Effect of Transport Road Slope on Fuel Consumption of Coal Mine Transport Truck

Dessy Lestari, Rachmat, Abdi, and Teguh* 1

1 Department of Civil Engineering, Politeknik Negeri Banjarmasin, Banjarmasin, Indonesia
2 Department of Mechanical Engineering, Politeknik Negeri Banjarmasin, Banjarmasin, Indonesia

Abstract. Fuel is a major component of mining operational costs. One of the factors that affect fuel consumption is the condition of the mine road conditions. This research was conducted in a coal mine in South Kalimantan to determine the effect of slope and hauling distance on the rate of fuel consumption. The research method used by researchers is a quantitative research method. From the results of the analysis, the total power required for the conveyance to overcome the slope of the road with a distance of 1.47 m is 6.47 MW and for one trip it requires 19.25 liters of fuel. Based on the results of calculations regarding the relationship between road slope and hauling distance to the speed of fuel consumption, it can be concluded that when in free conditions, if there is an addition of 1% road slope, fuel consumption will increase by 4,820 liters. Whereas in unloaded conditions, if there is an addition of 1% road slope, fuel consumption will increase by 2,071 liters.

1 Introduction

PT Kalimantan Prima Persada (PT. KPP) is a mining contractor working on a coal mining project located in South Kalimantan. For mining process activities, PT.KPP uses the open pit mining method, and one of its activities includes the process of transporting overburden material using a Komatsu HD 785-7 Dump Truck from the pit area to disposal. Currently, the share of open-pit mining is 50 - 65%, and in the future, it will increase to 80 - 85%. In the process of transporting mining materials, fuel is the main component that contributes greatly to mining operational costs [1]. The cost of fuel consumption for trucks in open pit operations reaches 22% of the total cost [2]. In coal mining exploitation, fuel costs can reach 30% - 40% [3]. The transportation of mining materials differs from the types of transportation in other industries. Mine roads are rougher than highways, with grades up to 15%. These conditions result in unique trends associated with fuel consumption [4]. Factors that affect fuel consumption include lifting height, load, haulage distance and operator’s habit [2], [5].

In mining, the grade of the road (slope) affects travel time, speed, and fuel consumption. This is directly proportional to the energy required by the dump truck to overcome obstacles. Different types of heavy equipment also show different effects [6]. In addition to affecting fuel consumption, the road slope also affects exhaust emissions [7]. Technology Road
transport is the most problematic challenge in mining. Deeper and wider pits increase hauling distances and the longitudinal slope of the road. To improve fuel efficiency, mining companies must design optimal road slopes.

Estimation of fuel consumption can be carried out by simulation or actually, but there are differences between 2 and 4% deviations from the actual measurements observed [8]. Estimating truck fuel consumption can be achieved by identifying the significant factors that affect fuel consumption: truck payload, total resistance and truck speed [9]. Based on this, it is necessary to carry out an analysis to determine the effect of an increase in road grade on fuel consumption based on actual conditions.

2 Method

2.1 Research sites

The research was conducted at PT. KPP is administratively located in Lokpaikat District, Tapin Regency, South Kalimantan Province (Fig. 1). The research was conducted on the haul road, from the high wall to the in-pit dump with a distance of 1472.1 m and has been divided into 12 segments. Lay out haul road is shown in Fig. 2.

2.2 Data collection procedures

Data collection procedures based on data taken during field research, including:

2.2.1 Fuel consumption

Fuel consumption is the amount of fuel used by each loading device to operate. Fuel consumption is calculated by the following equation:

\[
\text{Fuel Consumption} = \frac{\text{fuel (Liter)}}{\text{Operational time (hour)}}
\]

Fig. 1. Map of research locations
Fig. 2. Layout haul road

2.2.2 The slope of the haul road

The slope of a haul road is the percentage of the slope of a road that is obtained from the quotient of the height difference of a location with the actual distance of a location. To determine the slope of the haul road, the following formula is used:

\[
\text{Grade} \ (\%) = \frac{\Delta h}{\Delta x} \times 100 \%
\]  

(2)

with:
\( \Delta h \) = Difference in height between two points (meters)
\( \Delta x \) = Long flat distance between two points (meters)

2.2.3 Fuel consumption

To calculate fuel consumption, the following formula is used:

Fuel consumption per road segment = \( \% \) power x fuel consumption 1 cycle.

\[
\% \ \text{segment power} = \frac{\text{segment power}}{\text{total power}} \times 100\%
\]  

(3)

To calculate the engine power for each road segment, the following formula is used:

\[
\begin{align*}
\text{Pa} & = Va \times (a \times Va^2) + (c \times Wa) \\
\text{Pk} & = Vk \times (a \times Vk^2) + (b \times Wk)
\end{align*}
\]  

(4)\hspace{3cm}(5)

Where:
\( \text{Pa} \) = Power required to overcome the road grade on loaded condition (kW)
\( \text{Pk} \) = Energy required to overcome the grade no-load condition (kW)
\( Va \) = Average speed of loaded condition (m/s)
\( Vk \) = average unloaded speed (m/s)
\( Wa \) = Vehicle weight with load (Kg)
\( Wk \) = Unladen vehicle weight (Kg)
a, b, c = Constanta

Here is the formula used to calculate constants [10]:

\[
\begin{align*}
a & = \frac{1}{200} \left( \frac{Wk}{Vk} \right) \\
b & = \frac{Wk}{Va} \\
c & = \frac{Wk}{Wk - Wa}
\end{align*}
\]
\[ a = \frac{1}{2} \times C_d \times \rho u \times A \]  
\[ b = (g \times \cos \theta \times (f + C_{rr})) + (g \times \sin \theta) \]  
\[ c = (g \times \cos \theta \times (f + C_{rr})) - (g \times \sin \theta) \]

Where:
- \( C_d \) = (Coefficient of aerodynamic drag)
- \( \rho \) = (Density of air) (kg/m\(^3\))
- \( A \) = (Area of the front of the vehicle) (m\(^2\))
- \( G \) = (Gravity acceleration) (m/s\(^2\))
- \( \theta \) = road inclination angle (°)
- \( f \) = (Coefficient of tire friction with the road surface)
- \( C_{rr} \) = (Coefficient of rolling resistance)

### 2.2.4 Linear regression

The following is the linear regression equation in this study:

\[ Y = a + bx + \ldots + b_n x_n \]  

Where:
- \( Y \) = Dependent variable
- \( X \) = Independent variable
- \( a \) = constant (intercept)
- \( b \) = regression coefficient on each independent variable.

### 3 Result and discussion

In this study, the road slope is calculated based on the mine road layout in Fig. 2. The road is divided into 12 segments. The segment division is based on road conditions. The results of calculating the slope of the road are presented in Table 1.

<table>
<thead>
<tr>
<th>Road segment</th>
<th>Segment length (meter)</th>
<th>Height Difference (meter)</th>
<th>Grade (%)</th>
<th>Grade(°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>81.40</td>
<td>0.92</td>
<td>1.14</td>
<td>0.65</td>
</tr>
<tr>
<td>2</td>
<td>10.51</td>
<td>0.22</td>
<td>2.14</td>
<td>1.22</td>
</tr>
<tr>
<td>3</td>
<td>29.72</td>
<td>0.22</td>
<td>0.77</td>
<td>0.43</td>
</tr>
<tr>
<td>4</td>
<td>27.69</td>
<td>0.59</td>
<td>2.14</td>
<td>1.22</td>
</tr>
<tr>
<td>5</td>
<td>310.75</td>
<td>14.20</td>
<td>4.57</td>
<td>2.61</td>
</tr>
<tr>
<td>6</td>
<td>2.193</td>
<td>0.83</td>
<td>3.81</td>
<td>2.18</td>
</tr>
<tr>
<td>7</td>
<td>546.77</td>
<td>21.8</td>
<td>3.99</td>
<td>2.28</td>
</tr>
<tr>
<td>8</td>
<td>31.57</td>
<td>0.20</td>
<td>0.66</td>
<td>0.37</td>
</tr>
<tr>
<td>9</td>
<td>32.56</td>
<td>0.12</td>
<td>0.40</td>
<td>0.22</td>
</tr>
<tr>
<td>10</td>
<td>53.69</td>
<td>1.07</td>
<td>2.01</td>
<td>1.15</td>
</tr>
<tr>
<td>11</td>
<td>265.89</td>
<td>17.95</td>
<td>6.75</td>
<td>3.86</td>
</tr>
<tr>
<td>12</td>
<td>59.62</td>
<td>3.92</td>
<td>6.58</td>
<td>3.76</td>
</tr>
<tr>
<td>sum</td>
<td>1472.13</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Segment Description:
- Segments: 1,3,5,7,9,11 are roads with uphill conditions
- Segments: 2,4,6,8,10,12 are roads with downhill conditions.

The results of calculating fuel consumption are presented in Table 2.
Table 2. Fuel consumption

<table>
<thead>
<tr>
<th>Road Segment</th>
<th>Power (%)</th>
<th>Fuel consumption (Liter)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pa</td>
<td>Pk</td>
</tr>
<tr>
<td></td>
<td>loaded</td>
<td>unloaded</td>
</tr>
<tr>
<td>1</td>
<td>5.41</td>
<td>2.60</td>
</tr>
<tr>
<td></td>
<td>1.04</td>
<td>0.50</td>
</tr>
<tr>
<td>2</td>
<td>6.24</td>
<td>2.25</td>
</tr>
<tr>
<td></td>
<td>1.20</td>
<td>0.43</td>
</tr>
<tr>
<td>3</td>
<td>5.54</td>
<td>2.57</td>
</tr>
<tr>
<td></td>
<td>1.06</td>
<td>0.49</td>
</tr>
<tr>
<td>4</td>
<td>6.38</td>
<td>2.35</td>
</tr>
<tr>
<td></td>
<td>1.22</td>
<td>0.45</td>
</tr>
<tr>
<td>5</td>
<td>4.61</td>
<td>3.10</td>
</tr>
<tr>
<td></td>
<td>0.88</td>
<td>0.59</td>
</tr>
<tr>
<td>6</td>
<td>6.69</td>
<td>2.24</td>
</tr>
<tr>
<td></td>
<td>1.28</td>
<td>0.43</td>
</tr>
<tr>
<td>7</td>
<td>4.84</td>
<td>3.08</td>
</tr>
<tr>
<td></td>
<td>0.93</td>
<td>0.59</td>
</tr>
<tr>
<td>8</td>
<td>5.96</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>1.14</td>
<td>0.51</td>
</tr>
<tr>
<td>9</td>
<td>5.64</td>
<td>2.74</td>
</tr>
<tr>
<td></td>
<td>1.08</td>
<td>0.52</td>
</tr>
<tr>
<td>10</td>
<td>6.21</td>
<td>2.45</td>
</tr>
<tr>
<td></td>
<td>1.19</td>
<td>0.47</td>
</tr>
<tr>
<td>11</td>
<td>4.03</td>
<td>3.25</td>
</tr>
<tr>
<td></td>
<td>0.77</td>
<td>0.62</td>
</tr>
<tr>
<td>12</td>
<td>7.31</td>
<td>1.75</td>
</tr>
<tr>
<td></td>
<td>1.40</td>
<td>0.33</td>
</tr>
</tbody>
</table>

3.1 Effect of road slope on fuel consumption

Based on the results of multiple linear regression, the output is in the form of the relationship between road slope and hauling distance on fuel consumption when loaded and unladen. The regression results are as shown in Fig. 3 and Fig. 4.

![Fig. 3](image-url)

**Fig. 3.** The output of the regression of the relationship between fuel consumption and road slope and hauling distance under loaded conditions

![Fig. 4](image-url)

**Fig. 4.** The output of the regression of the relationship between fuel consumption and road slope and hauling distance under unloaded conditions

Based on Fig. 3 and Fig. 4, the coefficient of determination in loaded conditions is (R²=0.99) and in uncharged conditions, the coefficient of determination is (R²=0.95). The
regression equation for fuel consumption (Y) on the slope (X1) and hauling distance (X2) in loaded and unladen conditions is as follows:

\[ Y = 1.104 + 4.810X1 + 0.000024X2 \]  
\[ Y = 0.496 + 2.072X1 + 0.000014X2 \]

Based on equation (10) states that under loaded conditions, if there is no additional road slope and hauling distance (X1 = 0, X2 = 0) then the fuel consumption is 1.104 liters. If there is an additional road slope (X1 = 1) then fuel consumption when loaded is predicted to increase by 4.81 liters. Based on equation (11) states that under loaded conditions, if there is no additional road slope and hauling distance (X1 = 0, X2 = 0) then the fuel consumption is 0.49 liters. If there is an additional road slope (X1 = 1), the fuel consumption when loaded is predicted to increase by 2.072 liters.

4 Conclusion

Based on the results of the discussion, the total power to overcome the slope of the road is 6477.7 kW and consumes 19.2 liters of fuel for 1 trip. Based on the results of the regression calculation, the slope of the road greatly affects fuel consumption. If there is an addition of 1% of the road slope, fuel consumption will increase by 4.820 liters in a loaded condition and 2.071 liters in an unladen condition.

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References


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