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The effect of pavement condition on vehicle speeds and motor vehicles emissions

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Abstract

Pavement deterioration that happens at the highways causing huge losses, particularly for road users, such as increased journey time, congestions, accidents and etc. Moreover, the oncoming vehicles at slow speed will create more pollution through greater emissions and its impression on human wellness. This research examines how road damages effects of the vehicle speed subsequently to the motor vehicle emission. This research stages begins with assessment of pavement condition uses PCI methods, six locations with different pavement conditions (excellent, very good, good, fair, poor, very poor) are selected and calculated the average of vehicles speed on those locations. In the next stage, calculated emissions in six locations use mobilev software. The outcomes of this research indicate that in excellent roads condition, vehicle's average speed is 65,38 km/h, CO emissions by 20818.63 g/h/km, CO2 emissions by 1632864.82 g/km/h, NO2 emissions by 476.39 g/h/km, Particulate Mass by 168.078 g/h/km, SO2 emissions by 4.262 g/h/km. In really poor road condition, vehicle' average speed is 29.09 km/h, CO emissions by 21393.74 g/h/km, CO2 emissions by 1671812.447 g/h/km, NO2 emissions by 488.74 g/h/km, Particulate Mass emissions by 172.238 g/h/km, SO2 emissions by 4.359 g/h/km. The finale has been noticed that there is a decrease in vehicle's speed by 55 % in very poor road condition compared to excellent road condition. The average emission exhausted from the vehicles increase by 2.49 % in very poor road condition compared to first-class shape. Thus, it is necessary to keep the road condition in order to cut down the difficulties caused to the vehicle users and to keep the atmosphere in excellent shape.

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Keywords: PCI; vehicle speed; emission

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1. Introduction

The development of road infrastructure has a very important role to support economic growth, but it is evidence that the built roads were some time neglected from rehabilitation and maintenance so that created trouble with their conditions. The deteriorated roads affect the smooth stream of traffic, doubled with an increasing number of vehicles which cause traffic congestion that reduce the speed of all type vehicles on the roads. Besides increasing vehicle population, bears on the rising value of the exhaust emissions of vehicles along the deteriorated road. An oncoming vehicle in a country with slow motion vehicles produce a larger proportion of NO_2 exhausting, especially for large diesel vehicles (LDV) as the results from Beevers [1]. Emission levels are high for Carbon Oxide (CO) and HC for LDV at relatively decline velocities from ordinary speed is the results from Frey's research [2]. Moosmüller has conducted the research to determine the precise emission rates from unpaved shoulders within the San Joaquin Valley that require detailed information on the number of miles of this type of road, numbers and routes of dust entraining vehicles, and vehicle velocities [3].

Laboratory studies have been done by Kean et al [4] provided a foundation of knowledge regarding vehicle emissions, but questions remain regarding the relationship between on-road vehicle emissions and changes in vehicle speed and engine load that occur as driving conditions change. Light-duty vehicle emissions of CO, NOx, and NMHC were quantified as functions of vehicle speed and engine load in a California highway tunnel for downhill and uphill traffic on a 4% grade. Emissions were measured throughout the day; average speed decreased inside the tunnel as traffic volume increased. Emissions of CO were typically 16-34 g L-1 (i.e., grams of CO emitted per liter of gasoline consumed) during downhill driving and ranged from 27 to 75 g L-1 during uphill driving. Downhill driving and moderate-speed uphill driving resulted in similar CO emission factors. The factor of 2 increase in CO emissions observed during higher speed uphill driving is likely evidence of enriched engine fuel/ air ratios; this was unexpected because uphill driving observed in this study occurred at moderate engine loads within the range experienced during the city driving cycle of the U.S. emissions certification test. Emissions of NOx (as NO2) were typically 1.1-3.3 g L-1 for downhill driving and varied between 3.8 and 5.3 g L-1 for uphill driving. Unlike observations of CO, all uphill driving conditions resulted in higher NOx emission factors as compared to downhill driving. The NO_x emissions increased with vehicle speed for uphill driving, but not as strongly as CO emissions. Emissions of CO and NOx are functions of both vehicle speed and specific power; neither parameter alone captures all the relevant effects on emissions. On the other hand Pierson et al [5] reported based on their research that the emissions of NMHC per unit of fuel burned for downhill driving were over 3 times greater than NMHC emissions for uphill driving. Tong et al [6] conducted the research and analysis of on-road vehicle speed, emission, and fuel consumption data collected by four instrumented vehicles. Time, distance, and fuel-based average fuel consumption, as well as CO, HC, NOx, and soot emission factors, were derived.

Increased emissions on the highway due to the reduced of speed may affect the human health as stated by Kampa and Castanas [7], that hazardous chemicals escape to the environment by a number of natural and/or anthropogenic activities and may cause adverse effects on human health and the environment. Increased combustion of fossil fuels in the last century is responsible for the progressive change in the atmospheric composition. Air pollutants, such as carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NOx), volatile organic compounds (VOCs), ozone (O_3), heavy metals, and irrespirable particulate matter (PM2.5 and PM10), differ in their chemical composition, reaction properties, emission, time of disintegration and ability to diffuse in long or short distances. Air pollution has both acute and chronic effects on human health, affecting a number of different systems and organs. It ranges from minor upper respiratory irritation to chronic respiratory and heart disease, lung cancer, acute respiratory infections in children and chronic bronchitis in adults, aggravating pre-existing heart and lung disease, or asthmatic attacks. In addition, short- and long-term exposures have also been linked to premature mortality and reduced life expectancy.

Due to the fact that the deteriorated road significantly decline the vehicle speed on the highway and subsequently increase of emission, so that the research is required to define the effects of the pavement conditions on the vehicle emissions. This study aims to determine the Pavement Condition Index (PCI) of Kartosuro-Klaten Road, to analyze the effect of PCI on the vehicle's speed and finally to determine the effect of PCI on vehicle's emissions.

2. Method

The research was conducted on the Klaten Kartosuro Road from STA 0 + 000 to STA 21 + 600. Kartosuro-Klaten Road is a national road that connects the city of Solo to Yogyakarta. The procedure for road assesment used

Pavament Condition Index [8] and the calculation of emission used computer software named ”Mobilev” developed by Setyono et all named Mobilev 3.0 [9] based on Hand Book of Emission Factor (HBEFA) 3.1introduced by Keller [10].

2.1. Pavement Condition Assessment Method (PCI)

The procedure for PCI Assessment was followed according to ASTM [8], to facilitate the assessment of the existing pavement condition of the Klaten Kartosuro road segment. Data retrieval road damage carried out by the measurements and observations at the study site. Observed data retrieval damages are: road dimensions, length of road, type of damage, the dimensions of the damage and the severity level. From the data obtained at the existing road, it can be specified the type of pavement deterioration, the dimension of damage, according to the PCI standard procedure and the severity level, which then calculated to obtain the deduct value (DV), calculated the maximum data allowed (m) and specified the Corrected Deduct Value (CDV). The PCI’s values were then subtracted 100 by the total CDV. The PCI values for each segment is the average of PCI from the number of segments calculated.

2.2. Measurement of the average speed of vehicles at different pavement condition level

Having obtained the value of the Pavement Condition Index of all segments, then six locations with different values of pavement conditions were selected. The measurements of the average speed of vehicles at each location. At this stage the relationship between the values of pavement condition index (PCI) and the subsequent average speed of vehicles are developed .

2.3. Calculation of Vehicles Emissions with software Mobile v

The average speed of the data obtained in the preceding stage is used as reference data input at computer software mobilev. Data necessary to input data on software mobilev among other categories of roads, road length, speed, and Average Annual Daily Vehicle (AADV). After all, data are entered, software mobilev could be run to estimate the emission generated from vehicle with different velocity level. The data emissions were obtained, such as (CO, CO_2, NO_2, PM and SO_2) categorized at six locations with different pavement condition level.

3. Results and Discussions

3.1. The Pavement Condition Index (PCI)

The 21,600 m length of the pavement at the location of the study were divided into the right and left sides, each of segment represents 200 m, and subsequently every 5 segments are grouped into big segments per km. So there are 216 segments (each segment 200 m length for left and right side) and there are 22 big segments (km). The segments in the study sites have different level of pavement conditions, included: excellent, very good, good, fair, poor and very poor. The results of the PCI calculation in both directions are presented in Table1.

3.2. The effect of road damage on the average of vehicles speed

The average speed of vehicles was observed in the location with different PCI level. The six sections of road with PCI categories of excellent (100), very good (79), good (60), fair (44), poor (34) and very poor (19) were selected for the place of measuring the vehicle’s speed. The locations were also selected in the section where there are not affected by the traffic light and other traffic disruption. At the inspection sections, the speed of all types of vehicles were surveyed, the results of the measurement were then averaged and presented in Table 2.

The correlation between the Pavement Condition Index and the average of vehicle speed were statistically developed to measure the relationship between road condition and the speed of all types vehicles as presented in Fig. 1. The linear relationship was then used to develop to measure the correlation, the correlation and the coefficient of correlation (R2) are presented in Table 2. The graph in Fig. 1 clearly indicated that for all types of vehicles there are close relationship between road damage as indicated by the lower PCI value and subsequently reduced the vehicle speed, with R^2 more than 0.82, at the very poor road conditions the speed decrease of up to 55% compared with the speed on the excellent road conditions.

Table 1. The PCI value of Solo Jogja direction and Jogja Solo Direction measured at every section selected

No	Segment				Solo-Jogja Direction					Jogja - Solo Direction					PCI Average	Category
					PCI section 1	PCI section 2	PCI section 3	PCI section 4	PCI section 5	PCI section 1	PCI section 2	PCI section 3	PCI section 4	PCI section 5		
1	Km	0	-	1+000	91	63	45	52	27	67	37	36	40	36	49	Fair
2	Km	1+001	-	2+000	19	19	66	26	24	25	19	40	20	46	30	Poor
3	Km	2+001	-	3+000	34	46	53	50	50	40	22	40	36	48	42	Fair
4	Km	3+001	-	4+000	33	34	54	53	52	33	37	39	38	30	40	Poor
5	Km	4+001	-	5+000	53	59	58	47	49	35	100	100	100	20	62	Good
6	Km	5+001	-	6+000	45	47	100	100	100	20	47	20	100	80	66	Good
7	Km	6+001	-	7+000	100	100	100	100	100	100	100	100	100	41	94	Excellent
8	Km	7+001	-	8+000	44	47	44	45	45	36	42	37	43	35	42	Fair
9	Km	8+001	-	9+000	41	45	44	41	52	20	40	40	41	53	42	Fair
10	Km	9+001	-	10+000	42	46	47	50	70	40	52	54	48	55	50	Fair
11	Km	10+001	-	11+000	100	100	100	100	100	100	100	100	100	100	100	Excellent
12	Km	11+001	-	12+000	100	60	66	60	50	100	37	37	40	22	57	Good
13	Km	12+001	-	13+000	47	47	44	100	100	21	45	42	100	45	59	Good
14	Km	13+001	-	14+000	56	100	51	51	52	53	56	45	19	42	53	Fair
15	Km	14+001	-	15+000	48	79	45	42	100	45	47	50	52	55	56	Good
16	Km	15+001	-	16+000	100	100	100	100	100	54	52	100	100	100	91	Excellent
17	Km	16+001	-	17+000	100	100	100	100	48	100	100	100	100	100	95	Excellent
18	Km	17+001	-	18+000	53	45	49	45	46	100	100	100	100	52	69	Good
19	Km	18+001	-	19+000	42	47	40	39	46	42	45	40	20	19	38	Poor
20	Km	19+001	-	20+000	42	49	45	45	37	24	21	22	24	20	33	Poor
21	Km	20+001	-	21+000	36	40	34	35	40	20	20	40	22	42	33	Poor
22	Km	21+001	-	21+600	35	37	37			46	46	55			43	Fair

Table 2. Data on average vehicle speed for every road location with specified PCI values

No	Type of Vehicle and Speed	PCI Value						Correlation	R^2
		100	79	60	44	34	19		
1	Motor Cycle (km/hour)	66.77	57.05	49.50	44.21	33.84	27.93	y =-5.4886x + 54.536	0.92
2	Car (km/hour)	75.05	64.66	42.39	40.21	37.34	32.34	y = -5.1437x + 57.709	0.96
3	Bus (km/hour)	77.27	66.48	43.27	40.74	39.70	36.82	y = -7.6893x + 73.462	0.99
4	Truck (km/hour)	52.26	40.10	35.43	33.87	30.22	20.08	y = -8.5063x + 78.437	0.87
5	Big Truck (km/hour)	55.58	45.70	40.07	36.08	32.53	28.28	y = -8.1464x + 79.227	0.82

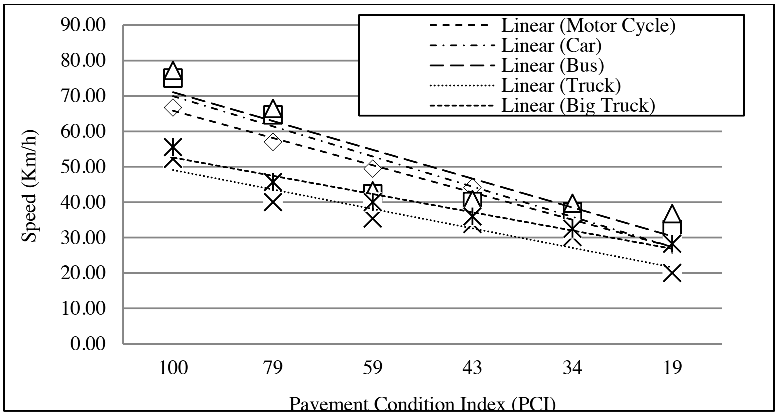

Fig. 1. The Relationship between PCI and the subsequent speed of vehicles

3.3. The effect of road deterioration on the total emission

The vehicle emissions at 6 locations with with various levels of PCI and the subsequent speed level were then calculated using computer software program Mobilev 3.0. The data required for Mobilev 3.0 to predict the emission of several pollutants and the respective road location attributes are:

a. Road Category: Rural Road
b. Vehicle type: There five vehicle types included in this research, ie. Motorcycle, car, bus, truck and big truck
c. Speed: There are six speed levels as the results from observation at six different levels of the Pavement Condition Index.
d. Average Annual Daily Vehicles (AADV) for both directions as presented in Table 3.

For example, Table 4 presents the calculated amount of several emission for each vehicle type at the section with a PCI value of 100, the data for other PCI value were calculated in the same way. For each PCI value, the emission of NO, CO_2, SO, PM and CO were calculated using Mobilev 3.0 and the total amount of emission are presented in Table 5.

Table 3. The Annual Average Daily Vehicle of both directions at Kartosuro-Klaten Road

Direction	Type of Vehicle/AADV					Total
	Motor Cycle	Car	Bus	Big Truck	Truck	
Solo - Jogja	30156	13968	984	828	1548	47484
Jogja - Solo	31992	13308	1440	1632	1104	49476

Table 4. The emission of several pollutants for each type of vehicle in the road section with PCI value of 100

Vehicle Type	AADT (Vehicle)	∑ CO Emission g/km/hour	∑NO Emission g/km/hour	∑ PM Emission g/km/hour	∑ CO_2 Emission g/km/hour	∑SO_2 emission g/km/hour
Motor Cycle	62148	15585.59	9.43	0.00	291566.85	0.76
Car	27276	1878.75	106.44	35.43	642105.96	1.66
Bus	2424	384.35	224.50	47.96	266966.93	0.69
HDV	2460	356.43	96.59	41.50	265907.14	0.69
LDV	6516	2613.49	39.41	43.17	166317.91	0.43
Total emissions (g/km/hour)	100824	20818.61	476.37	168.06	1632864.79	4.23

Table 5. The Total Emission of NO, CO2, SO, PM And CO at Various PCI Value and The Correlation between PCI and Total Emission.

PCI	∑ CO Emission g/km/hour	∑NO Emission g/km/hour	∑ PM Emission g/km/hour	∑SO_2 Emission g/km/hour	∑CO_2 Emission g/km/hour
19	21393.72	488.72	172.22	4.34	1671812
34	20999.81	482.65	170.12	4.29	1653416
43	20941.93	481.39	169.65	4.26	1642586
59	20871.1	478.82	168.94	4.24	1638428
79	20829.53	476.73	168.28	4.23	1634313
100	20818.61	476.37	168.06	4.23	1632865
The correlations	$y = 35.361x^2 - 148.75x + 20960$	$y = 0.4505x^2 - 0.8086x + 476.78$	$y = 0.1543x^2 - 0.3077x + 168.28$	$y = 0.0059x^2 - 0.0198x + 4.245$	$y = 1992.8x^2 - 6629.5x + 2E+06$
Correlation Index	0.9314	0.9739	0.9706	0.9981	0.9888

The correlation between the values of PCI which indicate the condition of the road and the total amount of emission resulted from an affected speed vehicle are presented in Fig.2 (a) for Particle Matter (PM), (b) for CO, (c) for NO, (d) for SO_2 and finally (c) for CO_2. The relationships are statistically developed using polynomial correlation, the results of the developed correlation and their correlation index are presented in Table 5.

Fig.2 and Table 5 show very clear relationship between road condition and their effect on the emission of vehicles due to the slower movements. The correlation indexes were very high, indicate that their relationship are closed. The more road getting worse the more amount of emission produced by the vehicles. It also can be counted that the average increase in the emission of very poor road conditions which rose by 2.49% compared to roads with excellent conditions.

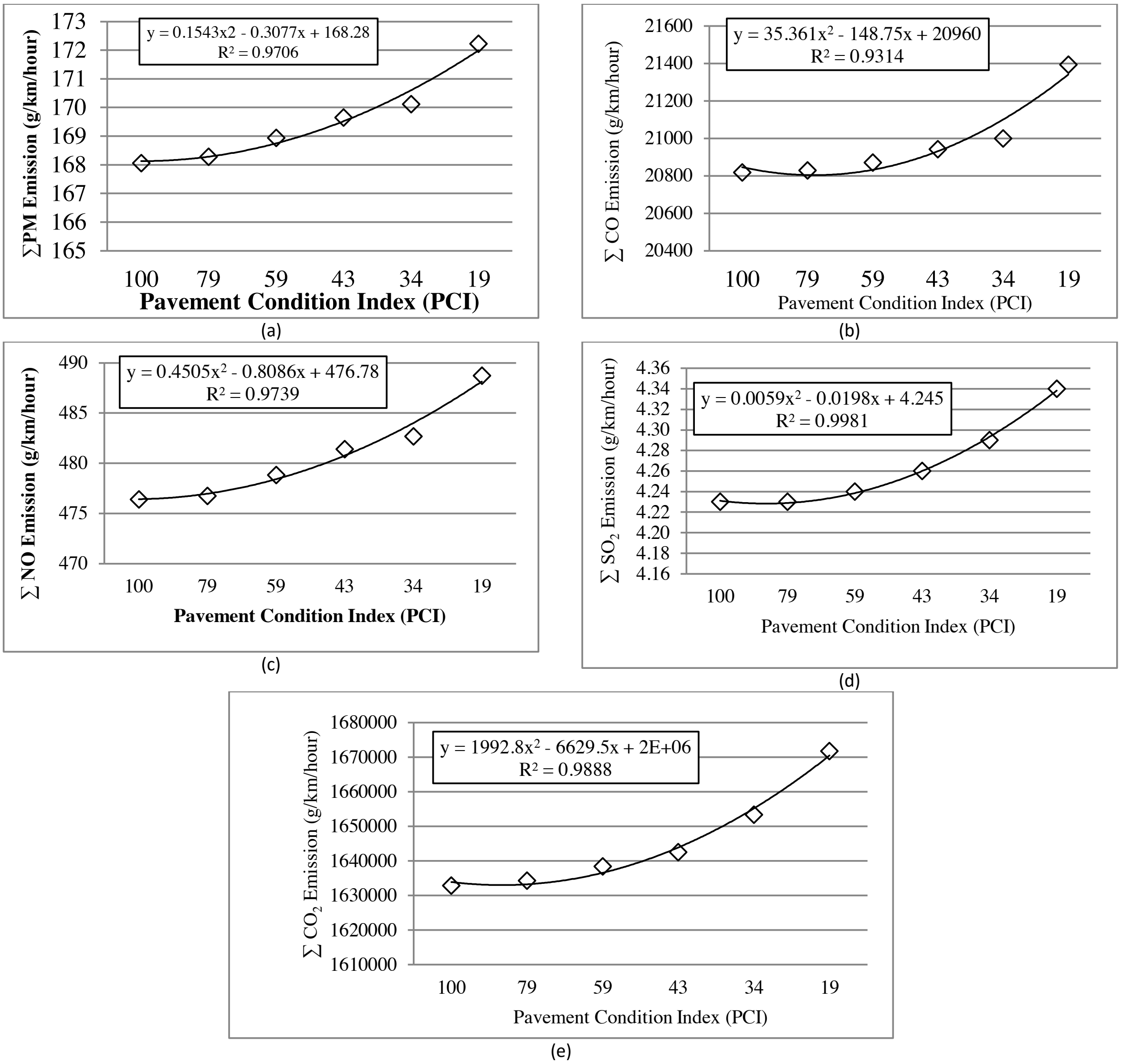

Fig. 2. The correlation between Total Emission Value of (a) PM, (b) CO, (c) N), (d) SO_2 (d) CO_2 and the PCI level

4. Conclusion

The conclusion could be derived that the road damages could affect the speed of the vehicles the correlations are linear for every type of vehicle with very satisfied index correlation. There is a decrease in vehicle's speed by 55 % in very poor road condition compared to excellent road condition. The decline in average vehicle's speed, consequently, increase the amount of emission produced by the slow movement of all types of vehicle, the relationships are polynomial with a very high coefficient of correlation. The average emission exhausted from the vehicles increase by 2.49 % in very poor road condition (19) compared to excellent road conditions (100).

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