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Analysis of Factors, Which Influence the Cycle Time of Dumpers of Open Cast Coal Mines to Improve Production

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Abstract

The cycle time of dumpers is one of the basic parameters, which influences productivity and performance of open cast coal mines. Length of haul roads and its gradients, rolling resistance of haul road, curvatures on roads and cross - over locations affects the movement of loaded and empty dumpers and play an important role to determine production and productivity of a mine. The other two factors, which can affect the cycle time of dumper, are efficiency of operators and conditions of dumpers. Authors of the paper conducted research study in an open cast coal mine and analyzed the effect of different factors, which influences the cycle time of dumpers. It helped mine management to improve production by optimum utilization of equipment by selecting the best fleet size for mine operation and reducing operational delays.

Key words

Dumper, Cycle Time, Haul Road, uphill, downhill.

1. Introduction

Dumpers in conjunction with loading equipment like front shovel, back hoe, front end loaders are generally used to transport waste and mineral from pit to dump or stockpile site. For continuous production at face, multiple numbers of transport systems are required. Hence, the capital and operating cost associated with dumpers always contribute towards heavy capital and inventory expenditure for surface mine operation [6]. Optimization of fleet size with a techno-economic evaluation on dumpers in respect to capacity of loading equipment has a significant impact on cost of production. Increase in fleet distance between loading and dumping locations and variation in haul road gradient with advancement of open pit face significantly affects the production cycle time and performance of dumpers. So, simulation of dumper cycle time of loaded and empty dumpers plying from different loading sites on the existing uphill and down-the-hill slope, can help in estimatation of production and operating cost of mines in changed operational scenario with the advancement of mines. It can also help to optimize productivity of loading - hauling equipments and formulation of annual budget of the mine with respect to mine plan. Prediction of dumper cycle time by artificial neural network or multiple regressions analysis gives the better results rather than computer simulation and it can help the mine management to improve the haul road conditions and significantly add value to mining operation, budget and productivity of the mine by optimizing required number of dumpers for excavation equipment [5].

2. Dumper Cycle Time

Actual cycle time of a dumper can be mathematically represented by equation-1. In addition to the above, the travel time of dumpers for both loaded and empty condition varies with rolling resistance, slope of haul roads (grade) along straight and curved path, haul road width, air or wind resistance, condition of vehicle and efficiency of operator.

$$T = t_{te} + t_{wl} + t_{ml} + t_{wd} + t_l + t_{md} + t_{tl} + t_d$$

(1)

where,

T	Total cycle time;	t_d	Time for dumping
t_{te}	Travel time of empty dumper;	t_{wl}	Waiting time of dumper at loading point
t_{ml}	Maneuver time near shovel for loading;	t_{wd}	Waiting time of dumper at dump point
t_{md}	Maneuver time at unloading point;	t_l	Loading time
t_{tl}	Travel time of loaded dumper		

3. Rolling resistance & Grade Resistance

The maximum potential speed for efficient plying of a dumper depends upon haul road grade and rolling resistance. The minimum force required to overcoming the retarding force acting between the tires of the dumper and the surface of the road, is the rolling resistance. The grade of haul road can be determined by equation-2. Rolling resistance is expressed in terms of percent of road grade or as a percentage of the Gross Vehicle Weight. Retarding force can be determined with the help of equation-3 & 4 to simulate dumper performance [2]. When dumper is moving on haul road the total resistance will be the combined effect of rolling resistance and grade resistance. In case of uphill transport, the effective grade resistance is the summation of rolling resistance and grade resistance, similarly for down-the-hill transport, the effective grade resistance is the difference between the rolling resistance and grade resistance. Effective Grade can be calculated from equation -5, where the total resistance is presented in terms of effective grades in percentage. Rolling resistance for different haul road ground condition is given in Table-1[1].

$$Grade = \frac{Y}{L}$$

(2)

where,

Y = Vertical rise of the vehicle, and L = distance travelled along the slope

$$R_{ret} = Mg\left(Sin\theta + R_R Cos\theta\right) + F_{cc}$$

(3)

$$F_{cc} = \frac{\pi\left(\frac{MV^2}{R_v}\right)^2}{180nC_s}$$

(4)

where,

R_{ret} = Retarding force R_R - Rolling resistance

M= Vehicle mass F_{cc}= Cornering drag force

V= Vehicle speed (in m/s) C_s= Cornering stiffness of each tire (Newton / degree)

n= Number of tires R_v= Curve radius (m)

Effective Grade (%) = Rolling Resistance (%) ± Grade resistance (%) (5)

4. Air or Wind Resistance

Air resistance or drag force also plays an important role on smooth movement of dumpers. This force is proportional to the contact surface area of the vehicle, air density and the relative speed of the wind [14]. Though this is an uncontrollable parameter during planning, air-drag force for safe movement of the fleet should be considered at procurement stage.

Table 1. Rolling Resistance for Different Haul Road Ground Condition [1]

Sl no	Types road surface	Rolling resistance (%)	
		Bias Tires	Radial Tires
1	Very hard, smooth road way, concrete, cold asphalt or dirt surface, no penetration or flexing	1.5%	1.2%
2.	Hard. Smooth, stabilized surfaced roadway without penetration under load, watered, maintained	2.0%	1.7%
3.	Firm, smooth, rolling, roadway with dirt or light surfacing, flexing, slightly under load or undulating, maintained fairly regularly, watered	3.0%	2.5%
4.	A dirt roadway, rutted or flexing under load, little maintenance, no water, 25 mm tire penetration or flexing	4.0%	4.0%
5.	A dirt roadway, rutted or flexing under load, little maintenance, no water, 50 mm tire penetration or flexing	5.0%	5.0%
6.	Rutted dirt roadway, soft under travel, no maintenance, no stabilization, 100 mm tire penetration or flexing	8.0%	8.0%
7.	Loose sand or gravel	10.0%	10.0%
8.	Rutted dirt roadway, soft under travel, no maintenance, no stabilization, 200 mm tire penetration and flexing.	14.0%	14.0%
9.	Very soft, muddy, rutted roadway, 300 mm tire penetration, no flexing	20.0%	20.0%

5. Curves and Super Elevation of Haul Road

Curves on haul roads with required width and elevation are essential for safe negotiation of dumpers. For permissible speed and smooth plying of dumpers along haul road, larger curve radius is required for safe road speed and increased dumper stability. Super-elevation along curves is provided to balance outward centrifugal force experienced by the dumper and lateral (side) friction between tires and road. For a given speed, the safe curve radius for smooth movement of dumpers can be determined with the help of equation-6 [3]. Similarly, the minimum radius required for safe movement of vehicles along the curvatures has been formulated by R.J. Thompson, and is given in Equation-7 [12].

$$R = \frac{V^2}{127(e + f))} \tag{6}$$

$$R = \frac{V^2 + (U_{min}\, e)}{127e} \tag{7}$$

where,

R = curve radius (m) V = vehicle speed (km/hr) e = super-elevation (m/m)
f = coefficient of friction between tires and road surface (friction factor or traction dimension less)
e = elevation applied (m/m width of road)
U_{min} = coefficient of lateral tire-road friction, is usually taken as zero (wet, soft, muddy) to 0.20 (dry, compacted gravel surface)

6. Width and Intersection of Haul Roads

If haul roads are not maintained to standard width then switchback of dumper movement may take place and would be the primary cause to increase the dumper travelling time. For safe movement of two dumpers the width of haul roads should be three times the dumper width [4]. Couzens, 1979 in his findings have communicated that four times for two-way traffic and five times for three-way traffic with an additional lane for uphill traffic will speed up the fleet movement. Intersections of haul roads are very less in case of small mines but in the large mine; there will be higher traffic on a tighter network of haul roads with numerous intersections. Drivers used to meet other traffic at intersections and they are forced to stop the vehicle and there will be loss of time, consequently the cycle time of the dumpers is extended [10].

7. Operator' Efficiency of Dumper

At the time of hauling, drivers try to drive dumpers at an average speed depends upon the haul road and site condition. The speed of the dumpers and time for positioning or spotting the dumper at loading, unloading varies with operator's efficiency [8]. The efficiency of driver depends upon age, experience and health etc. A research paper by Patrick Stahl et.al, 2011 indicates that fatiguing and negative transfer are the major contributing factors of operator. Skill, ability, motivation and ergonomics vis-à-vis human-machine interface may also account for work performance and/or increase in operational costs and number of accidents [11]. Drivers have a unique impact on skills; due to health and lifestyle habits such as obesity, poor diet, poor sleeping, and sleep disorders and has a strong correlation with performance [9].

8. Case Study

The time study and analysis was carried out for five 85T, two 60T and two 35T dumpers in an open cast coal mine. 85T dumpers were used for transportation of waste whereas 60T and 35T dumpers were used for Coal transportation from the pit. Time study data strength of 60 samples for all the dumper capacities was considered for its analysis. The data generated for two days was during heavy rainfall and has not been considered for the analysis. Air-drag forces generated upon dumpers were not considered and a constant magnitude of 2.5% has been assumed as rolling resistance for the analysis. Data were collected for different dumpers with varying pay load in different haul road gradients and curves. The average speed of dumpers at different gradients and curves was calculated by using equation-8. Length of haul roads at different gradients and its slope was measured with the help of total station, Fig. 1.

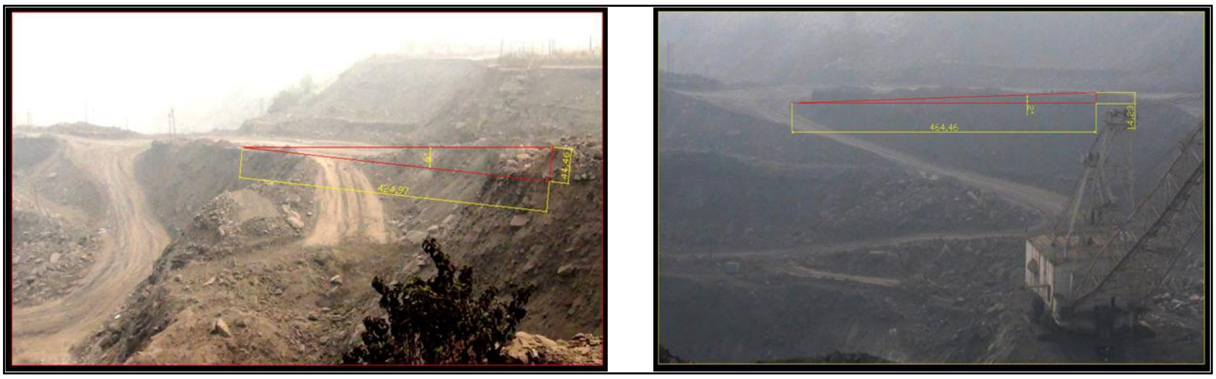

Fig. 1. Gradients of Haul Road at Two Locations

$$S_a = \frac{\sum_{i=1}^{n} \frac{L_g}{t_{i,j}}}{n} \quad (8)$$

where,

S_a = Average speed at a particular gradient,

T_{ij} = Time taken by 'j' type dumper in 'i' *th* time to travel a particular grade at particular condition excluding loss of time during the travel

L_g = Length of a particular grade of road n = Number of sample data

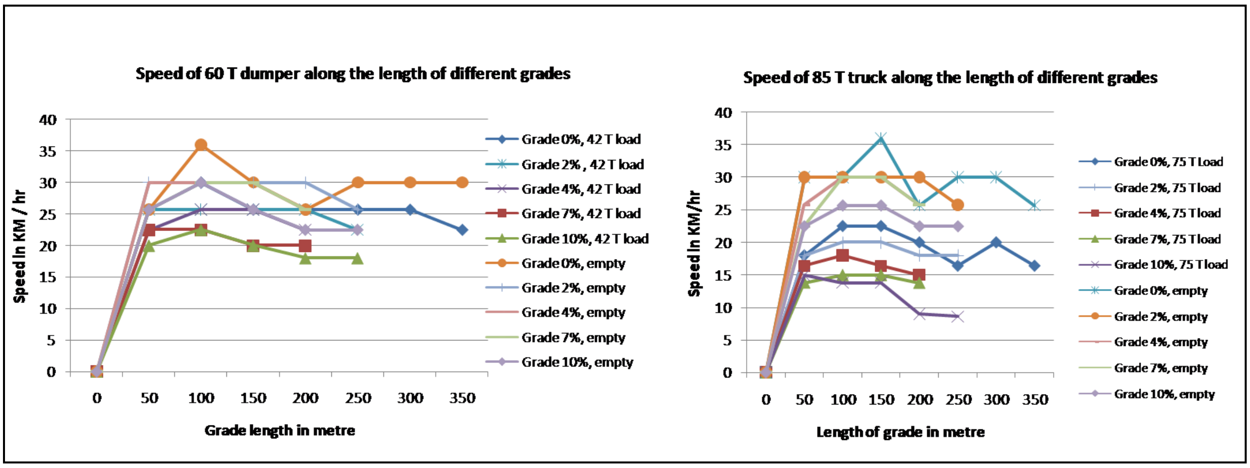

Fig. 2. Speed of 85 T & 60 T Dumpers along Different Length of Different Grades

Considering the above equation and measuring the distance of travel along the different slopes, the speed of different types of dumpers were determined for both loaded and empty condition at uphill transport, Fig. 2, 3 & 4 and the speed of different types of empty dumpers at downhill transport were evaluated and the same is represented in Fig. 5.

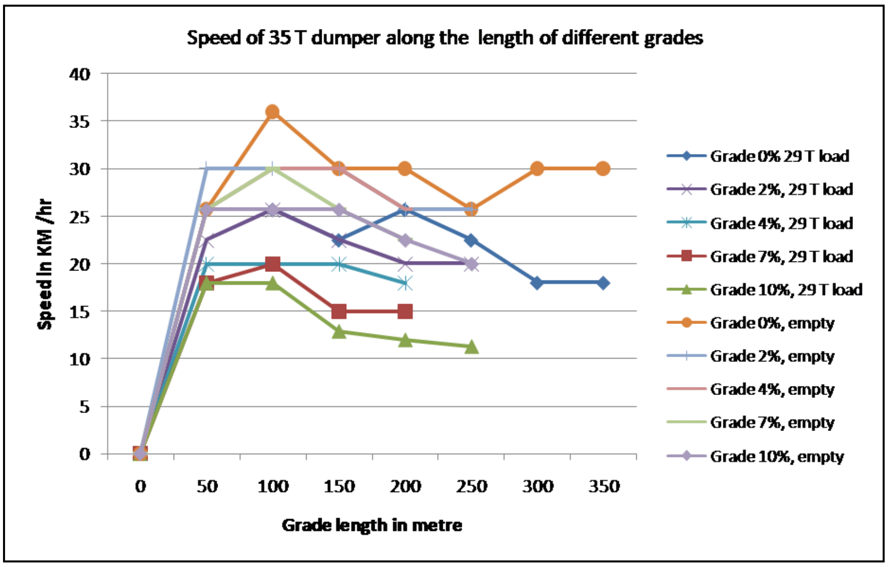

Fig. 3. Speed of 35 T Dumpers along the Different Length of Different Grades

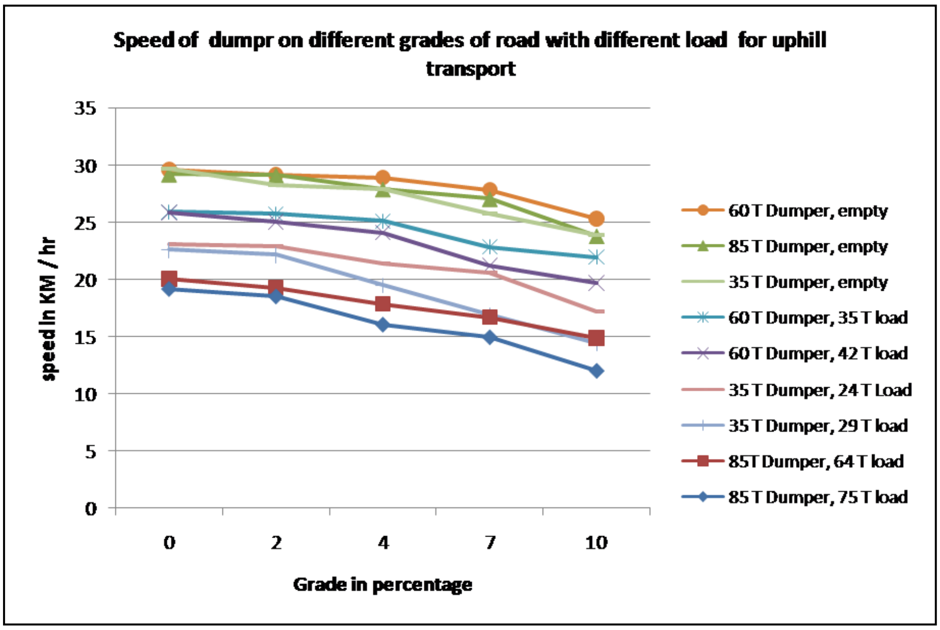

Fig. 4. Speed of Different Dumpers with Different Load on Different Grades

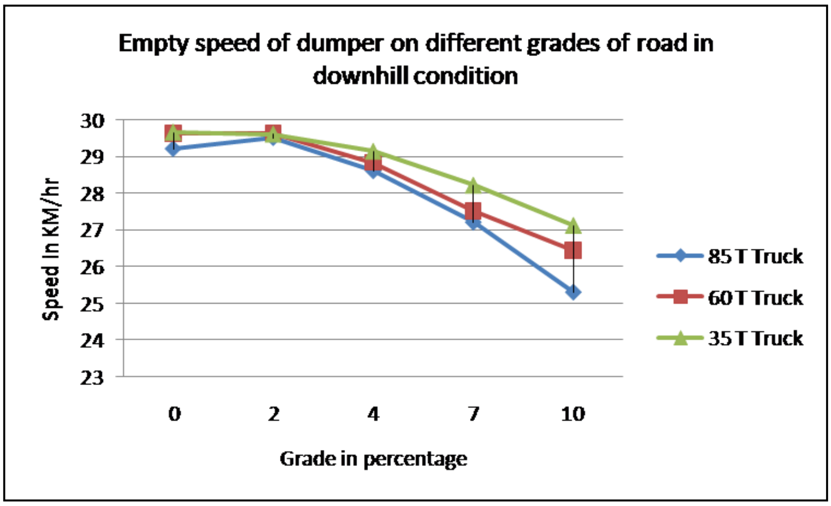

Fig. 5. Speed of Empty Dumpers during Downhill Transport

8.1 Study and Analysis of Effect of Grade Resistance

During the study it was observed that in general, driver tries to run the dumper in steady state condition on flatter surface road. However, few were observed to accelerate the speed with frequent application of brakes at poor road condition and thus the speed varies. It is revealed that fuel consumption increases due to variation of speeds on the haul roads and the speed, varying between 20 – 30 km/hr, gives the best fuel economy and safe drive along the haul road.

For uphill transport, the speed of dumper generally decreases with an increase of grade percentage of road and pay load. The rate of reduction of dumper speed increases above 4% grade road. The speed also reduces with the length of the grade and rate of reduction of the speed along the length is a function of grade percentage and pay load. For initial up-hill movement dumpers are accelerated with low speed gear with high torque for more power in axle and gears are shifted to high speed consequently. But, it has been observed that shifting of gear in low speed rather than optimum speed results into gear shifting impact on dumper speed where, optimum speed is a function of weight to power ratio [7]. After maximizing the acceleration in any particular gear for uphill transport, the operator shifts to low speed gear for safe uphill transport.

Similarly, for down-hill transport, the slope assists the dumper to gain speed while the rolling resistance slows the dumper. The retarding force is a function of the Gross Vehicle Weight (GVW), grade assistance and rolling resistance. During the movement of empty vehicle on down-hill, it was observed that speed of the dumpers increases or remain same as on flatter surface roads upto 2% grade road and reduces with the increase of the grade percentage. The rate of reduction of speed increases with increase of grade beyond 4%. However, for experienced drivers, speed of dumpers on downhill condition is controlled by means of gear reduction and application of brake with an increase of grade. Drivers generally decrease the speed decently to ensure safe stopping distances while ascending dumpers require frequent gear reduction with consequent speed losses for safe driving. As observed during the study, there is very little variation in speed of empty dumpers of different GVW.

8.2 Study and Analysis of Dumping and Positioning Time

Effective unloading time near dump yard depends mainly on the positioning of dumper vis-à-vis skill of operator. It has been observed that positioning a dumper at loading point is always more than that at dumping point with little variation in the type of material to be dumped. The average time at dumping and positioning of dumper at loading point and unloading point with histogram plot is given in Table -5 and Figure- 6 respectively.

Table 6. Average Time Taken at Loading and Unloading Points

	Maximum time in second	**Minimum time in second**	**Mean time in second**	**Standard deviation**
Dumping time	43	25	33.58	5.323
Positioning for dumping	63	39	50.27	6.612
Positioning at loading	108	63	87.15	14.35

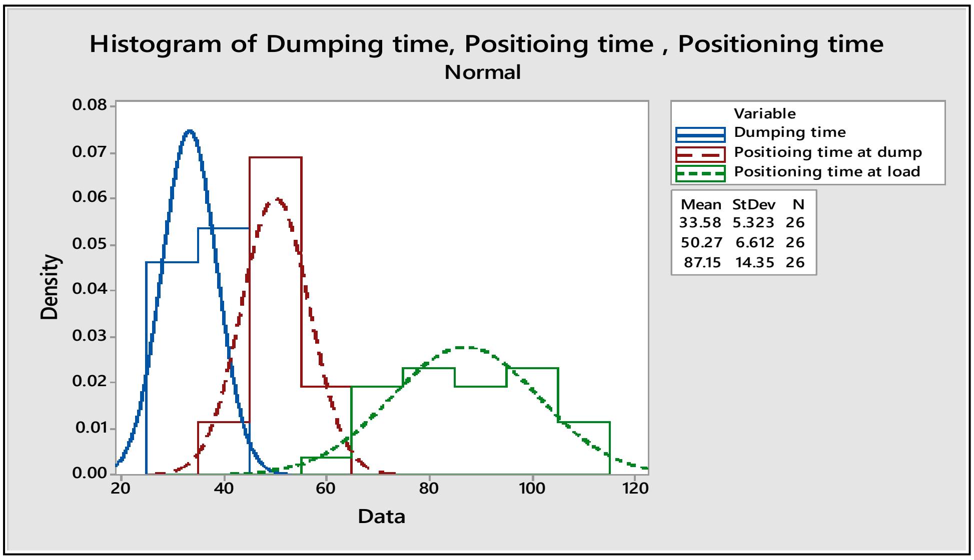

Fig. 6. Histogram Plot Dumping Time, Positioning Time at Loading & Unloading Point

8.3 Study and Analysis of Travelling Time along Curves

Curvatures in haul roads are generally of different radii as well as of different super-elevation. To observe the impact of curves of cycle time, a time study was done to calculate the average time taken to cross the curves as well as compare the impact of curved radius for both uphill and down-the-hill transport. It is observed that the maneuvering of dumpers along curves generally depends on operator's skill, efficiency and condition of dumper. It was also observed that time taken was more during crossing over of two dumpers in opposite direction on the curve. The time study of the dumpers during maneuvering at different curves at different load condition is given in Table 3.

Table 3. Travel Time of Dumpers along the Curvatures at Different Load Conditions

Types of curves	Loading condition	Average time in second	Standard deviation	Minimum time in second	Maximum time in second
On flat surface	with load	4.02	1.23	3	7
On flat surface	without load	3.94	1.11	2	6
Up hill	with load	9.33	1.94	7	13
Up hill	without load	6.83	1.02	6	9
Down hill	without load	7.58	1.75	5	12

Table 5. Travel Time of Dumpers along the Curvatures with Different Loads

Types of curves	Loading condition	Average time in second	Standard deviation	Minimum time in second	Maximum time in second
On flat surface	with load	4.02	1.23	3	7

On flat surface	without load	3.94	1.11	2	6
Up hill	with load	9.33	1.94	7	13
Up hill	without load	6.83	1.02	6	9
Down hill	without load	7.58	1.75	5	12

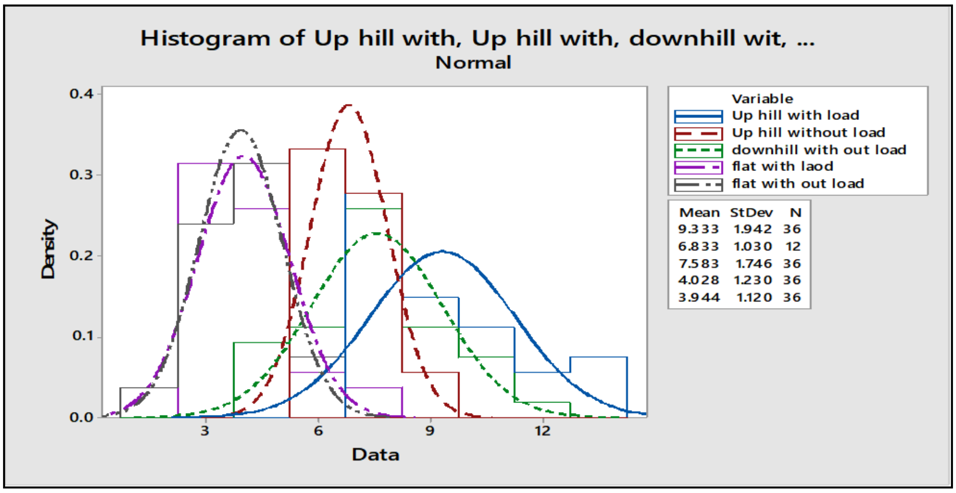

Fig. 5. Histogram Plots of Different Loads on Different Radii of Curvatures

8.4 Study and Analysis of Effect of Operator's Efficiency

In general, operators try to drive dumpers on the haul roads in a steady state speed and within the speed limit determined by the governing authority. However, the efficiency of driver and condition of the vehicle affects the cycle time of dumpers. The Table- 2 clearly indicates that Driver – II had minimum cycle time amongst five 85T dumpers. However, all the five drivers took comparatively more time to complete the cycle with Dumper –V, indicating problems in either engine or transmission of the dumper. Similarly, for dumper-I, cycle time was less for all the operators because of its major repairing and complete regular maintenance.

Amongst all the operators, the cycle time for driver-II was least for dumper-I, because the operator drove the vehicle efficiently and at nearly a constant speed with accelerated motion for uphill transport. It has also been observed that change of operators with respect to dumpers and alteration of transport route initially increases the cycle time, but once driver accustomed in the existing dumper as well as in the changed transport route the cycle time reduces.

Table 2. Effect of Experienced Drivers and Vehicle Condition on Travel Time in Seconds

	85T No – I		**85T No – II**		**85 T No - III**		**85 T No - IV**		**85 T No V**	
	Avg. time	**Std. Dev.**	**Avg. time**	**Std. Dev.**	**Avg. time**	**Std. Dev.**	**Avg. time**	**Std. Dev.**	**Avg. time**	**Std. Dev.**
Driver – I	879.8	46.23	913.2	66.2	881	33.82	888.6	30.73	1258.6	54.97

Driver- II	819.4	24.38	841.8	31.92	860.4	30.1	862	40.97	1175.4	48.29
Driver – III	878.6	38.44	905	29.31	894.2	22.62	905.8	12.24	1278.8	35.63
Driver- IV	859.6	22.9	883	16.36	900	30.39	895	27.51	1244.8	53.51
Driver- V	873.8	13.39	893	24.65	906.2	13.29	875.8	25.97	1274.8	34.51

8.5 Study and Analysis of Operational Delays

For any cycle of operation, there is every possibility of predictable and unpredictable delays. The predictable delays related to any mine production are scheduled maintenance and shift change hours. The unpredictable operation delays relates to waiting at cross roads, queuing at loading and unloading points, unscheduled maintenance or minor repair of dumpers vis-à-vis fueling of dumpers etc. With time study data, Fig. 6, clearly indicates that intersection of roads causes the maximum operational delays (average) amongst the four in a cyclic operation of dumper whereas, loss of time due to waiting of dumper in queue at loading point is largest operational delay in case of 8 hours shift operation. Proper understanding is required for reduction of operational delays to achieve maximum utilization of both excavators and dumpers.

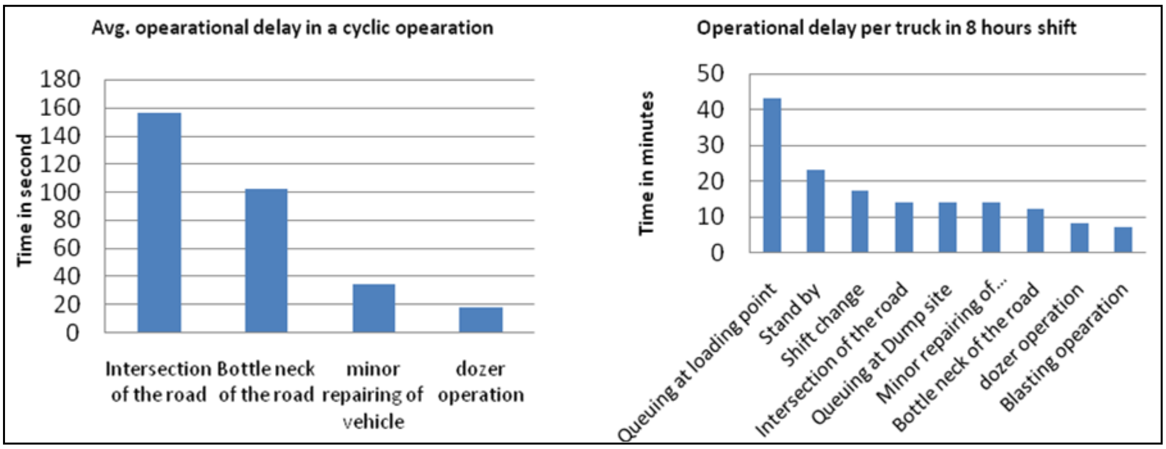

Fig. 6. Operational Delay in Cyclic and 8 HRS Shift Operation

Conclusion

A comprehensive time study of dumper movements on different haul road condition with different loads can help the mine management to optimize fleet size to achieve the production target as well as to estimate the cost of production. Study of operational delays during dumper movement in actual production hours can help the planners to identify the possibilities for reduction in cycle time and to reduce the operational delays accordingly. Study on operator's efficiency and vehicle condition can help to select the best dumper fleet. The outcome of the study of dumper movements can vary with the variation of mines and should be carried out for its best application. This study can also help to plan the gradient, radius of curvature and super-elevation at curvatures for best operation of dumpers.

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