Rolling resistance plays a critical role in fuel consumption of mining haul trucks

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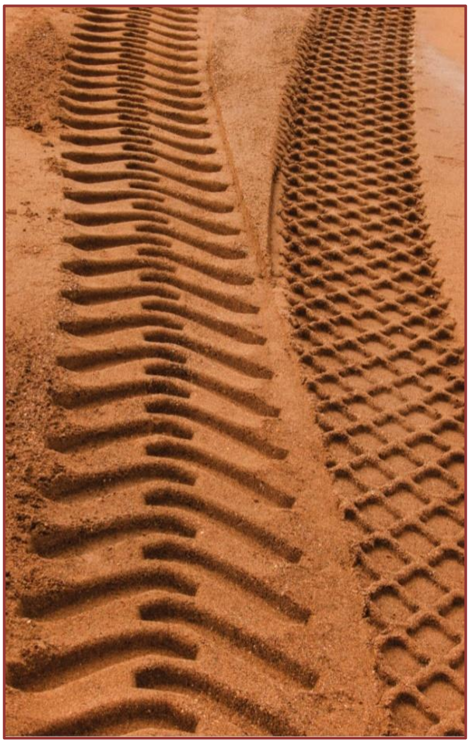


Rolling resistance as a part of total resistance plays a critical role in the productivity, fuel consumption, gas emissions, maintenance and safety of haul truck operations in surface mines. This article aims to identify the most influential parameters on rolling resistance and complete an investigation about the effect of these parameters on the fuel consumption of haul trucks. In this project, a comprehensive literature review has been completed to identify the parameters that are influential on rolling resistance. Through that process, 15 parameters have been identified and an online survey conducted to determine the most influential of these parameters on rolling resistance, based on the knowledge and experience of a number of professionals within the mining and haul road industries. In this survey, 50 industry personnel have been contacted with a 76% response rate. The results of the survey have shown that road maintenance, tyre pressure and truck speed are the most important effective parameters on rolling resistance. As a case study, a computer model based on the nonlinear regression method has been created to find the correlation between fuel consumption and the most influential parameters on rolling resistance in a large coal surface mine in central Queensland, Australia. The results of the case study indicated that by decreasing the maintenance interval, increasing tyre pressure and decreasing truck speed, the fuel consumption of haul trucks can be decreased. It means that there are a lot of energy efficiency opportunities in haulage operation through the controlling some effective parameters on rolling resistance.

This research has been conducted by a group of researchers at Mining3 and the University of Queensland Australia.

Keywords: Rolling Resistance; Haul Truck; Surface Mine; Fuel Consumption

Rolling resistance is defined as a measure of the force required to overcome the retarding effect between the tyres and road[1] and is commonly represented by a rolling resistance coefficient, which can be determined by dividing the rolling resistance by the normal force applied to a truck tyre. Figure 1 presents a schematic diagram of a truck tyre and some of the parameters affecting rolling resistance.

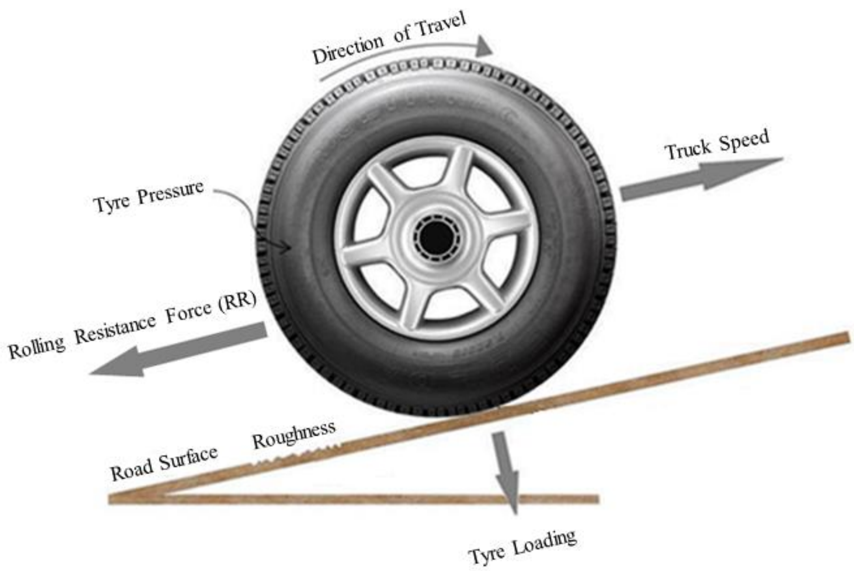


Figure 1: Rolling Resistance and the most Influential Parameters

Study in the area of rolling resistance has potential implications in the area of tyre management in surface mining. Tyre's remain a large cost in the operation of haul trucks, and are affected by rolling resistance in a number of ways. The build-up of heat in truck tyres is a leading cause of tyre degradation and is influenced by the rolling resistance experienced by the tyre. This accrual of heat can potentially lead to tyre failure, a costly and potentially dangerous event. Rolling resistance is influenced by a number of parameters, all of which can be placed into one of four groups of road, tyre, system and weather. Each of the parameters is also categorised as a Design (D), Construction (C), Operational (O) or Maintenance (M) parameter (Table 1).

Table 1 - Influential Parameters on Rolling Resistance

	Group	Category* D	C	O	M	Parameter
Rolling Resistance	Road	✓			✓	Roughness
		✓	✓		✓	Defects
		✓	✓		✓	Material Density
				✓		Moisture Content
					✓	Road Maintenance
	Tyre	✓		✓	✓	Tyre Penetration
		✓				Tyre Diameter
				✓		Tyre Pressure
			✓	✓	✓	Tyre Condition
				✓		Tyre Loading
				✓		Tyre Temperature
	System			✓		Truck Speed
				✓		Driver Behaviour
	Weather			✓		Humidity
				✓		Precipitation
				✓		Ambient Temperature

* **D**:Design **C**:Construction **O**:Operational **M**:Maintenance

An online survey was conducted to determine the most influential parameters on rolling resistance, based on the knowledge and experience of a number of professionals within the mining and haul road industries. 50 industry personnel were contacted with a 76% response rate. Of the personnel surveyed, 10% worked in the area of haul road planning, 30% in maintenance, 40% in design and 20% in operations. This survey allowed participants to estimate the influence of parameters identified as affecting rolling resistance. A score was assigned to each parameter between 0 and 100 representing the influence of a particular parameter on rolling resistance, where 0 is not influential and 100 is highly influential. The results of the survey show that tyre diameter has the lowest influence on rolling resistance with a result of 40%. Defects, Tyre Condition, Tyre Temperature, Driver Behaviour and Ambient Temperature were all given rankings of approximately 50%. Maintenance, Tyre Pressure and Truck Speed were all identified as having the greatest influence on rolling resistance, with scores between 80 and 90%. The remaining parameters all scored between 50 and 70% (Figure 2).

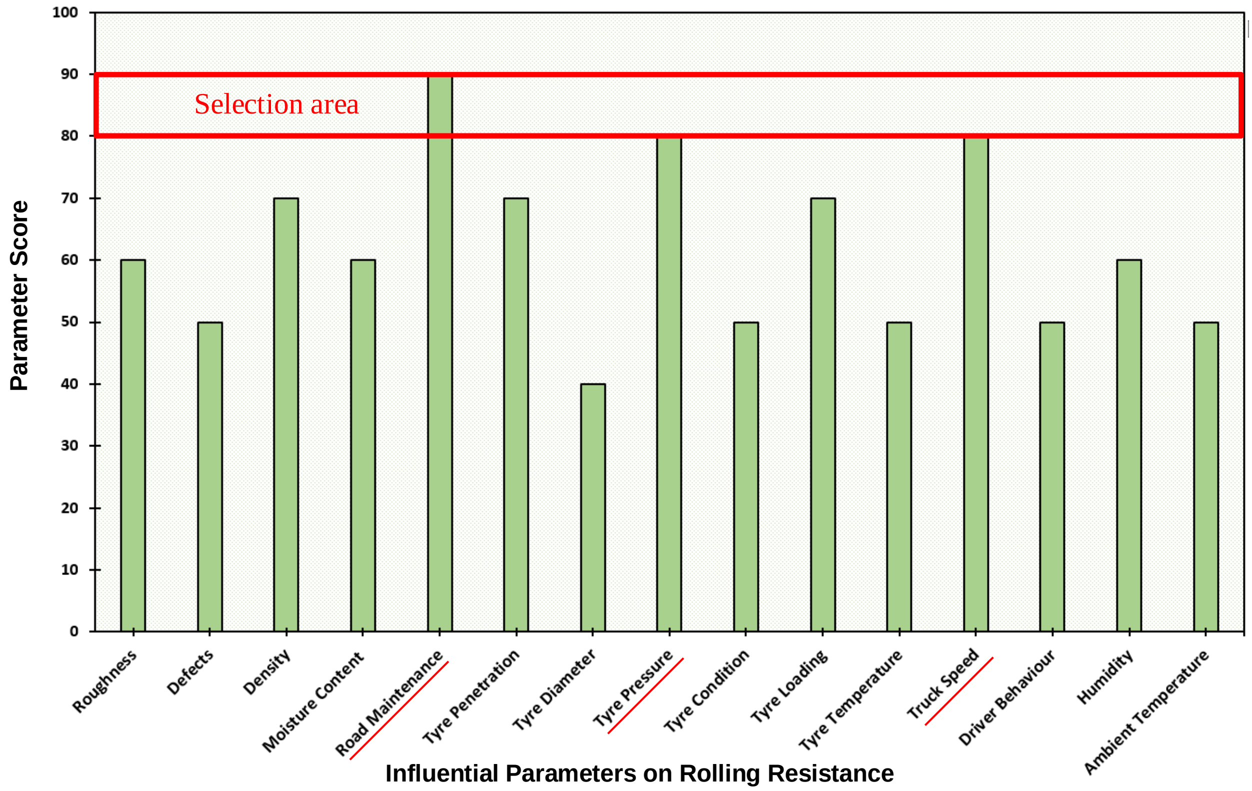


Figure 2: Survey Results

1- **Road maintenance** refers to the processes undertaken on mine haul roads, to repair defects and other road surface issues. It also refers to processes undertaken to reduce the probability of these defects occurring and increase the general quality of the road surface. The maintenance interval is determined by a number of factors including the mine plan, financial requirements and constraints, personnel availability and the quality/condition of a haul road. For this research, a dataset was obtained for several ramp and bench roads located in a single area of an open surface mine site, using a haul truck to test and obtain data. The data makes use of the maintenance interval or period, which refers to the amount of time between instances of road maintenance work, measured in days. The relationship between maintenance interval and rolling resistance for a specific mine site is illustrated in Figure 3. This figure shows that a larger period of time between maintenance instances results in increased rolling resistance[2].

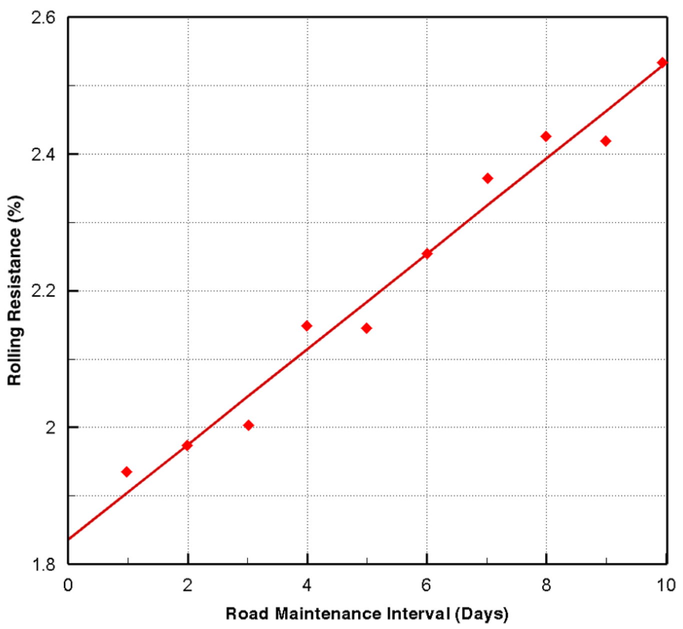


Figure 3: Rolling Resistance vs. Road Maintenance Interval

2- **Tyre Pressure** is a tyre operational property, identified as being highly influential on rolling resistance. The tyre pressure is easily modified on a mine site and adjusted relatively easy. It should be noted that tyre pressure is not constant during truck operation, and is in fact affected by the temperature of the tyre. This temperature changes during normal truck operation and so affects the tyre pressure during material hauling. In this research all necessary data was obtained from a completed study on tyre pressure in France. The measurement conditions were in accordance with the ISO 8767 standards, which require a temperature of 25 degrees Celsius, tyre loading of 80% of the tyres maximum capacity and a speed of 80km/h. the results show that increasing tyre pressure effects in a decreased rolling resistance coefficient[3]. This corresponds to a decrease in the rolling resistance at higher tyre pressures. The relationship is illustrated in Figure 4.

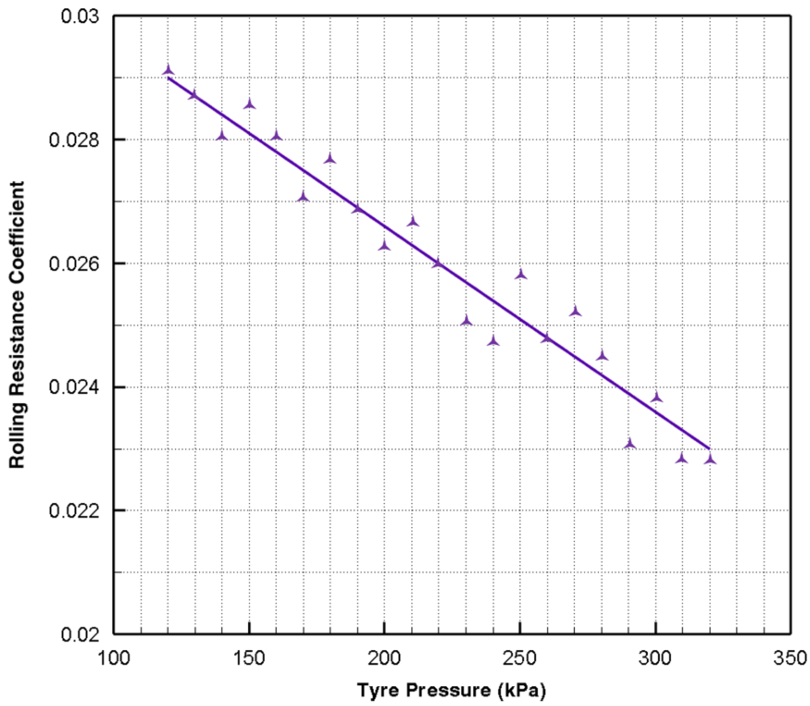


Figure 4: Rolling Resistance Coefficient vs. Tyre Pressure

3- **Truck speed** falls under a system operational property and refers to the speed at which the haul truck is travelling over the road surface. Truck speed is influenced by a number of different factors including the payload, road conditions, tyre condition, driver behaviour and the grade of the haul road. The results illustrated in Figure 5 were obtained for approximately 100 haul truck tyres, tested in The Technical University of Gdansk's drum facility. They were obtained for two differing drum surfaces, representative of smooth and rough road surfaces. The tyres tested consisted of a number of different brands and geometrical dimensions. The final results show that increasing truck speed results in an increased rolling resistance coefficient[4]. The relationship was found to be the same for both rough and smooth road surfaces, and is illustrated in Figure 5.

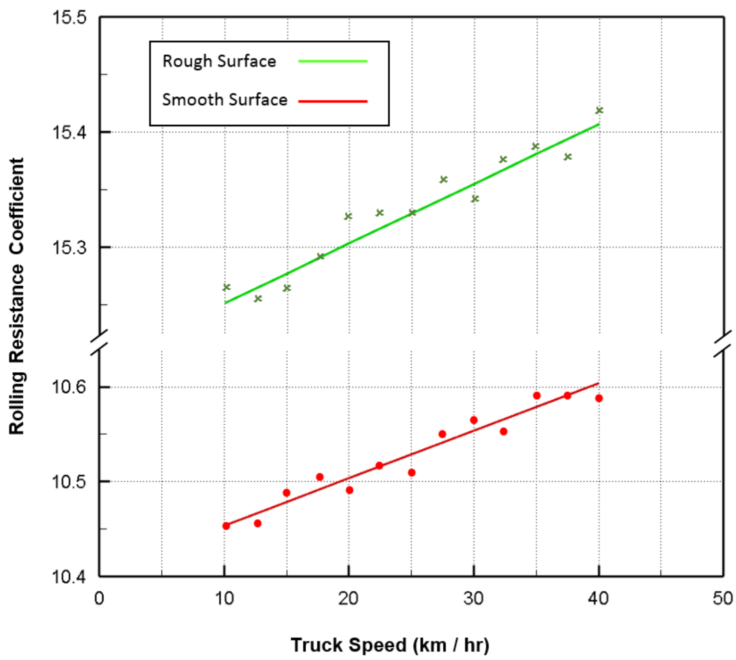
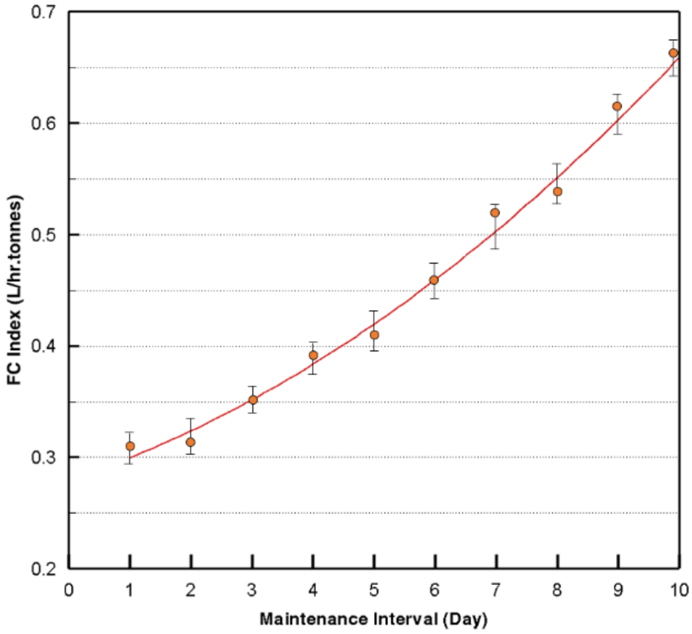


Figure 5: Rolling Resistance Coefficient vs Truck Speed

The survey and relationships discussed are useful when considering the efficiency with which haul trucks operate on open surface mines. Rolling resistance can be controlled on mine sites, especially when efforts are focused on the most influential parameters. It is recommended that haul road maintenance intervals be optimised in accordance with cost considerations to reduce rolling resistance. In relation to tyre pressure, it is clear that higher pressures result in lower rolling resistance. It is therefore recommended that tyre pressures be maintained in accordance with the manufacturer's recommendations. Lastly, increasing truck speed is linked to higher rolling resistance, and so lower truck speeds are desirable when only rolling resistance is considered. However, a number of other factors must be considered when choosing a suitable truck speed including safety requirements, cycle times and productivity requirements. All of these alterations will reduce rolling resistance, and be useful when considering further hauling operations and their efficiency.

In addition to potential improvements in rolling resistance, this study aimed to identify opportunities to improve haul truck fuel efficiency. Rolling resistance is a major contributor to energy loss in hauling operations and is affected by numerous parameters. By identifying which of these parameters are the most influential on rolling resistance, the mining industry can focus its efforts on a smaller area of fuel efficiency improvements.

In this project, a real mine site dataset collected from a large surface mine in central Queensland, Australia has been analysed. Figure 6 demonstrates the relationship between maintenance interval and FC_{Index}. This relationship shows that a main solution for increasing the energy efficiency in haulage operation is decreasing the maintenance interval. This Figure



also shows that by reducing the maintenance interval from 10 to 5 days, FC_{Index} will be decreased from 0.65 to 0.4 L/(hr.tonnes). This amount of fuel savings can be a great opportunity for mine managers to reduce their operational costs.

Figure 6: Relationship between maintenance interval and FC_{Index}

Figure 7 illustrates the correlation between FC_{Index} and tyre pressure in different conditions. In this figure the relationship between haul truck fuel consumption and tyre pressure has been completed for a normal range of tyre pressures found for trucks in the studied surface mine. This relationship shows that by increasing the tyre pressure, FC_{Index} will be decreased sharply. Therefore, it is obvious that by a regular pressure check, increasing the fuel efficiency in haulage operations will be possible.

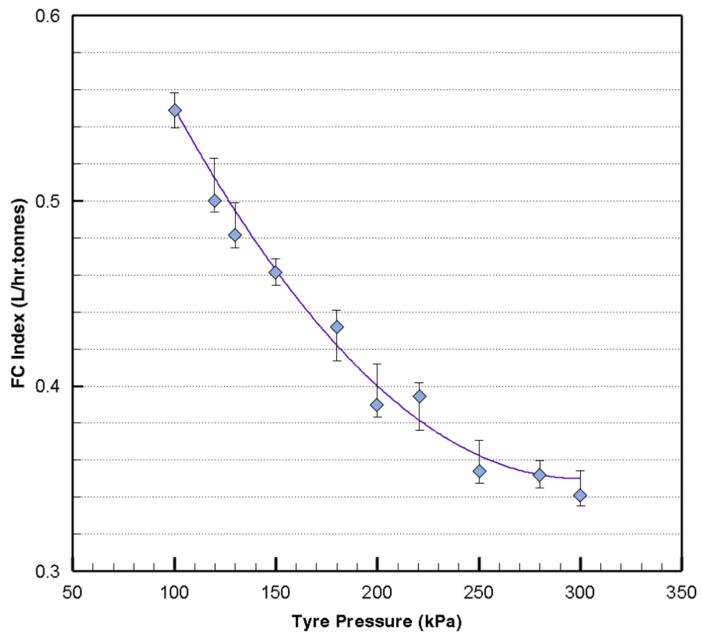


Figure 7: Correlation between FC_{Index} and Tyre Pressure

The effect of truck speed on FC_{Index} is illustrated in Figure 8. The non-linear correlation between FC_{Index} and truck speed shows that by increasing the speed, fuel consumption by the truck increases. This figure also shows that a valid approach for decreasing the fuel consumption is to decrease the total resistance, and in this case could be achieved by reducing rolling resistance.

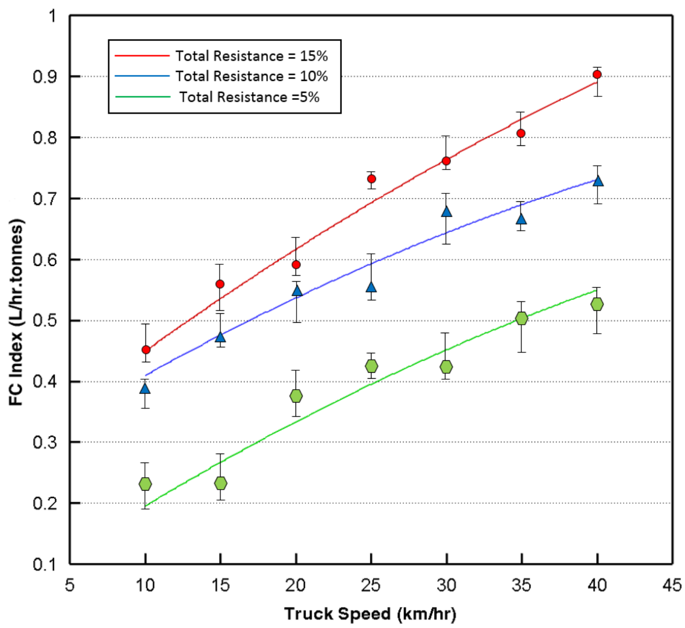


Figure 8: The effect of truck speed on FC_{Index}

In summary the results of this project show indicate that there are a lot of energy efficiency opportunities in hauling operation by controlling effective parameters on rolling resistance.

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