undertaken to understand the pattern of fuel consumption of loaded and empty dumpers so that a proper economical analysis can be carried out while offloading this work to contractors. In this paper, a methodology is established to determine the fuel consumption of loaded dumper for (i) lifting the material from the loading points to the pit top, (ii) traveling of loaded dumper on the surface from pit top to discharge point, (iii) travelling of empty dumpers from discharge point to pit top and (iv) travelling of empty dumpers from pit top to the loading points. In addition, the cycle time and waiting time of shovels are also collected and analyzed based on the different probability distribution functions.

1. Introduction

The extraction of the mineral body with shovel-dumper combination is the most popular in the opencast mine workings [1-2]. The production rate from opencast mine depends on the efficiency by which the cyclic operations such as drilling, blasting, loading and transportation of blasted material are carried out. The loading and transportation operations are to be optimized by keeping appropriate match factor, utilizing the shovel and dumper available hours, design of proper haul road, minimizing the breakdown time, improving of operator efficiency in order to boost the productivity of the mine [3-5]. Out of these operations, the loading and transportation are the most critical activities and contributes major cost share of opencast workings. The cost of transportation especially fuel consumption depends on working depth, lead distance, speed of the dumper, waiting time for loading and dumping and pay load capacity of dumper [2, 6,7].

Several studies have been undertaken for the optimization of opencast operations in order to achieve a desired profit [3,5,6]. A few studies have been conducted to optimize the transportation operation to assess the energy consumption [1,2,8]. Currently, the trend is to outsource both the loading and transportation of material to a third party and reduce the cost of these two operations. Since the transportation of material costs fuel, it is desirable to perform time and motion study of the dumpers to evaluate the efficiency.

In this study, attempt is made to develop a simple methodology by which fuel consumption of dumpers working in opencast mine can be determined for lifting materials from loading points to the surface and then dumping them to a designated site. Fuel consumption of dumper or truck is dependent on the vertical lift from loading point to pit surface and horizontal distance from pit surface to dumping point. The fuel consumption will be different for loading and empty dumper for travelling the same distance as well as the age of the fleet. Here, fuel consumption of the dumper is determined based on the four components, (i) fuel consumption for lifting rock material from the pit to a height (h) up to the surface level, (ii) travelling with loaded rock material at a distance d from the pit top to the dump site, (iii) travelling empty at a distance d from the dump site to pit top, and (iv) travelling down empty to the pit to height (h) from the surface level. In order to determine the fuel consumption of the dumper, dumpers (Terex and Tipper) have been assigned to two different shovels working at different locations at 160 mRL and 84 mRL as shown in Fig.1. The fuel consumption data of the dumpers have been collected and a methodology has been presented for their analysis.

This paper describes the detailed procedure to determine the various components of fuel consumption of dumper or transporting equipment which will be beneficial for increasing the productivity of the mine or sometimes quoting the prices for offloading contractors. The cycle time of shovel also recorded and analyzed based on the different probability distributions profiles.

Dr. Debasis Deb, Professor, Department of Mining Engineering, IIT Kharagpur 721 302. E-mail: deb.kgp@gmail.com and Mr. Sreenivasa Rao Islavath, Assistant Professor, Department of Mining Engineering, University of Engineering (KU), Kothagudem 507 101. E-mail: islavathsreenivas@gmail.com

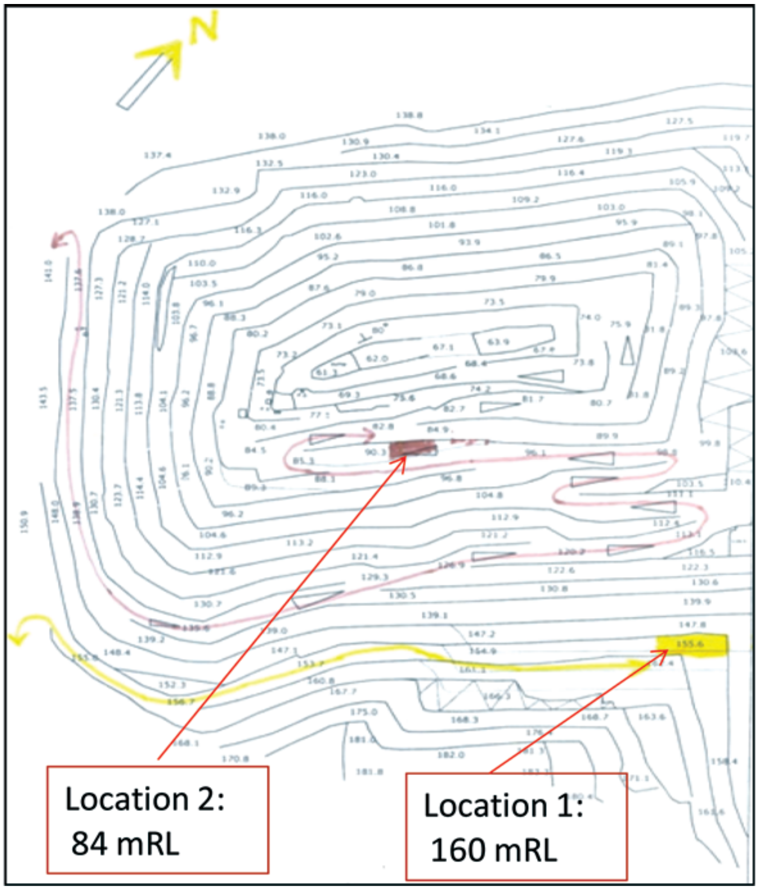


Fig.1 The opencast mine showing the shovel positions

2. Description of the mine site

The opencast mine was operated in the Sukinda Tehsil of Jajpur district of Odisha. The working depth of the mine at the time of analysis was 78 m and surface RL varies between 140 m and 160 m. The length and width of the mine boundary were around 420 m and 500 m respectively. The mine was operated with shovel-dumper combination with deep hole drilling blasting at a grid pattern 2.5 m (burden) × 3 m (spacing). The height and width of the bench were maintained as 8 m and 12 m respectively with intermittent ramp at 1 in 12. The slope angle of individual benches was 75-80 degrees and the overall slope angle was around 25 degrees on all sides of opencast mine. The width and length of the ore body was 30 m and 420 m respectively. The country rocks of chromite deposit were quartzite, limonite, chert and laterite.

3. Collection of data from the mine site

Fuel consumption data of dumpers (both Terex and Tippers) have been collected from the mine site in shift wise operation. Fuel tank of a dumper has been completely filled at the beginning of the shift. Then the dumper is assigned to an excavator located at a particular level in the pit. After the end of the shift, tank has been refilled completely and the amount of fuel refilled is noted as the fuel consumption of the dumper for that shift. For each dumper, 2 sets of fuel consumption data have been recorded for 2 shifts by assigning it to an excavator located at 2 different levels in the pit as shown in Fig.1. Table 1 lists the data recorded for Terex no.13 and 16 and Tipper no.1929.

Apart from the fuel consumption study, cycle time and waiting time of the excavator of excavator no.1 has also been conducted to determine probabilistic patterns. Table 6 shows the recorded time taken by the excavator for its various operations. These data have been collected for 29 cycles to estimate the probability distributions of various operations [8].

4. Methodology

In this study, a lift-haul-dump-travel back cycle of a dumper is divided into 4 categories based on its fuel consumption as defined below:

- Case 1: k_1 = Fuel consumption of dumper for lifting rock material from the pit to h height up to the surface level (lit per meter of lift).
- Case 2: k_2 = Fuel consumption of dumper for travelling down empty to the pit up to h height from the surface level (lit per meter of lift).

TABLE 1: DATA COLLECTED FROM THE MINE

	Dumper	Location of excavator (mRL)	Surface elevation (mRL)	Haul distance to dump site from surface (m)	Number of trips (lit)	Fuel consumption
1	Terex no.13	160	161	1050	10	79
2	Terex no.16	160	161	1050	10	75
3	Tripper no.1929	160	161	1050	7	13.1
4	Terex no.13	84	140	1280	10	97
5	Terex no.16	84	140	1280	10	96
6	Tripper no.1929	84	140	1280	10	26

- Case 3: k_3 = Fuel consumption of dumper for travelling with rock material at a distance d from the pit top to the dump site (lit per meter of haul).
- Case 4: k_4 = Fuel consumption of dumper for travelling empty at a distance d from the dump site to pit top (lit per meter of haul).

Based on the above definition, fuel consumption for a lift-haul-dump-travel back cycle of a dumper can be expressed as

$$(k_1 + k_2)h + (k_3 + k_4)d + q = l \quad ... \quad (1)$$

where, l denotes total fuel consumption per cycle (lit) and q signifies miscillineous fuel consumption due to (i) waiting time (ii) dumping of material at the site, and (iii) any other unforeseen conditions.

Assuming, parameter k_2 and k_4 are α and β fraction of k_1 and k_3 respectively, we can write

$$k_2 = \alpha k_1 \quad ... \quad (2a)$$

$$k_4 = \beta k_3 \quad ... \quad (2b)$$

Hence, equation 1 can be written by ignoring fuel consumption q as

$$(1+\alpha)hk_1 + (1+\beta)dk_3 = l \quad ... \quad (3)$$

Equation 3 has 2 unknown parameters k_1 and k_3 which needs to be determined from the fuel consumption data. For this purpose, fuel consumption data of a dumper have been collected considering excavator located at 2 different locations in the pit. Let us assume $h_i (i = 1,2)$ and $d_i (i = 1,2)$ represent the vertical lift and haul distance respectively for 2 locations and $l_i (i = 1,2)$ is the fuel consumption of the dumper. Then equation 3 can be rewritten as

$$(1+\alpha)h_1k_1 + (1+\beta)d_1k_3 = l_1 \quad ... \quad (4a)$$

$$(1+\alpha)h_2k_1 + (1+\beta)d_2k_3 = l_2 \quad ... \quad (4b)$$

In matrix form, equation 4 can be expressed as

$$\begin{bmatrix} (1+\alpha)h_1 & (1+\beta)d_1 \\ (1+\alpha)h_2 & (1+\beta)d_2 \end{bmatrix} \begin{Bmatrix} k_1 \\ k_3 \end{Bmatrix} = \begin{Bmatrix} l_1 \\ l_2 \end{Bmatrix} \quad ... \quad (5)$$

or

$$\mathbf{AK} = \mathbf{L} \quad ... \quad (5)$$

Hence, vector k can be obtained as

$$\mathbf{K} = \mathbf{A}^{-1}\mathbf{L} \quad ... \quad (6)$$

5. Estimation of fuel consumption of dumpers

In the following, fuel consumption of 2 dumpers and one truck are presented considering equation 6. It may be noted that the two excavators were located at 1 m and 56 m below the surface at the time of data collection.

5.1 Fuel consumption of terex no. 13

Terex No.13 has been assigned to an excavator located in the pit having elevations 160 mRL (location 1) and 84 mRL (location 2) as listed in Table 1. It can be seen that fuel consumption per cycle is 7.6 litre per cycle (trip) for location 1 and 9.7 litre per cycle for location 2. The vertical lifts are h_1 = 1m and h_2 = 56m respectively for 2 locations. The haul distances for location 1 and location 2 are d_1 = 1050 m and d_2 = 1280m respectively. The value of α and β must be decided judiciously and can also be determined with meticulous measurement. In this study, it is assumed that while an empty truck travels down to a pit, fuel consumption will be much less as compared to loaded truck rising up via haul road. Therefore, α = 0.3 and β = 0.6 are assumed for this calculation and hence, equation 6 can be expressed as

$$\begin{bmatrix} 1.3 & 1680 \\ 72.8 & 2048 \end{bmatrix} \begin{Bmatrix} k_1 \\ k_3 \end{Bmatrix} = \begin{Bmatrix} 7.6 \\ 9.7 \end{Bmatrix}$$

After solving equation 6, we find

k_1 = 0.00611 ltr/m or 163.6 m/ltr

k_3 = 0.00452 ltr/m or 221.2 m/ltr

This means that for vertical lift of 100 m, Terex no.13 consumes 0.61 ltr of fuel while hauling with material on the surface and it consumes 0.45 ltr per 100 m of haul distance. From the above data, it is also estimated that Terex no.13 consumes 0.18 ltr per 100 m of vertical height while travelling empty down to the pit from the surface. It also burns 0.27 ltr of fuel per 100 m of haul distance while travelling back empty from the dump site to the top of the pit. Table 2 provides a sensitivity analysis based on the assumed α and β.

5.2 Fuel consumption of terex no.16

Terex No.16 has been also assigned to an excavator located in the pit having elevations 160 mRL (location 1) and 84 mRL (location 2) as listed in Table 1. It can be seen that fuel consumption per cycle is 7.5 litre per cycle (trip) for location 1 and 9.6 litre per cycle for location 2. The vertical lifts are h_1 = 1m and h_2 = 56m respectively for 2 locations. As before, the haul distances for location 1 and location 2 are d_1 = 1050m and d_2 = 1280m respectively. Assuming α = 0.3 and β = 0.6, equation 4 can be expressed as

$$\begin{bmatrix} 1.3 & 1680 \\ 72.8 & 2048 \end{bmatrix} \begin{Bmatrix} k_1 \\ k_3 \end{Bmatrix} = \begin{Bmatrix} 7.5 \\ 9.6 \end{Bmatrix}$$

After solving equation 6, we find

k_1 = 0.00642 ltr/m or 155.78 m/ltr

k_3 = 0.0446 ltr/m or 224.25 m/ltr

This signifies that for vertical lift of 100 m, Terex no.16 consumes 0.64 ltr of fuel while hauling with material to the surface and it consumes 0.45 ltr per 100 m of haul distance. From the above data, it is also estimated that Terex no.16 consumes 0.19 ltr per 100 m of vertical height while travelling empty down to the pit from the surface. It also burns 0.27 ltr of fuel per 100 m of haul distance while travelling back empty from the dump site to the top of the pit. Table 3 lists the fuel consumption values based on different α and β parameters.

Table 2: Various components of fuel consumption of terex no.13 dumper

	α	0.2	0.25	0.3	0.35	0.4	0.45	0.5
β = 0.6	k_1(m/lit)	151.037	157.33	163.624	169.917	176.21	182.503	188.796
	k_2(km/lit)	0.75519	0.62932	0.54541	0.48548	0.44053	0.40556	0.37759
	k_3(m/lit)	221.284	221.284	221.284	221.284	221.284	221.284	221.284
	k_4(km/lit)	0.368	0.368	0.368	0.368	0.368	0.368	0.368
β = 0.4	k_1(m/lit)	151.037	157.33	163.624	169.917	176.21	182.503	188.796
	k_2(km/lit)	0.755	0.629	0.545	0.485	0.440	0.40556	0.37759
	k_3(m/lit)	193.623	193.623	193.623	193.623	193.623	193.623	193.623
	k_4(km/lit)	0.484	0.484	0.484	0.484	0.484	0.484	0.484
β = 0.5	k_1(m/lit)	151.037	157.33	163.624	169.917	176.21	182.503	188.796
	k_2(km/lit)	0.75519	0.62932	0.54541	0.48548	0.44053	0.40556	0.37759
	k_3(m/lit)	207.454	207.454	207.454	207.454	207.454	207.454	207.454
	k_4(km/lit)	0.41491	0.41491	0.41491	0.41491	0.41491	0.41491	0.41491
β = 0.7	k_1(m/lit)	151.037	157.33	163.624	169.917	176.21	182.503	188.796
	k_2(km/lit)	0.75519	0.62932	0.54541	0.48548	0.44053	0.40556	0.37759
	k_3(m/lit)	235.114	235.114	235.114	235.114	235.114	235.114	235.114
	k_4(km/lit)	0.33588	0.33588	0.33588	0.33588	0.33588	0.33588	0.33588

Table 3: Various components of fuel consumption of terex no.16 dumper

	α	0.2	0.25	0.3	0.35	0.4	0.45	0.5
β = 0.6	k_1(m/lit)	143.8	149.792	155.783	161.775	167.767	173.758	179.75
	k_2(km/lit)	0.719	0.59917	0.51928	0.46221	0.41942	0.38613	0.3595
	k_3(m/lit)	224.25	224.25	224.25	224.25	224.25	224.25	224.25
	k_4(km/lit)	0.37375	0.37375	0.37375	0.37375	0.37375	0.37375	0.37375
β = 0.4	k_1(m/lit)	143.8	149.792	155.783	161.775	167.767	173.758	179.75
	k_2(km/lit)	0.719	0.59917	0.51928	0.46221	0.41942	0.38613	0.3595
	k_3(m/lit)	196.218	196.218	196.218	196.218	196.218	196.218	196.218
	k_4(km/lit)	0.49055	0.49055	0.49055	0.49055	0.49055	0.49055	0.49055
β = 0.5	k_1(m/lit)	143.8	149.792	155.783	161.775	167.767	173.758	179.75
	k_2(km/lit)	0.719	0.59917	0.51928	0.46221	0.41942	0.38613	0.3595
	k_3(m/lit)	210.234	210.234	210.234	210.234	210.234	210.234	210.234
	k_4(km/lit)	0.42047	0.42047	0.42047	0.42047	0.42047	0.42047	0.42047
β = 0.7	k_1(m/lit)	143.8	149.792	155.783	161.775	167.767	173.758	179.75
	k_2(km/lit)	0.719	0.59917	0.51928	0.46221	0.41942	0.38613	0.3595
	k_3(m/lit)	238.265	238.265	238.265	238.265	238.265	238.265	238.265
	k_4(km/lit)	0.34038	0.34038	0.34038	0.34038	0.34038	0.34038	0.34038

5.3 Fuel consumption of tipper no.1929

Similar to Terex nos.13 and 16, Tipper 1929 has been also deployed with the same excavators located at the same locations. The vertical lift and haul distance are the same for the Tipper. However, the fuel consumption for a cycle is much less as compared to the Terex. It is recorded that for one cycle, fuel consumptions are l_1 = 1.87ltr and l_2 = 2.6ltr respectively for locations 1 and 2. Using these data, equation 4 can be written as

$$\begin{bmatrix} 1.3 & 1680 \\ 72.8 & 2048 \end{bmatrix} \begin{Bmatrix} k_1 \\ k_3 \end{Bmatrix} = \begin{Bmatrix} 1.87 \\ 2.60 \end{Bmatrix}$$

After solving equation 6, we find

k_1 = 0.004499 ltr/m or 222.3 m/ltr

k_3 = 0.00111 ltr/m or 901.2 m/ltr

These data reflect that for vertical lift of 100 m, Tipper No. 1929 consumes 0.44 ltr of fuel. It burns 0.11 ltr per 100 m of haul distance while hauling with material on the surface. From the above data, it is also estimated that Tipper no.1929 consumes 0.13 ltr per 100 m of vertical height while travelling empty down to the pit from the surface. It also burns 0.06 ltr of fuel per 100 m of haul distance while travelling back empty from the dump site to the top of the pit. In other word, the empty Tipper can travel 1.5 km for 1 ltr of fuel on the periphery road from the pit top to the dump site. Sensitivity analysis of fuel consumption based on α and β values are given in Table 4.

TABLE 4: VARIOUS COMPONENTS OF FUEL CONSUMPTION OF TIPPER NO.1929 DUMPER

α		0.2	0.25	0.3	0.35	0.4	0.45	0.5
β = 0.6	k_1(m/lit)	205.184	213.734	222.283	230.832	239.382	247.931	256.480
	k_2(km/lit)	1.026	0.855	0.741	0.660	0.598	0.551	0.513
	k_3(m/lit)	901.214	901.214	901.214	901.214	901.214	901.214	901.214
	k_4(km/lit)	1.502	1.502	1.502	1.502	1.502	1.502	1.502
β = 0.4	k_1(m/lit)	205.184	213.734	222.283	230.832	239.382	247.931	256.480
	k_2(km/lit)	1.026	0.855	0.741	0.660	0.598	0.551	0.513
	k_3(m/lit)	788.562	788.562	788.562	788.562	788.562	788.562	788.562
	k_4(km/lit)	1.971	1.971	1.971	1.971	1.971	1.971	1.971
β = 0.5	k_1(m/lit)	205.184	213.734	222.283	230.832	239.382	247.931	256.480
	k_2(km/lit)	1.026	0.855	0.741	0.660	0.598	0.551	0.513
	k_3(m/lit)	844.888	844.888	844.888	844.888	844.888	844.888	844.888
	k_4(km/lit)	1.690	1.690	1.690	1.690	1.690	1.690	1.690
β = 0.7	k_1(m/lit)	205.184	213.734	222.283	230.832	239.382	247.931	256.480
	k_2(km/lit)	1.026	0.855	0.741	0.660	0.598	0.551	0.513
	k_3(m/lit)	957.540	957.540	957.540	957.540	957.540	957.540	957.540
	k_4(km/lit)	1.368	1.368	1.368	1.368	1.368	1.368	1.368

TABLE 5: TOTAL FUEL CONSUMPTION OF DUMPERS

Dumper	Location	*N*	*F.F*	*B*	Material handled (m^3)	Fuel consumption (ltr/m^3), $\times 10^{-3}$
Terex no.13	1	4	0.9	2.7	9.72	0.63
	2	4	0.9	2	7.2	47.52
Terex no.16	1	4	0.9	2.7	9.72	0.66
	2	4	0.9	2	7.2	49.93
Tipper 1929	1	2	0.9	2	3.6	1.24
	2	4	0.9	2	7.2	34.76

5.5 FUEL CONSUMPTION BASED ON VOLUME OF ROCK EXCAVATION

Total material handled by dumper (per trip) is estimated based on equation 7 [3,7,8].

$$N * B * F.F \text{ m}^3 \qquad \ldots \quad (7)$$

where, N = Number of passes required to fill the Terex or Tipper, F.F = fill factor of an excavator bucket and B = bucket capacity of an excavator.

Terex no.13 dumper was assigned to an excavator located in the pit at an elevation of 160 mRL at location 1 and the surface elevation is 161 mRL. It is found that it takes about 4 passes of bucket capacity 2.7 m^3 having fill factor 0.90 to fill the dumper. Hence, the total volume of rock is 9.72 m^3. Now, fuel consumption of dumper for lifting rock material from the pit to 1m height up to the surface level is found to be k_1 = 0.00611 ltr (from section 5.1, $k_1 \times 1$). The total fuel consumption of dumper for lifting rock material of 9.72 m^3 will be = 0.0006286 lits.

Based on the equation 7, the total fuel consumption of dumper for lifting the rock material from location 1 (1 m vertical lift) and location 2 (56 m vertical lift) are given in Table 5.

6. Time study of excavator

Time study of the excavator no.1 has been conducted considering time for (i) Crowding (ii) Lifting (iii) Swinging (iv) Unloading (v) Swinging back operations. Table 6 provides data of such 29 cycles (passes). Cycle time is estimated by adding the time taken for these 5 operations. In this study, histogram, probability density function and cumulative density function of time taken for (i) Crowding (ii) Lifting-Swinging-Unloding-Swinging Back (LSUSB) combined (iii) one cycle have been determined from the data given in Table 6. This information is useful to the mine management for improving operational efficiency of the excavators.

Generally, two Terex and one Tipper are assigned to the excavator. It has been noticed that the excavator waits considerable time for the dumpers. Dumpers however do not have to wait for the excavator.

6.1 HISTOGRAM AND PROBABILITY DISTRIBUTIONS OF CROWDING TIME

Based on the data given in Table 6, histogram of crowding time is developed (Table 7) and shown in Fig.2. Frequency plot suggests exponential distribution of data. Using these data, parameter (mean) of exponential probability distribution

TABLE 6: SHOVEL CYCLE TIME DATA OF 29 PASSES

Number of passes	Crowding time (sec)	Lifting time (sec)	Swinging time (sec)	Unloading time (sec)	Swinging back time (sec)	Total time (sec)
1	5	2	8	5	5	25
2	8	5	5	5	5	28
3	5	4	5	5	5	24
4	6	3	5	5	5	24
5	5	5	5	10	5	30
6	5	5	5	5	5	25
7	10	3	7	4	8	32
8	5	5	5	6	5	26
9	5	5	5	5	5	25
10	7	3	5	5	5	25
11	5	5	5	5	7	27
12	10	3	10	5	5	33
13	9	5	2	5	5	26
14	8	5	5	5	5	28
15	10	3	5	5	5	28
16	7	2	5	5	7	26
17	5	3	5	5	5	23
18	7	3	5	5	5	25
19	7	3	8	4	9	31
20	7	3	10	5	5	30
21	10	4	6	6	3	29
22	10	3	7	3	10	33
23	7	3	2	9	4	25
24	5	5	7	3	7	27
25	5	3	6	5	5	24
26	13	3	6	4	4	30
27	5	5	5	5	5	25
28	15	5	5	5	5	35
29	10	3	7	3	7	30

TABLE 7: FREQUENCY DISTRIBUTION OF CROWDING TIME

Crowding time (sec)	Frequency
< 5	11
5-7	7
7-9	3
9-11	6
11-13	1
13-15	1
> 15	0

function has been obtained as $1/\lambda = 7.4483$. Equations 8a and 8b give the probability density function and cumulative density function as mentioned below [9]:

$$f(t) = \lambda e^{-\lambda t}\ t > 0 \qquad \text{... (8a)}$$

$$F(T) = f(t < T) = 1 - e^{-\lambda T} \qquad \text{... (8b)}$$

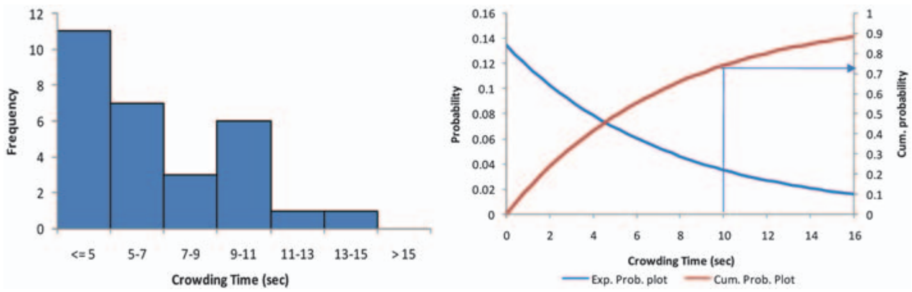
where, t denotes crowding time in sec. Fig.2 plots the both probability functions. From cumulative density plot, probability of crowding time less than (or greater than) a specified time can be obtained. For example, if mine management is interested to find the probability of crowding time less than 10 sec, they can apply the equation 8 directly or get it from the plot as shown in Fig.2b as 0.738.

6.2 HISTOGRAM AND PROBABILITY DISTRIBUTIONS OF LSUSB TIME

Frequency distribution of LSUSB time is determined and shown in Fig.3a. It is clear that frequency plot suggests normal distribution of data. Using these data, parameters mean and standard deviation of normal probability function have been obtained as $\mu = 20.1034$ sec and $\sigma = 2.1271$ sec. Based on the equation 8, the probability density function and cumulative density function are obtained and shown in Fig.3b [8,9]. In this case, t in equation 8 denotes LSUSB time in sec.

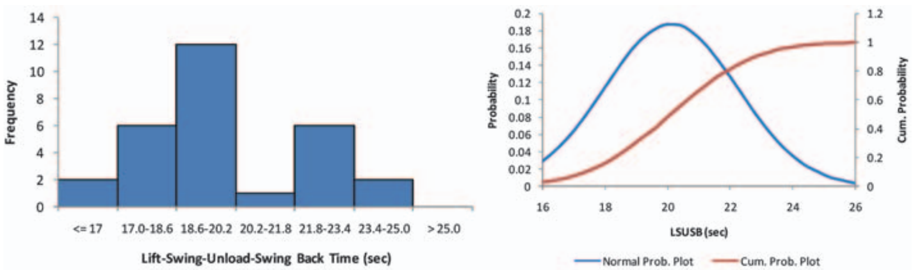
6.3 HISTOGRAM AND PROBABILITY DISTRIBUTIONS OF CYCLE TIME

Frequency distribution of cycle time is determined and shown in Fig.4a. It is clear that frequency plot suggests gamma distribution of data. Using these data, parameters scale and shape of gamma probability function have been obtained as $\lambda = 90.1207$ and $r = 0.3439$. Based on the equation



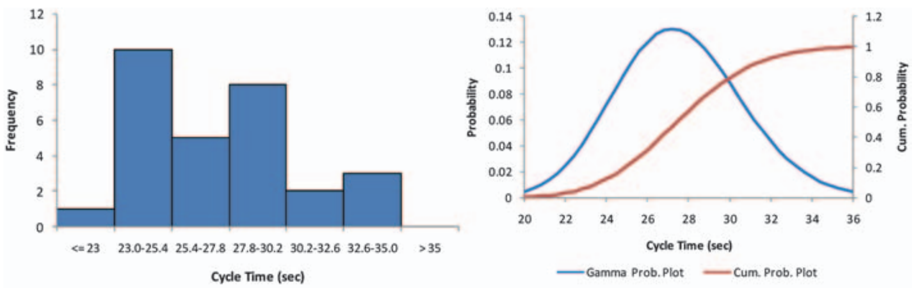
(a) Frequency (b) Probability

Fig.2 Frequency and probability distribution of crowding time



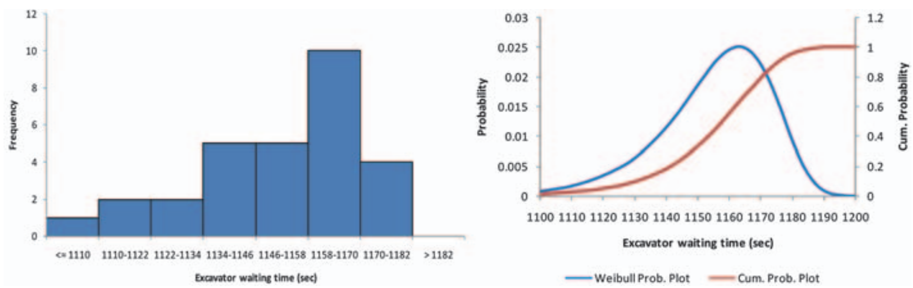
(a) Frequency (b) Probability distribution

Fig.3 Frequency and probability distribution of LSUSB time



(a) Frequency (b) Probability

Fig.4 Frequency and probability distribution of crowding time



(a) Frequency (b) Probability

Fig.5 Frequency and probability distributions of waiting time of dumpers

8, the probability density function and cumulative density function are obtained and shown in Fig.4b [8,9]. In this case, t denotes cycle time in sec.

6.4 Histogram and probability distributions of waiting time

Fig.5a shows that the frequency distribution of waiting time. It is clear that frequency plot suggests Weibull distribution of data. Using these data, parameters scale and shape of gamma probability function have been obtained as α = 1163.33 and β = 79.2823. The probability density function and cumulative density function (Fig.5b) are obtained based on equation 8 [8,9]. In this case, *t* denotes waiting time in sec.

Conclusions

This study has established a methodology to determine the various components of fuel consumption of dumpers in an opencast mine. It is found that for a vertical lift of 100 m, Terex no.13 consumes 0.61 ltr of fuel and while hauling with material on the surface it consumes 0.45 ltr per 100 m of haul distance. It also consumes 0.18 ltr per 100 m of vertical height while travelling empty down to the pit from the surface and also burns 0.27 ltr of fuel per 100 m of haul distance while travelling back empty from the dump site to the top of the pit.

Similarly, Terex no.16, for vertical lift of 100 m, consumes 0.64 ltr of fuel while hauling with material on the surface and it consumes 0.45 ltr per 100 m of haul distance. It burns 0.19 ltr per 100 m of vertical height while travelling empty down to the pit from the surface. It also burns 0.27 ltr of fuel per 100 m of haul distance while travelling back empty from the dump site to the top of the pit. Tipper no.1929 consumes 0.44 ltr of fuel for a vertical lift of 100 m. It burns 0.11 ltr per 100 m of haul distance while hauling with material on the surface. It also consumes 0.13 ltr per 100 m of vertical height while travelling empty down to the pit from the surface. It also burns 0.06 ltr of fuel per 100 m of haul distance while travelling back empty from the dump site to the top of the pit. In other word, the empty Tipper can travel 1.5 km for 1 ltr of fuel on the periphery road from the pit top to the dump site.

Data related to cycle time, waiting time and crowding time of excavator shows that different probability distribution functions fit different parameters. This exercise is useful to

Continued on page 12