Journal of Physics: Conference Series **1444** (2020) 012048 doi:10.1088/1742-6596/1444/1/012048

Sensitivity analysis of road roughness on transportation costs

***Fardzanela Suwarto[1], Anjang Nugroho[2], Riza Susanti[1], Didik Purwadi[1]**
[1]Department of Civil and Planning,
[2]Institute of Road Engineering.

*Corresponding author email: fardzanela@live.undip.ac.id

Abstract. Understanding the costs of pavement construction, pavement maintenance, and vehicle operation is essential to planning the management of life cycle and pavement investments, especially under increasing infrastructure demands and limited budget resources. It has long been known that the road user costs (RUC) of vehicle operation are by far the largest component of pavement total life-cycle costs. Those cost are influenced by many factors; one of the most important factor is pavement performance. Pavement condition will have a significant impact on RUC attribute for instance fuel consumption, tier consumption, vehicle maintenance cost, and crew wages. Therefore a study of influence and sensitivity analysis of RUC on difference pavement condition is required. Hence this study is aiming to investigate the sensitivity analysis by varying International Roughness Index (IRI) as pavement performance indicator using the Road User Cost Knowledge System (RUCKS) program. From the research result, with sensitivity equation RUC ($/vehicle-km) = a0 + a1 * IRI + a2 * IRI^2 + a3 * IRI^3, it is highlighted that IRI has the highest impact on Articulated Truck and Large Bus in terms of transport cost with Sensitivity to Roughness Cubic Polynomial Coefficients a0 1.12958, a1 -0.06418, a2 0.02110, a3 -0.00136.

1. Introduction

The cost of the freight industry in Indonesia is very expensive and inefficient compared to other countries especially in Asia. For domestic land transportation services, Indonesia has a poor record in logistics distribution. In order to increase logistics performance, Indonesia has a connectivity program by encompassing regulation of services, sustainability, and resilience [1]. However the goals will be difficult to achieve without adequate infrastructure, particularly road quality.

The lack of good quality district road is an obstacle not only for connecting cross-district trades but also for integrating remote area with a larger market. At the district level, 41% of district roads throughout Indonesia are in bad condition [2], which causes reduction on small businesses profit significantly due to the time and cost which are needed to reach larger market. In Indonesia aapproximately 70% of goods are transported by trucks [3], consequently the supply chain system which depends on road is in critical condition.

Despite of trading needs, transportation expenses of each person are also important. Transportation costs will influence the choice of transport modes, whether it is by public or by private vehicles, which is closely related to ability to pay and willingness to pay [4,5].

Pavement is an asset that plays an important role in the passenger and cargo distribution but it suffers from inevitable deterioration and periodic maintenances. Given that most funding is inadequate under normal circumstances, road agencies are challenged with project budget constraint due to limited resources. Additionally, road agencies place more emphasis on better efficiency and lower budgets. Hence since maintenance expenditure generally covers half of annual road infrastructure funds, it is very important to emphasize efficiency in road maintenance.

One of the criteria used to determine the priority of road maintenance is pavement life cycle cost (LCC). LCC is an economic analysis process used to evaluate the cost-efficiency of maintenance alternatives based on the Net Present Value (NPV) concept. It increases the estimated long-term economic feasibility of various investment options. When calculating LCC, both costs of road agencies and costs of socio-economic sustainability should be taken into consideration. The most important aspect that was taken into consideration on selecting pavement maintenance program to achieve reasonable long-term investment is Road User Cost (RUC).

Recent study results suggest that the pavement performance has a significant influence on RUC [6–10]. However, the sensitivity of parts consumption to road roughness appeared to vary strongly in different vehicle types. One or two types of vehicles cannot explain the influence of road roughness to RUC [11]. In order to address these issues, this study were undertaken to analyze the sensitivity of IRI, as road performance parameter, on RUC on all types of vehicles using Road User Cost Knowledge System (RUCKS). RUCKS is a part of the Highway Development and Management Model (HDM-4) developed by World Bank [12].

HDM-4 RUCKS targets road user costs specifically, i.e. only the user costs associated with the use/operation phase. It provides highly detailed environmental and economic outputs about user costs without tackling other pavement life-cycle phases. It entails in-depth details regarding vehicle [13]. This paper focuses on the Road User Effects Modelling in RUCKS, the model will provides an approach to the modelling of Road User Cost under varying IRI and calculate the RUC sensitivity of each vehicle type on the changes of IRI.

2. Methodology

The objective of the RUCKS model was to assess the influence of road characteristic and its condition on the total road user cost (RUC) by calculating the operating cost of various types of vehicles. This research focused on the Semarang–Ungaran route (Jl. Diponegoro) as a study case which has IRI number varied from 2.1 to 6.9. Subsequently the variation of those IRI values will be associated with the changes in RUC values.

Table 1. Vehicle type adjustment from IRMS to RUCKS

Group	IRMS	RUCKS model
1	Motorcycle, scooter, beetle and 3-wheeled motorized vehicles.	Motorcycle
2	Sedans, jeeps and station wagons.	Car Small
3	Opelet, pick-up opelet, suburban, combi and minibus.	Car Medium
4	Pick-up, micro truck and delivery car or pick-up box.	Delivery Vehicle
5a.	Small bus	Bus Light
5b.	Big bus	Bus Heavy
6.a	2 axle 4 wheel truck	Truck Light
6.b	2 axis 6 wheels	Truck Light
7.a	3 axis truck	Truck Medium
7.b	Trailer truck	Truck Heavy
7.c	Semi-trailer truck	Truck Articulated
8	Non-motorized vehicles; bicycles, pedicab, horse cart / dokar, ox cart	Excluded

The variables affecting RUC on a given route were differentiated into three groups; Road factors, Vehicle factors, and Regional factors. Road factor consisted of geometric design, surface type and condition of the route, and lane width. Vehicle factor comprised of vehicle operating characteristic such as engine power, weight and load capacity, suspension design, and numbers of hours and kilometre travelled per year. While regional factor constituted from economic and social characteristic i.e. region-wide speed limit, fuel prices, relative prices of new vehicle, parts, and labour.

RUCKS model has a default type of vehicles. In this study, the vehicles were analysed and adjusted from vehicle classification in Indonesia according to Integrated Road Management System (IRMS) to RUCKS model classification as seen in the Table 1.

The calculated operational cost covered fuel consumption, lubricant usage, tire usage, crew/driver time, spare parts, maintenance personal, depreciation, interest rates, and overhead. The amounts of resources consumed were calculated together with the vehicle speed as a function of the vehicle characteristic, road geometry, surface condition, and the current condition of the road environment. Total RUC were determined by multiplying various resource quantities by Indonesian economic unit cost and adding rate of depreciation, interest, delay cost for passenger or cargo holding. In addition, economic cost was the cost to the economy of vehicle operation and ownership, where adjustment was done into an account for market prices distortions such as foreign exchange restrictions, taxes, labour wage laws.

Vehicle operating costs were computed simply by multiplying the predicted quantities of physical resources consumed with their relative prices. Travel costs were computed by multiplying the travel time per unit distance (the inverse of vehicle speed) by the value of time. Sensitivity analysis was conducted to determine the levels of sensitivity of the input parameters and to rank them. Sensitivity was quantified by the input elasticity, which is simple the ratio of the percentage change in a specific result to the percentage change of the input parameter, holding all other parameters constant at a mean value. The higher the elasticity, the more sensitive are the model predictions.

3. Result and Discussion

The RUCKS model generated the RUC in $ per vehicle–km from all of vehicle types. Figure 1 showed that the top three RUC at the given route with 4.1 IRI, m/km were articulated truck, large bus, and heavy truck as much as 1.13, 1.06, and 0.77 sequentially in $/vehicle-km. Taking into account the RUC variables, almost 97% of articulated truck and heavy truck's RUC was derived from vehicle operating cost especially fuel and maintenance parts with 1.099 $/vehicle-km and 0.745 $/vehicle-km. While, the vehicle operating cost in the RUC of large bus was only 58.8% (0.621 $/vehicle-km) because the passenger time factor contributed 40.1% of the total RUC as shows in Table 2.

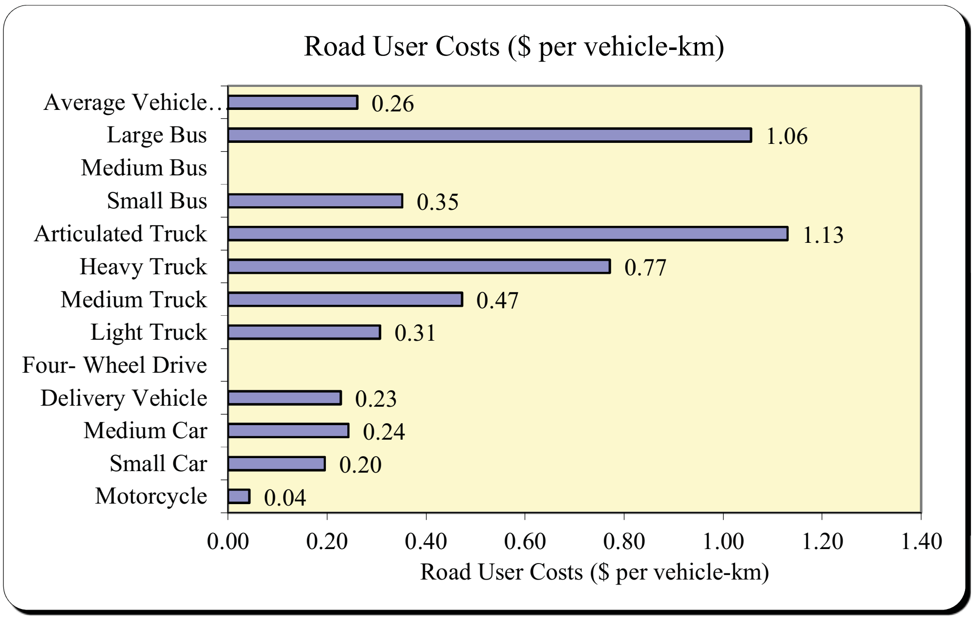

Figure 1. Road User Cost per vehicle-km for IRI 4.1

Table 2. Road User Cost ($/vehicle-km)

	Heavy Truck	Articulated Truck	Large Bus
Road User Costs ($/vehicle-km)	0.771	1.130	1.056
Vehicle Operating Cost ($/vehicle-km)	**0.745**	**1.099**	**0.621**
Fuel ($/vehicle-km)	0.289	0.371	0.194
Lubricants ($/vehicle-km)	0.010	0.011	0.008
Tire ($/vehicle-km)	0.027	0.061	0.020
Maintenance Parts ($/vehicle-km)	0.167	0.289	0.081
Maintenance Labor ($/vehicle-km)	0.043	0.046	0.029
Crew Time ($/vehicle-km)	0.098	0.112	0.111
Depreciation ($/vehicle-km)	0.064	0.081	0.056
Interest ($/vehicle-km)	0.028	0.038	0.025
Overhead ($/vehicle-km)	0.019	0.091	0.098
Value of Time Cost ($/vehicle-km)	**0.010**	**0.010**	**0.424**
Passenger Time ($/vehicle-km)	0.006	0.006	0.424
Cargo Time ($/vehicle-km)	0.004	0.004	0.000
Emissions Cost ($/vehicle-km)	**0.016**	**0.021**	**0.011**
Road Safety Cost ($/vehicle-km)	**0.001**	**0.001**	**0.000**

In the more depth analysis, RUCKS model simulated RUC by varying roughness from 2.1 to 6.9 IRI. The result showed that there was an increasing number of RUC as the road roughness goes up in figure 2. On average, a reduction of roughness from 2.1 IRI to 6.9 IRI can raise RUC by about 12.8%. The change in IRI value had a significant effect on the RUC. The rank of ΔRUC due to roughness reduction from maximal to minimal route condition can be seen in Table 3. Road roughness variance had the highest impact on articulated truck while the motorcycle was the least affected by the decrease of IRI value. The articulated truck has RUC sensitivity to roughness cubic polynomial coefficients a0= 1.12958, a1= -0.06418, a2= 0.02110, a3= -0.00136. Therefore, the RUC Sensitivity formula were $1.12958-0.06418*IRI+0.02110*IRI^2-0.00136*IRI^3$ ($/vehicle-km).

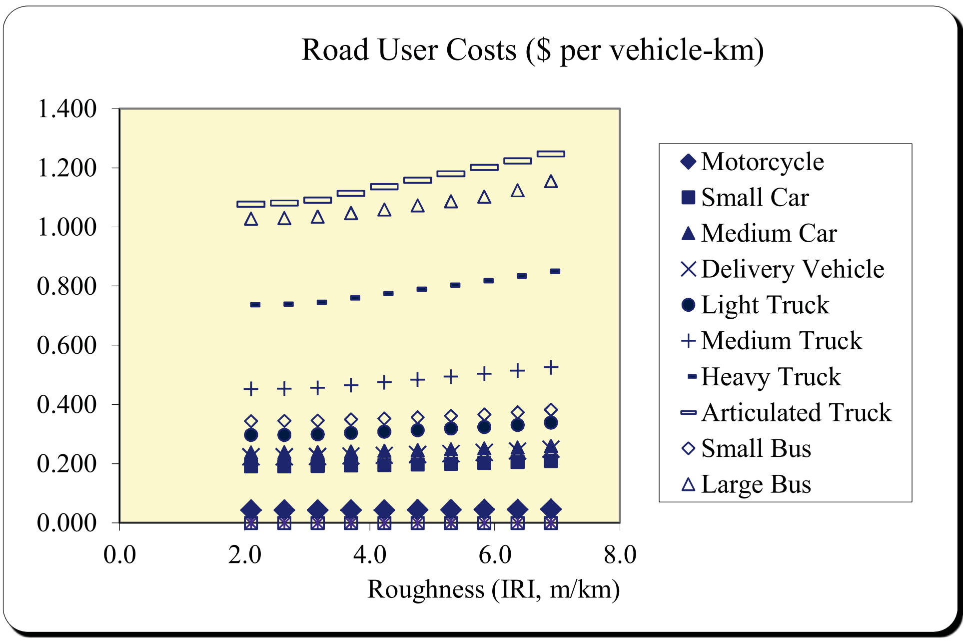

Figure 2. Sensitivity Road User Cost to Roughness

Table 3. RUC due to roughness reduction from 6.9 IRI to 2.1 IRI

No	Vehicle types	RUC	No	Vehicle types	RUC
1	Articulated Truck	$ 0.170	7	Delivery Vehicle	$ 0.026
2	Large Bus	$ 0.127	8	Medium Car	$ 0.022
3	Heavy Truck	$ 0.113	9	Small Car	$ 0.018
4	Medium Truck	$ 0.074	10	Motorcycle	$ 0.004
5	Light Truck	$ 0.042	11	Four-Wheel Drive	$ -
6	Small Bus	$ 0.039	12	Medium Bus	$ -

**RUC is in $/vehicle-km*

Furthermore, if the roughness can be improved from average IRI 4.1 to 2, the saving from RUC could be calculated by multiplying ΔRUC per vehicle by its annual traffic as shown in Table 4. The total saving from upgrading the road roughness from 4.1 IRI to 2 IRI was $ 191,953.73 per year per km (without construction cost).

Table 4. Total saving earned by reducing the road roughness by 2 IRI, m/km

No	**Vehicle types**	**RUC per vehicle-km**	**AADT vehicle**	**Annual Traffic vehicle**	**Saving**
1	Motorcycle	$ 0.001	18,715	6,830,975	$ 4,878.29
2	Small Car	$ 0.004	13,758	5,021,670	$ 19,576.16
3	Medium Car	$ 0.005	7,556	2,757,940	$ 13,176.28
4	Delivery Vehicle	$ 0.005	6,498	2,371,770	$ 11,970.26
5	Light Truck	$ 0.010	3,879	1,415,835	$ 14,655.82
6	Medium Truck	$ 0.020	6,818	2,488,570	$ 50,623.49
7	Heavy Truck	$ 0.034	1,368	499,320	$ 16,729.95
8	Articulated Truck	$ 0.053	2,317	845,705	$ 44,619.76
9	Small Bus	$ 0.008	1,516	553,340	$ 4,426.10
10	Large Bus	$ 0.029	1,082	394,930	$ 11,297.62
		Total Saving			$191,953.73

In addition, even though articulated truck, large bus, and heavy truck were the most sensitive vehicles on road roughness, the highest savings was obtained from medium truck due to the number of its traffic based on the annual average daily traffic data.

4. Conclusion

The sensitivity analysis of road user costs on roughness shows that IRI has the highest impact on Articulated Truck with Sensitivity to Roughness Cubic Polynomial Coefficients a0= 1.12958, a1= -0.06418, a2= 0.02110, a3= -0.00136. The total RUC savings earned by reducing the road roughness from 4.1 to 2 IRI was $ 191,953.73 per year per km. As a result, the government should concern about the road roughness to reduce RUC by not forgetting that IRI does not always describe the structural condition of road pavement so the benefit cost ratio from the transportation process could be maximized.

5. Reference

[1] Arvis J-F, Ojala L, Wiederer C, Shepherd B, Dairabayeva K, and Kiiski T 2018 Connecting to Compete 2018 : Trade Logistics in the Global Economy The World Bank: 2018.

[2] Aji P 2015 *Summary of Indonesia's poverty analysis.*

[3] Sudjana BG 2011 *Road Transport of Goods in Indonesia : Infrastructure , Regulatory* **10(2)** 163–84.
[4] Krisnanto AR, Legowo SJ, and Yulianto B 2015 *Matriks Tek Sipil* **3(1)** 118–24.
[5] Pradika R, Legowo SJ, and Yulianto B 2015 *Matriks Tek Sipil* **3(2)** 386–93.
[6] Das A A, Koshy BI, and Pradeep J 2013 *Proc Int Conf Energy Environ* **2(1)** 59–65.
[7] Loprencipe G, Pantuso A, and Mascio P *Sustainable Pavement Management System in Urban Areas Considering the Vehicle Operating Costs* 2017.
[8] Louhghalam A, Akbarian M, and Ulm F 2015 *Transp Res* Rec **2525(1)** 62–70.
[9] Zaabar I and Chatti K 2010 *Transp Res Rec* **2155(1)** 105–16.
[10] Zaabar I and Chatti K 2012 *Transp Res Rec* **2285(1)** 47–55.
[11] Hine JL, Sinaga HP, and Rudjito D 2002 *10th REAAA Conf.*
[12] Kerali HG *HDM-4.*
[13] Hamdar Y, Chehab GR, and Srour I 2020 *Life-Cycle Evaluation of Pavements : A Critical Review* **9(6)** 12–26.