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Assessment of the Field and Engineering Parameters on the Specific Fuel Consumption (SFC) of Rear Dump Trucks (RDT) in Mines

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Abstract

RDTs are primarily responsible for transporting large quantities of overburden and coal from extraction sites to disposal sites in mining operations. Their efficiency, however, depends on a variety of factors, including geo-mining conditions, haul road quality, and the characteristics of the RDTs themselves, such as their age, capacity, make, maintenance and many other factors. These variables not only affect operational performance but also have a direct impact on fuel consumption and its environmental outcomes, particularly on the Greenhouse Gas Emissions (GHGE). This paper investigates the effect of some geo-mining conditions, age and tonnage factors of the RDTs on its performance in a large opencast coal mining project. Data from RDTs of different makes, ages, and capacities operating under varying haul road conditions and lead distances were collected for analysis. Using mathematical tools, the study draws inferences on how these factors influence diesel consumption, operational efficiency, and impact the environment. The results demonstrate that, while lead distance, haul road quality, and capacity of the RDTs are critical parameters, the make of the dumper also plays a significant role in the performance.

Major Findings: *The findings suggest that improving geo-mining conditions and proper maintenance could lead to reduced fuel consumption, lower GHGE emissions, and better cost-efficiency in surface coal mining operations.*

Keywords: *Haul Road, HEMM, Opencast Mines, Rear Dump Trucks, Specific Fuel Consumption*

1.0 Introduction

The impact of geo-mining conditions, alongside the capacity and age of Rear Dump Trucks (RDTs), on Greenhouse Gas Emissions (GHGE) has emerged as a critical area of study in surface mining operations. RDTs play a pivotal role in the material transportation cycle, making them substantial contributors to fuel consumption, which has adverse environmental impacts. Research in this domain has increasingly focused on optimising the performance of RDTs to mitigate emissions while maintaining operational efficiency.

Fuel consumption in RDTs and the associated GHGE are heavily influenced by factors such as haul road characteristics, lead distance, payload, equipment age, etc. For instance, Zhu *et al.*[1] optimised speed and acceleration profiles to minimise Specific Fuel Consumption (SFC), achieving significant fuel savings through tailored vehicle dispatch strategies. Heavier loads were found to enhance fuel efficiency under optimised conditions, demonstrating the complex interplay between operational parameters and energy consumption. Similarly, Siami-Irdemoosa and Dindarloo[2] employed neural networks to predict fuel

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consumption cycles, emphasising the need for predictive tools to manage fuel usage effectively.

Emerging technological advancements also contribute to improving the environmental performance of mining trucks. Khazin *et al.*[3] proposed the integration of gas piston engines as a sustainable alternative to conventional power systems. Mi *et al.*[4] explored fatigue life optimisation in electric mining dump truck frames, addressing reliability and lightweight design as important factors that indirectly influence fuel efficiency and emissions.

The operational reliability of RDTs is another critical determinant of their environmental footprint. Pryalukhin *et al.*[5] developed a mathematical model for assessing the reliability of electrical systems in mining dump trucks, stressing the importance of maintenance to reduce downtime and enhance energy efficiency. Furthermore, Rahimdel[6] demonstrated the significance of environmental conditions, such as temperature, on the performance and lifespan of mining truck components like tires, directly impacting overall operational sustainability.

In the Indian context, Dey *et al.*[7] analysed factors affecting the cycle time of RDTs in opencast coal mines, identifying haul road length, gradient, and rolling resistance as significant contributors to cycle time variations. Their research emphasised the importance of optimising these parameters to enhance production efficiency. Similarly, optimisation of shovel-dumper combinations using queuing theory was explored to reduce idle time and improve equipment utilisation, thereby increasing the transportation system's potential capacity.

Energy performance benchmarking has also been studied, with models developed to analyse the energy consumption of dump trucks operating between crushers and excavators[1]. These models identify opportunities for reducing specific fuel consumption, contributing to cost savings and emission reductions[2]. Despite these contributions, research addressing the combined effects of geo-mining conditions, dumper size, and age on GHGE remains limited. Existing literature tends to focus on isolated aspects, such as energy consumption optimisation or equipment reliability, without holistically evaluating their interdependencies in real-world mining scenarios[8].

This paper addresses the aforesaid research gap by investigating how these factors collectively influence dumper performance in a large-scale surface coal mine. Data from RDTs of varying makes, ages, and capacities were collected under diverse haul road conditions and lead distances. Mathematical tools were employed to analyse their impact on SFC, operational efficiency and GHGE. The study underscores the importance of improving geo-mining conditions, upgrading dumpers, and ensuring proper maintenance to achieve reduced fuel consumption, lower emissions, and enhanced cost efficiency. By bridging the existing research gap, this work contributes to the broader goal of sustainable mining operations.

2.0 Brief Objectives

- Analyse the impact of geo-mining conditions on the performance and efficiency of RDTs in coal mining operations.
- Examine the relationship between RDT characteristics (age, capacity, make) and their operational performance, particularly fuel consumption and environmental outcomes.
- Propose recommendations for improving geo-mining conditions and maintaining RDTs to optimise cost-efficiency, fuel use, and minimise environmental effects.

3.0 Methodology

The methodology adopted in this study involved a comprehensive assessment of rear dump trucks (RDTs) operating in a large-scale opencast coal mining project with an annual capacity of 30 MTPA. The site selected featured a diverse fleet of RDTs varying in capacity (100 Te, 120 Te, and 190 Te) and make, enabling a robust analysis of the effects of geo-mining parameters, dumper characteristics, and operational conditions on SFC. Data was collected over one month from 66 dumpers belonging to two different companies, capturing variables such as lead distance, haul road condition, dumper age, and SFC. Haul road conditions were categorised into good, average, and poor based on predefined criteria involving gradient, surface condition, visibility, and turning geometry. Analytical techniques, including linear regression and correlation analysis, were applied to examine the influence of input variables on fuel consumption. To ensure data reliability, idling and maintenance periods were

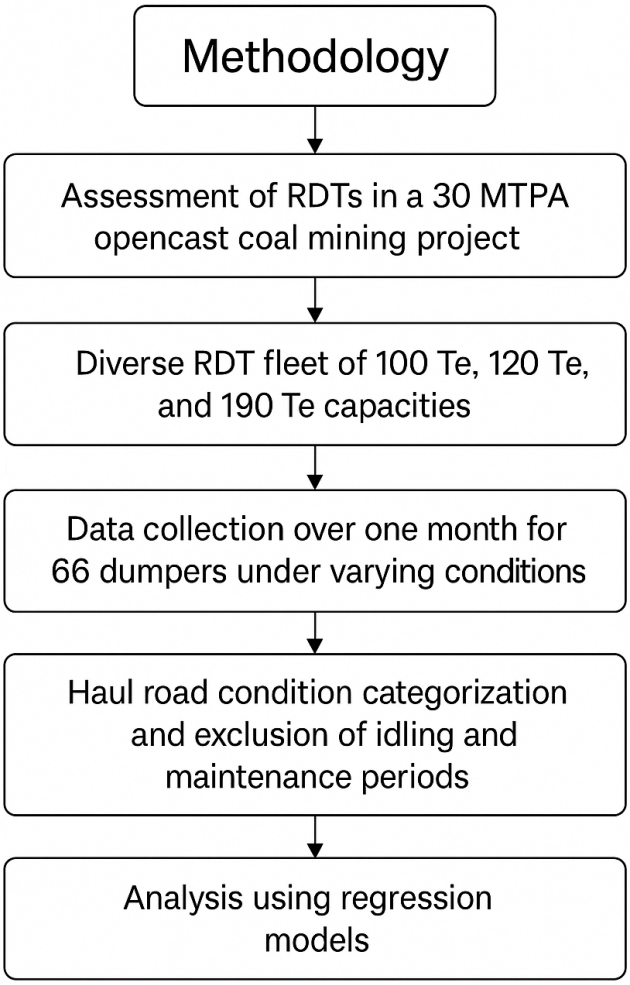


Figure 1. Methodology of the study conducted.

excluded from the dataset. The resulting regression models enabled the prediction of SFC, facilitating a detailed understanding of how operational and equipment factors jointly influence fuel efficiency in mining transport operations.

4.0 Site Selection

For the purpose of this study, a large-scale opencast coal mine project was selected. The mine has an annual capacity of 30 million tonnes per annum (MTPA) and operates with huge size shovels, RDTs and draglines to meet the target. The fleet primarily consists of RDTs with varying capacities of 190 tonnes (Te), 120 Te, and 100 Te, sourced from two different manufacturers. This diversity in dumper capacity and make provides an ideal setting to analyse the influence of geo-mining conditions, age, and tonnage on dumper performance and specific fuel consumption (Figure 2).



Figure 2. An overview of the large-scale opencast coal mine project considered for this study.

4.1 Data Collection

Data for this study were collected from 36 RDTs of company A and 30 RDTs of company B. The fleet from Company A included 18 RDTs with a capacity of 190 tonnes (Te), 6 RDTs with a capacity of 120 Te, and 12 RDTs with a capacity of 100 Te. Similarly, the fleet from Company B comprised 9 RDTs with a capacity of 190 Te, 10 RDTs with a capacity of 120 Te, and 11 RDTs with a 100 Te capacity. Alongside dumper-specific data, information on haul road conditions, lead distances, age of dumpers, and their SFC, over one month, was also collected.

The average values of these parameters were used for data analysis to ensure consistency and reliability. Linear regression and correlation analyses were performed to determine the relationships between the parameters and their collective impact on performance metrics. Idling periods and maintenance periods were excluded to compute rational average values, ensuring accurate comparisons. Based on mathematical analyses, the results obtained were interpreted to draw meaningful inferences that contribute to understanding and improving dumper efficiency in the study mines.

The haul road conditions are described on the basis of some parameters such as: Gradient, Ground condition of road, visibility due to dust and number of turns. Based on the above parameters, the haul road condition is classified as good, average and poor (Figure 3). The criteria and



Figure 3. Haul road condition, picture on left depicts the road with better condition, while the right depicts a road with higher gradient, uneven surface and too much water.

Table 1. Rating of haul road condition

Haul road condition	Parameters-based classification	Rating
Good	• Gradient: less than 1 in 12 • Ground condition of road: Compact and even • Visibility: Clear visibility due to less dust and a higher frequency of water sprinkling. • Number of turns: Least turns with no turn sharper than 150 degrees	1.0
Average	• Gradient: less than 1 in 10 to 1 in 12 • Ground condition of road: Compact and uneven • Visibility: Average visibility • Number of turns: The fewer the number of turns sharper than 120 degree	0.8
Poor	• Gradient: Higher than 1 in 10 • Ground condition of road: Loose material and uneven • Visibility: Poor visibility • Number of turns: More turns sharper than 120 degrees	0.5

the rating for mathematical evaluation purposes were judiciously set as presented in Table 1.

4.2 Data Analysis

The data collected for company A RDTs fleets and Company B RDTs fleets have been analysed by linear regression and correlation techniques.

The characteristics of 190, 120, and 100 Te Rear Dump Trucks (RDTs) differ significantly in terms of design, engine power, and operational efficiency, which directly influence their SFC. The 190 Te RDTs are equipped with high-powered engines and advanced transmission systems, optimised for heavy payloads and long distances. While their larger engines lead to higher fuel consumption under lighter loads, they offer improved fuel efficiency when fully loaded. The 120 Te RDTs feature medium-sized engines and transmissions designed for medium-duty applications, offering a balanced fuel economy for both medium and heavy loads. Smaller 100 Te RDTs, with small capacity engines, are the most fuel-efficient when carrying lighter loads, but their efficiency drops with larger payloads. Larger tires on the 190 Te RDTs contribute to rolling resistance but are durable for extended use, while smaller tires on the 100 Te RDTs reduce fuel consumption for short, light-duty operations.

The data from 190, 120, and 100 Te RDTs are taken for study.

4.3 Company a Data Analysis

The fleet from Company A included 18 RDTs of 190 tonnes (Te) capacity, 6 RDTs of 120 Te capacity, and 12 RDTs of 100 Te capacity. The data collected is presented in Table 2.

Table 2. Data collected for 36 RDTsof Company A

Company A					
Capacity (te)	**Lead Distance (Km)**	**Haul road condition (good/average/poor)**	**Age in years**	**Sp. Fuel consumption lit/km**	**Predicted using Equation (1)**
190	3.00	0.5	14.25	15.99	14.97
190	2.50	0.5	11.5	14.50	15.26
190	2.20	0.8	5.08	13.90	14.73
190	3.50	0.8	10.25	13.80	13.99
190	2.80	0.5	26.08	15.90	15.01
190	3.20	0.8	18.25	13.90	14.10
190	2.20	0.5	4.17	16.60	15.47
190	3.00	0.5	1.17	15.10	15.05
190	2.50	0.5	26.08	13.50	15.17
190	2.20	0.8	18.25	15.60	14.65
190	2.80	0.8	11.5	14.80	14.36
190	2.80	0.8	5.08	14.60	14.40
190	3.20	0.5	10.25	14.80	14.89
190	4.50	1	26.08	12.46	12.86
190	2.20	1	14.25	13.80	14.18
190	2.80	1	5.67	13.80	13.91
190	2.80	0.8	4.17	13.90	14.41
190	3.20	0.8	1.17	14.70	14.21
120	2.20	0.8	26.08	12.60	11.57
120	1.50	0.5	1.17	13.10	12.83
120	4.50	1	5.67	10.30	9.94
120	1.50	0.5	10.25	12.60	12.78
120	2.50	0.5	5.08	11.74	12.26
120	3.50	0.8	1.17	11.50	11.00
100	3.00	0.8	3.67	10.67	10.39
100	2.20	0.5	4.17	10.90	11.56
100	3.50	0.5	1.17	10.80	10.87
100	2.20	1	4.17	9.98	10.34
100	3.50	1	14.5	9.10	9.57
100	2.20	0.5	7.08	10.90	11.55
100	3.00	0.8	11.5	11.60	10.35
100	2.50	1	10.25	11.78	10.14
100	2.20	1	4.17	8.90	10.34
100	2.20	0.5	26.08	11.38	11.43
100	1.50	0.5	18.25	12.10	11.86
100	4.50	1	26.08	8.30	8.95

The capacity, lead distance, haul road condition and age of the RDTs were taken as input parameters, and the SFC was taken as output parameters. The relationship obtained for the RDTs of Company A from the linear regression of the collected data is given in Equation 1.

$$SFC_A = 0.0434 \times C - 0.547 \times D - 2.45 \times H - 0.006 \times A + 9.677 \quad (1)$$

Where,

SFC_A is the Specific fuel consumption for Company A dumper

C is the capacity in tonnes

D is the lead distance in km

H is the haul road condition

A is the Age of the dumper in years.

The linear regression summary output is presented in Table 3.

The equation obtained has a coefficient of determination of 0.88 and an RMSE value of ± 0.72 Lit/km. The predicted values from Equation 1 are also presented in Table 1. The actual vs predicted values of SFC are compared in Figure 4.

For the RDTs of company A, the correlation analysis between the different parameters has been conducted to investigate the impact of each parameter on the SFC. It can be seen from Table 3 below that the capacity has the direct and highest correlation with the SFC, followed

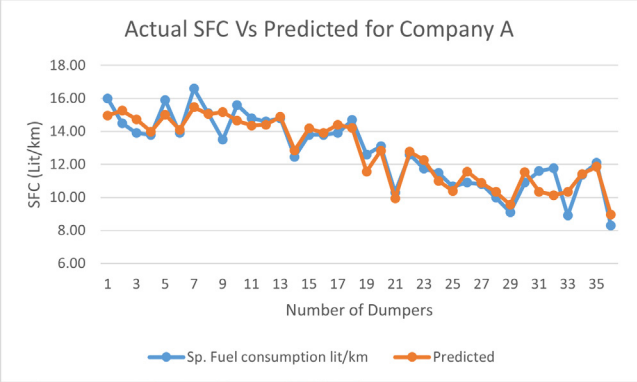


Figure 4. Comparison between the actual vs predicted values of SFC for company A dumpers.

Table 3. Summary output of linear regression of data collected for RDTs of company A

Regression Statistics								
Multiple R	0.94							
R Square	0.88							
Adjusted R Square	0.86							
Standard Error	0.79							
Observations	36.00							
ANOVA								
	df	**SS**	**MS**	**F**	**Significance F**			
Regression	4.00	140.25	35.06	56.85	0.00			
Residual	31.00	19.12	0.62					
Total	35.00	159.37						
	Coefficients	**Standard Error**	**t Stat**	**pvalue**	**Lower 95%**	**Upper 95%**	**Lower 95.0%**	**Upper 95.0%**
Intercept	9.6772	0.7339	13.1868	0.0000	8.1805	11.1739	8.1805	11.1739
Capacity (te)	0.0435	0.0032	13.7906	0.0000	0.0370	0.0499	0.0370	0.0499
Lead distance (Km)	–0.5469	0.1962	–2.7873	0.0090	–0.9470	–0.1467	–0.9470	–0.1467
Haul road condition	–2.4490	0.7125	–3.4372	0.0017	–3.9022	–0.9959	–3.9022	–0.9959
Age in years	–0.0057	0.0158	–0.3616	0.7201	–0.0380	0.0266	–0.0380	0.0266

Table 3. Correlation between the parameters for RDTs of Company A

	Capacity (te)	Lead distance (Km)	Haul road condition	Age in years	Sp. fuel consumption
Capacity (te)	1.000				
Lead distance (Km)	0.111	1.000			
Haul road condition	–0.060	0.427	1.000		
Age in years	0.091	0.115	0.027	1.000	
Sp. fuel consumption	0.862	–0.203	–0.374	0.027	1.000

by Haul road condition and the lead distance, which are inversely correlated to the SFC. Age of the dumpers is insignificantly correlated with the SFC. It has the lowest correlation with the SFC.

4.4 Company B Data Analysis

The fleet from Company B comprised 9 RDTs with a capacity of 190 Te, 10 RDTs with a capacity of 120 Te, and 11 RDTs with a capacity of 100 Te. The data collected is presented in Table 4.

The capacity, lead distance, haul road condition and age of the RDTs were taken as input parameters, and Specific fuel consumption is taken as output parameters.

The following Equation 2 was obtained for company B RDTs from the linear regression of the collected data:

$$SFC_B = 0.062 \times C - 0.62 \times D - 1.1 \times H - 0.05 \times A + 8.2 \quad (2)$$

Where,

SFC_B is the Specific fuel consumption for Company A dumper

C is the capacity in tonnes

D is the lead distance in km

H is the haul road condition

A is the Age of the dumper in years

The linear regression summary output is presented in Table 6.

The equation obtained has a coefficient of determination of 0.84 and an RMSE value of ±1.063 Lit/km. The predicted values from Equation 2 are also presented in Table 4. The actual vs predicted values of SFC of company B RDTs are compared in Figure 5.

For company B dumpers, the correlation analysis between the different parameters has been conducted to investigate the impact of each parameter on the SFC.

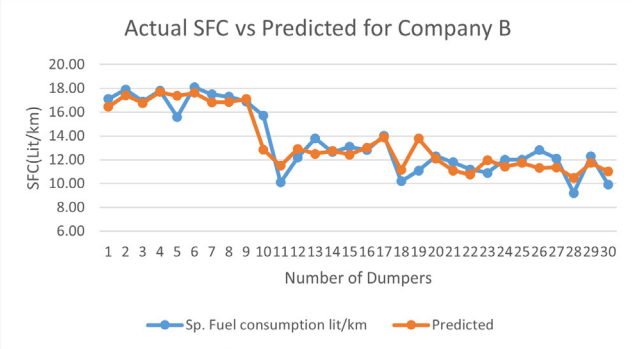


Figure 5. The comparison of actual vs predicted values of the SFC of company B dumpers.

It can be seen from Table 5 below that in this case also the capacity has the direct and highest correlation with the SFC, followed by Haul road condition and the lead distance, which are inversely correlated to the SFC. Age of the dumpers is insignificantly correlated with the SFC. It has the lowest correlation with the SFC.

5.0 Results and Discussions

From the above analysis of the collected data, it has been found that the capacity of the RDTs has the highest and direct correlation with the SFC. Figures 6(a) and (b) present the scatter plot between the capacity and SFC of company A and company B, respectively.

From Figure 3, it can be seen that the higher the capacity of the dumper higher will be the specific diesel consumption.

Figures 7(a) and (b) present the scatter plot between the lead distance and the SFC of RDTs of companies A and B, respectively.

From Figure 4, it is observed that there is no particular pattern between the lead distance and the specific diesel consumption for different capacity dumpers. However,

Table 4. Data collected for 30 RDTs of Company B

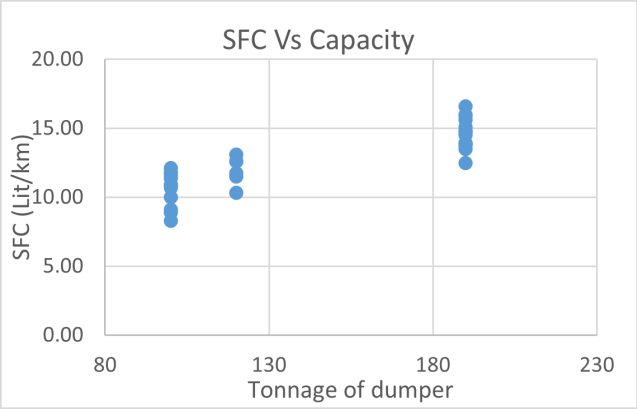
Capacity (te)	Lead distance (Km)	Haul road condition (good/average/poor)	Age in years	Sp. Fuel consumption lit/km	Predicted using Equation (2)
190	3.50	0.8	9.50	17.10	16.46
190	2.80	0.5	5.60	17.90	17.41
190	3.20	0.8	7.00	16.90	16.77
190	2.20	0.5	7.50	17.80	17.69
190	3.00	0.5	4.17	15.60	17.36
190	2.50	0.5	5.08	18.10	17.63
190	2.20	0.8	18.25	17.50	16.82
190	2.80	0.8	10.25	17.30	16.85
190	2.80	0.8	5.08	16.90	17.11
120	3.20	0.5	5.08	15.70	12.85
120	4.50	1	5.08	10.10	11.50
120	2.20	1	5.00	12.20	12.93
120	2.80	1	6.00	13.80	12.50
120	2.80	0.8	5.60	12.64	12.74
120	3.20	0.8	7.00	13.10	12.43
120	2.20	0.8	7.50	12.80	13.02
120	1.50	0.5	5.60	14.02	13.88
120	4.50	1	12.00	10.20	11.15
120	1.50	0.5	7.50	11.10	13.79
100	2.50	0.5	4.17	12.30	12.09
100	3.50	0.8	5.08	11.80	11.10
100	3.00	0.8	18.25	11.20	10.75
100	2.20	0.5	10.25	10.90	11.97
100	3.50	0.5	5.08	12.00	11.43
100	2.20	1	4.17	12.00	11.73
100	2.80	1	5.08	12.80	11.31
100	3.20	0.5	10.25	12.10	11.35
100	4.50	0.8	5.08	9.20	10.48
100	2.20	1	4.17	12.30	11.73
100	2.80	1	11.00	9.90	11.01

Table 5. Correlation between the parameters for RDTs of Company B

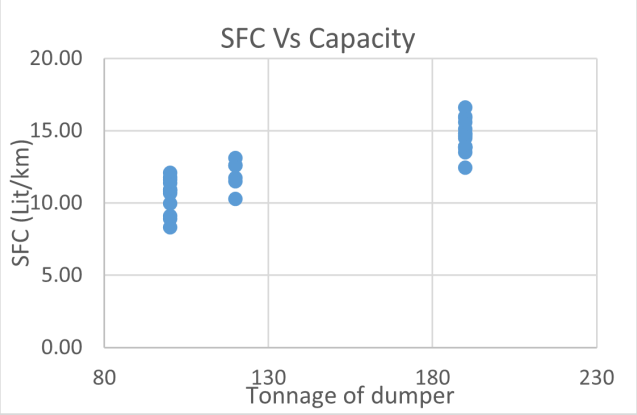
	Capacity (te)	Lead distance (Km)	Haul road condition	Age	Sp. fuel consumption
Capacity (te)	1.000				
Lead Distance (Km)	–0.083	1.000			
Haul road Condition	–0.231	0.273	1.000		
Age in years	0.095	0.006	0.089	1.000	
Sp. Fuel consumption lit/km	0.894	–0.266	–0.336	0.002	1.000

Table 6. Summary output of Linear regression of data collected for RDTs of Company B

Regression Statistics								
Multiple R	0.921							
R Square	0.848							
Adjusted R Square	0.824							
Standard Error	1.163							
Observations	30.000							
ANOVA								
	df	**SS**	**MS**	**F**	**Significance F**			
Regression	4.00	188.66	47.17	34.87	0.00			
Residual	25.00	33.82	1.35					
Total	29.00	222.48						
	Coefficients	**Standard error**	**t Stat**	**pvalue**	**Lower 95%**	**Upper 95%**	**Lower 95.0%**	**Upper 95.0%**
Intercept	8.223	1.434	5.734	0.000	5.269	11.176	5.269	11.176
Capacity (te)	0.062	0.006	10.743	0.000	0.050	0.074	0.050	0.074
Lead Distance (Km)	–0.620	0.295	–2.105	0.046	–1.228	–0.013	–1.228	–0.013
Haul road Condition	–1.115	1.132	–0.985	0.334	–3.446	1.216	–3.446	1.216
Age in years	–0.053	0.059	–0.907	0.373	–0.174	0.068	–0.174	0.068



(a)



(b)

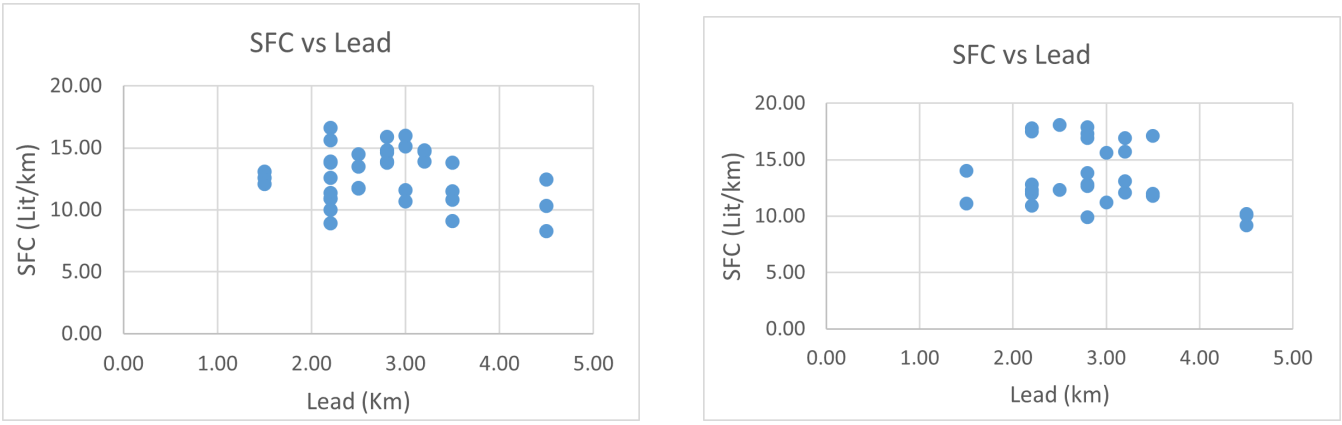
Figure 6. SFC vs capacity for Company A and Company B.

to further investigate the impact of lead distance on SFC, the scatter plots between the SFC and lead distance for different RDTs (100 tonne, 120 tonne and 190 tonne) were plotted as presented in Figures 8(a-c), respectively.

Figure 5 depicts that for different capacity RDTs, irrespective of the make, the trend between SFC and lead obtained is almost similar. Therefore, it may be inferred that with an increase in the lead distance, the SFC decreases.

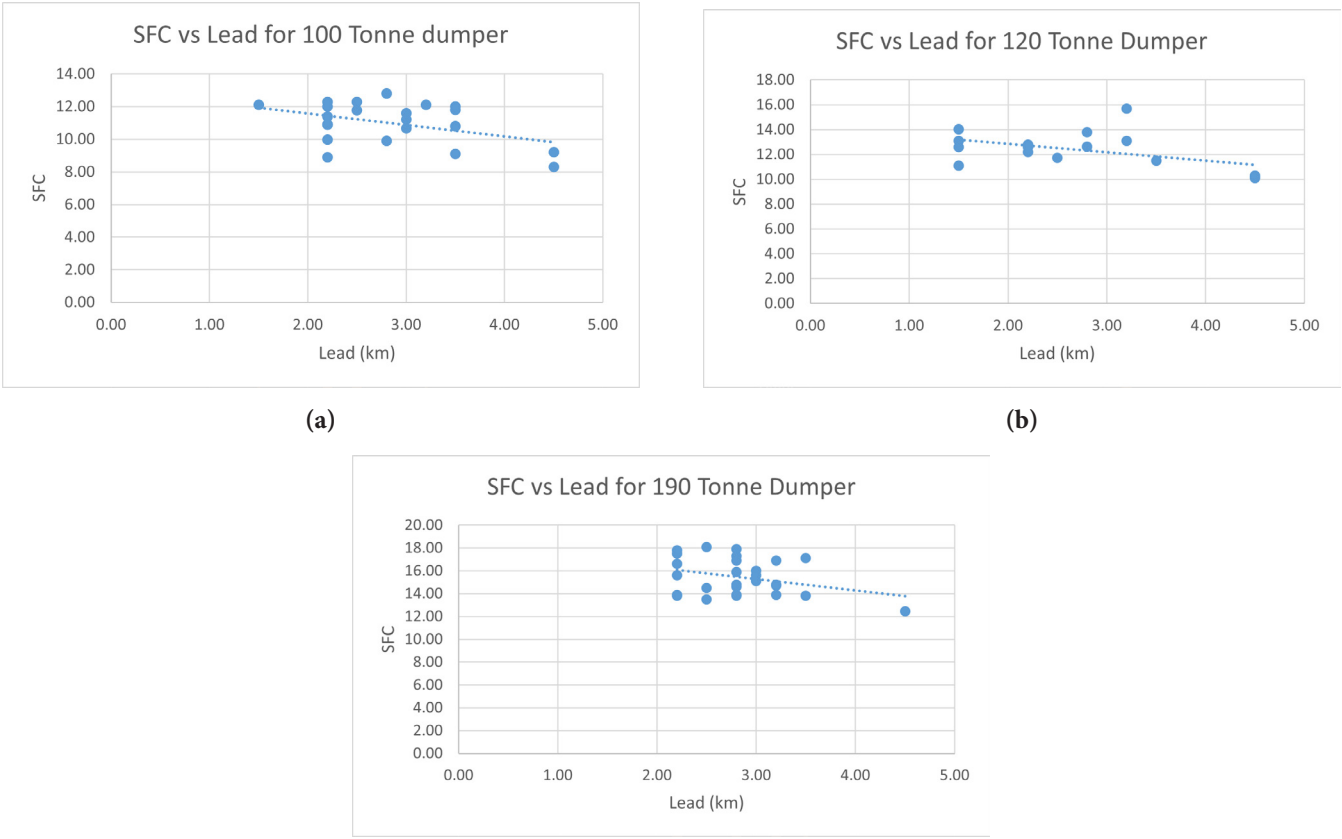
Figures 9(a) and (b) present the scatter plot between the Haul road condition and SFC of different capacity RDTs of companies A and B, respectively.

From Figure 10, it can be seen that the better the haul road condition lower the specific Fuel consumption.



(a) **(b)**

Figure 7. SFC vs lead for Company A and Company B.

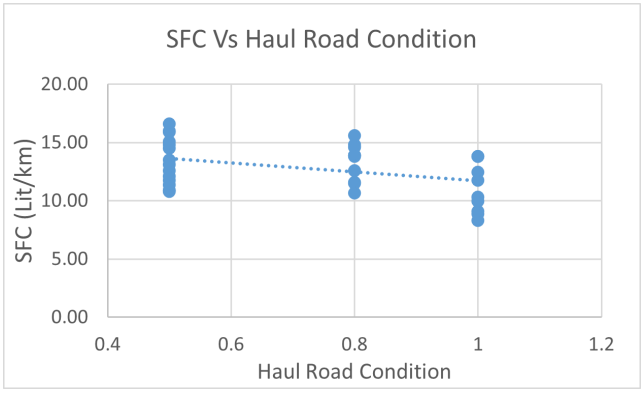


(a) **(b)**

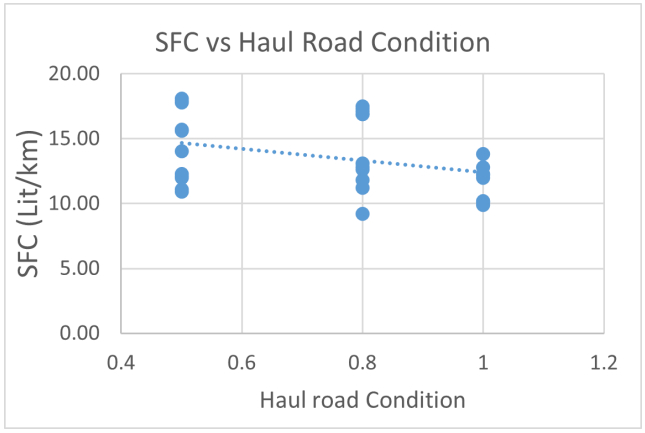
(c)

Figure 8. SFC vs lead for 100, 120 and 190 tonne RDTs combined for company A and B RDTs.

Figure 10 reveals that the age of the RDTs has no significant impact on the SFC. The age and performance of RDTs vary with the make of the dumpers. This may be due to varied maintenance of the dumpers; the dumper, although being old but had good maintenance throughout, may perform well and better than the new dumper. Also, the skills and experience of the operator will be a significant parameter.

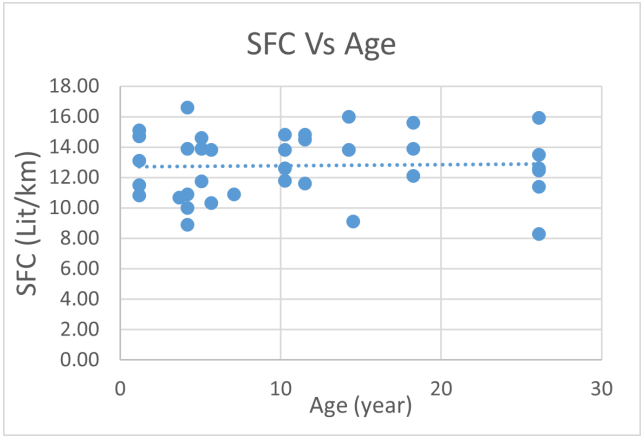


(a)

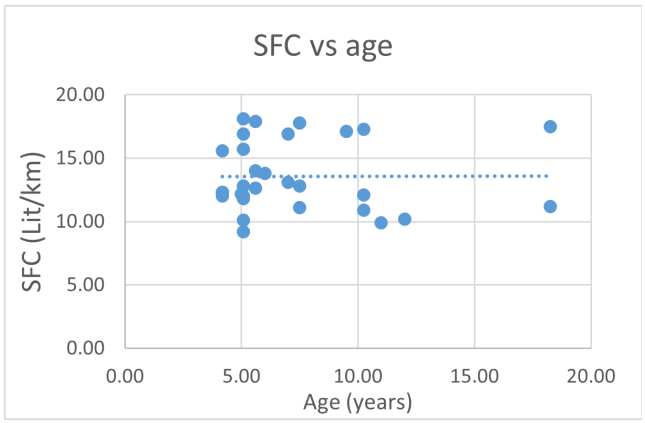


(b)

Figure 9. SFC vs haul road condition for Company A and B.



(a)



(b)

Figure 10. SFC vs haul road condition for Company A and Company B.

6.0 Conclusions

From the foregoing study, results and discussion following important conclusions may be evolved:

- The capacity of exerts direct and highest impact on the SFC, followed by haul road condition and the lead distances, which inversely impact the SFC.
- The relationship trends between the SFC and lead distance, irrespective of the capacity and shape of the RDTs, remain similar. With the increase in the lead distance, the SFC decreases.
- Haul road conditions have a significant influence on the SFC. The better the haul road condition, the lower the SFC will be.
- The age of the RDTs has not revealed any significant relationship with the SFC. Maybe this result could be attributed to better maintenance of such large capacity RDTs. Fleet management practices play a crucial role in optimising the SFC. Having a fleet with a high SFC can be managed through regular maintenance, optimised route planning, and appropriate truck scheduling. By maintaining equipment in peak condition and reducing idle times, fuel efficiency can be improved. Additionally, fleet managers should ensure proper tire pressure, efficient load distribution, and ensure that RDTs are operating within their optimal performance parameters to mitigate the effects of high SFC. Proper training of operators can also significantly contribute to reducing unnecessary fuel consumption.

7.0 References

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