

Impact of vehicle type proportion and speed bump on traffic characteristics and emission

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Abstract

The installation of speed bumps on local roads in Indonesia is one solution to reduce vehicle speeds. Motorcycles and passenger car are the most common types of vehicles on local roads. The use of speed bumps can have environmental impacts due to traffic activity. The purpose of the research is to determine differences in the influence of the proportion of vehicle types on speed, fuel consumption, and emissions in conditions on and before speed bumps. Methodology of research is collecting traffic flow and speed census data by vehicle type for 6 days at the road segment point before the speed bump and on the speed bump location. The guidelines used in the research analysis are based on the Regulation of the Minister of Transportation of the Republic of Indonesia No. PM 14 of 2021 concerning Road User Devices and Safety, and the 2010 Environmental Guidelines, Indonesia. Principal results is when a vehicle travels over a speed bump, there is a significant change in speed, especially for motorcycles. Compared to motorcycles, the increased proportion of passenger car results in a more sensitive increase in fuel consumption and emissions. Contributions to the field is provide vehicle speed management especially on local road with many residential areas to improve air quality from the traffic perspective. Research limitation is limited to only two types of vehicles, namely motorcycles and passenger cars. Practical implication is can reduce climate damage caused by traffic activities, road user safety and social implication is improved safety and air quality and discipline in traffic. Vehicle speed restriction management on local roads with speed bumps to reduce emissions and fuel consumption usage is a maximum of 5.981 km/hour.

Keywords: Local road, Speed bump, Fuel consumption, Emission, Vehicle's type proportion

1. Introduction

On low-volume roads, such as local roads, motorcyclists often travel at high speeds. While higher driving speeds shorten travel times, the risk of accidents also increases [1].

Traffic risk reduction on local roads can be achieved through traffic control measures, including traffic management and design solutions to regulate accessibility in certain urban areas. One such approach is traffic calming, which involves the use of road devices to reduce and control vehicle speeds, resulting in slower driving speeds that can result in better fuel efficiency. Traffic calming can be used to reduce the risk of traffic accidents, divert traffic from local roads, encourage walking and cycling, encourage a shift to public transportation, promote healthy lifestyles and public health goals, reduce traffic noise, improve air quality, reduce carbon emissions, provide opportunities for urban renewal (tree planting, spatial planning changes), and enhance community equity and economic development goals [2, 3].

Biring Romang street is one of the local roads in Makassar City, Indonesia that applies a device to control vehicle speed (speed bump) with a distance of 5 meters between the regulator devices. The geometric information of this road is a width of 4.76 meters (2 lanes, with a lane width of 2.38 meters), the type of rigid pavement, and mixed land use on this road (there are offices, commerce, housing, places of worship, and universities). With the presence of speed bumps on the road segment, vehicles experience repeated deceleration and acceleration cycles, this condition causes energy waste through fuel consumption. This is also influenced by the dimensions and proportions of vehicle types that pass through the segment. The aims of this research is to determine the difference in the effect of the proportion of vehicle types on speed, fuel consumption, and emissions in the conditions on and before the speed bump.

The research gap is that there are no studies that discuss the effect of vehicle type proportions on fuel consumption and vehicle emissions when comparing conditions over speed bumps and before speed bumps.

The original purpose of constructing speed bumps was to control the speed of passing vehicles, aiming to ensure the safety of drivers and citizens. However, the installation of these speed bumps does not always meet design standards and specifications [3], even though their installation is simple and does not require large costs [4]. Instead, speed bumps have actually shown an increase over time, resulting in negative impacts for road users, such as vehicle damage, single-vehicle accidents for drivers, potential conflicts within the community, decreased aesthetic appeal of the road, higher vehicle operating costs, reduced road capacity, and undesirable experiences for drivers and passengers [5]. Speed bumps cause inconvenience to passing emergency vehicles, both for rescue teams and for injured victims [6]. From an environmental perspective, speed bumps significantly increase pollutant emissions when a single lane has a low

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traffic volume [7]. To mitigate the negative impact of speed bumps, namely Curved Speed Bumps (CSH), consisting of a main speed bump in the form of a raised and curved area placed along the lane and a complementary speed bump, adjacent to it [8]. Drivers can choose to use the curved lane, thereby reducing speed and avoiding the disadvantages of speed bumps. In market locations, residential areas, universities, and parking lots, the installation of circular covers is also expected to be a promising solution for traffic calming purposes [9].

Although speed bumps are more common on local roads, the speed reduction benefits of speed bumps are more pronounced on major roads than on local roads. Several previous studies revealed that the reduction percentage is 41.65% for speed bumps, 73.52% for speed bumps, and 86.27% for triple speed bumps [10]. Installing speed bumps at a speed of 50 km/h will significantly increase the average delay at intersections by 109–448% [11]. The effect of speed bumps is about 23% greater at a distance of 50 meters compared to a distance of 200 meters. In areas where buildings are located further from the road, speeds are 4% higher [12]. The installation of speed bumps on the main road leading to the campus effectively reduces vehicle speeds by 46% to 52% [13]. Installing speed bumps near intersections also reduces delays at intersections. The addition of speed bumps resulted in a 38%, 63%, 21%, 31%, and 93% decrease in traffic accident deaths for pedestrians, cyclists, motorcyclists, Light Vehicles (LDVs), and Heavy Vehicles (HDVs), respectively. Other studies also support this statement that traffic accident injuries decreased by 56%, 17%, 13%, 32%, and 74% for pedestrians, cyclists, and motorcyclists, respectively [14].

Several studies that have discussed the impact of speed bumps on fuel consumption and emissions are the trapezoidal shaped speed control device spacing suggests that there is a reduction in fuel consumption on the order of 17% [15]. That lower vehicle speeds, particularly between 0-15 km/hour, are associated with higher emissions of pollutants, including carbon monoxide (CO) and other pollutants, that speed bumps significantly promote the generation of pollutants when the number of vehicles on a lane is low, also, in a free-flow region, the increase of speed bumps leads to the continuous rise of CO₂, NO_x and PM emissions [16, 17]. Regarding the speed reduction due to speed bumps, research has shown a significant decrease in speed for light trucks, but a very small decrease in speed for heavy trucks [18]. Speed humps may deteriorate the pavement condition, before and after the location of hump, due excessive acceleration and deceleration movements [19]. On roads with speed bumps, vehicle speed is generally reduced by around 5 km/hour or more [20], this condition will increase travel time, especially when traffic increases [21]. That drivers started to diminish vehicle speeds about 30 m ahead of speed humps, reached their lowest speeds at the humps, and recovered to their original speeds 30 m after passing the humps [22].

2. Materials and methods

The data collection locations are divided into several research location points to differentiate speed data at locations where there are speed bumps and those where there are no speed bumps devices. Primary data were obtained by conducting a direct survey at the research location on Jalan Biring Romang. The observation period in the field was carried out on Monday to Sunday. Starting from 7 AM to 5 PM, with the note that there were no parking activities, non-motorized vehicles, and pedestrians on both sides of the road, which could affect the decrease in vehicle speed. The data obtained were based on direct observations and calculations in the field in the form of:

2.1 Speed

The speed survey was conducted using a speed gun. In this survey, the surveyor recorded the instantaneous speed of each type of vehicle that passed over the speed bump and before speed bump. The speed data obtained from the subsequent survey were statistically tested (paired t-test) to determine whether there is a significant difference in vehicle speeds without/before and on the speed bump. The 50th and 85th percentiles of speed before and on the speed bump for the 50th percentile speed as the average or median speed of all observed vehicles. This metric is often used as a reference for standard design speed or to represent the normal speed flow of vehicles on a road segment. It is the speed at which 85% of drivers travel at or below that speed.

2.2 Road and speed bump geometry

Biring Romang street consists of 2 lanes and 2 directions without a median. The width per lane is 2.38 m. The length, width, and height of the speed reduction device at the location are 4.76 m, 55 cm, and 10 cm. The results of measuring the width, length, and height of the speed reduction device can be seen on Figure 1.



Figure 1 Speed bump measurement (width, length, and height)

2.3 Traffic volume

The types of vehicles included in the motorcycle category are 2 and 3 wheeled motor vehicles with a length of less than 2.5 meters, while passenger car are sedans, wagons, jeeps, minibuses, minibuses, pick-ups, small trucks, with a length of less than or equal to 5.5 meters. This road is a local road with a maximum axle load limit of 5 tons, thus vehicles with a tonnage exceeding 5 tons (heavy

vehicles) are not allowed/served on this road [23]. This method uses vehicle volume data that has been converted into passenger car units (PCU). Determination of passenger car equivalent values based on Indonesian Highway Capacity Manual guidelines. The passenger car equivalent value for passenger car is 1 and for motorcycles is 0.4 [23].

2.4 Fuel consumption

Fuel consumption is calculated using the equation published by Affiliated Research Institute of Bandung Institute of Technology (LAPI-ITB). This method has been specifically adapted to the characteristics of traffic and infrastructure in Indonesia, additionally, it uses standardized conversion units that have been adjusted (such as passenger car units/pcu) in accordance with the IHCM 2023 guidelines. The application of ITB LAPI method to speed bumps is carried out by measuring vehicle fuel wastage due to deceleration-acceleration, and time delays when vehicles pass over those speed control facilities. The presence of speed bumps forces vehicles to brake, move slowly/idle, and then accelerate again. The calculation of vehicle fuel consumption is then divided into three conditions: vehicle stationary with the engine running (idle), vehicle accelerating or decelerating, and vehicle moving at a constant speed [24]. The equation for calculating vehicle fuel consumption can be seen in equation (1) to (4).

$$F = F_1 + F_2 + F_3 \quad (1)$$

$$F_1 = a + bV + cV^2 \quad (2)$$

$$F_2 = eV^2 \quad (3)$$

$$F_3 = d \quad (4)$$

$$a = 170 \times 10^{-1}$$

$$b = -455 \times 10^{-3}$$

$$c = 490 \times 10^{-5}$$

$$d = 140 \times 10^{-2}$$

$$e = 770 \times 10^{-8}$$

F_1 : fuel consumption when the vehicle is moving at a constant speed (litres/pcu/km)

F_2 : fuel consumption when the vehicle is accelerating or decelerating (litres/pcu)

F_3 : fuel consumption at idle (litres/pcu/hour)

V : speed (km/hour)

2.5 Emission

Emissions predictions are obtained from emission factor values, vehicle volume, fuel consumption, and vehicle kilometers traveled. This is based on the 2010 Environmental Guidelines, Indonesia which explains the inventory of pollutant sources from motor vehicles (moving emission sources) for all provinces in Indonesia [24]. This method has been adapted to the characteristics of fuels and vehicle engine technologies in circulation in Indonesia; it is sufficient to multiply the vehicle activity volume (as calculated by the previous LAPI ITB method) by the emission factor values provided in this guideline. Carbon Monoxide (CO) comes from incomplete combustion in vehicle engines. Nitrogen Oxides (NO_x) result from high combustion temperatures. Hydrocarbons (HC) create from unburned fuel residues. Particulates (PM₁₀ and PM_{2.5}) are produced mainly by diesel-powered vehicles. Sulfur dioxide (SO₂) emissions from vehicles become a key indicator for measuring the population and movement of diesel-powered vehicles (such as trucks and buses) that still use high-sulfur diesel. The emission factor values used in this study are based on the type of vehicle, namely motorcycles and passenger car which use RON 92, and are based on pollutant factors. The emission factor values for motorcycles with pollutants CO, HC, NO_x, PM₁₀, and SO₂ are 14 grams/kilometer, 5.9 grams/kilometer, 0.29 grams/kilometer, 0.24 grams/kilometer, 3,180 grams/kilometer, and 0.08 grams/kilometer, respectively. Meanwhile, the emission factor values for passenger car with pollutants CO, HC, NO_x, PM₁₀, and SO₂ are 40 grams/kilometer, 4 grams/kilometer, 2 grams/kilometer, 0.01 grams/kilometer, 3,180 grams/kilometer, and 0.026 grams/kilometer, respectively.

$$E_i = F_{ei} \times VKT \times V_i \times F_{ci} \quad (5)$$

E_i : emission

F_{ei} : emission factor

VKT : vehicle kilometer travelled (km)

V_i : vehicle volume

F_{ci} : fuel consumption (litre)

Research framework can be seen on Figure 2.

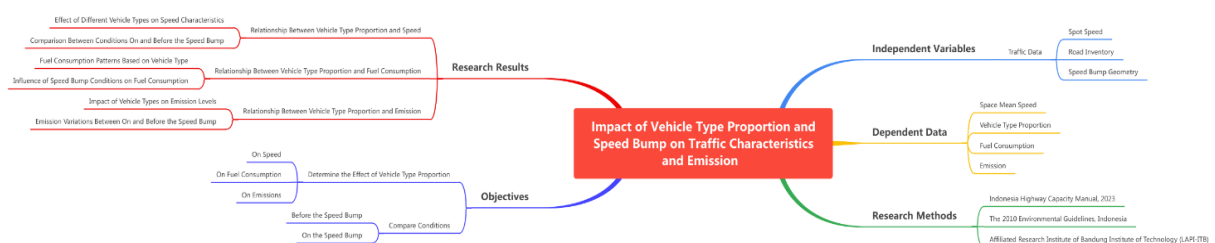


Figure 2 Research framework

3. Results

3.1 Statistic test

Paired t-test on this data to test the performance or response of the same subject under two different situations or stimuli. The t-test was used to determine whether there is a significant difference between vehicle speeds when passing over a speed bump and without a speed bump. A p-value less than 0.01 indicates that there is a significant difference between vehicle speeds before a speed bump and on a speed bump. The t-test results are shown in Table 1.

Table 1 Paired t-test

Components	N	Statistics	Median	df	p
Before speed bump	On speed bump	344	6.88	239	< .001

The average speed of motorcycles without speed bump is 33.234 km/hour and 20.529 km/hour is the average speed of passenger car. The sample standard deviation of passenger car speeds before speed bump is 30.572 km/hour and 33.289 km/hour for motorcycles. The average speed (50th percentile) of motorcycles and passenger car before speed bumps is 31.710 km/hour. The lower limit (15th percentile) of vehicle speed is 28.83 km/hour and 33.134 km/hour as the upper limit (85th percentile). Effective 85th percentile spot speed of motorcycles and passenger car before crossing speed bump can be seen on Figure 3(a).

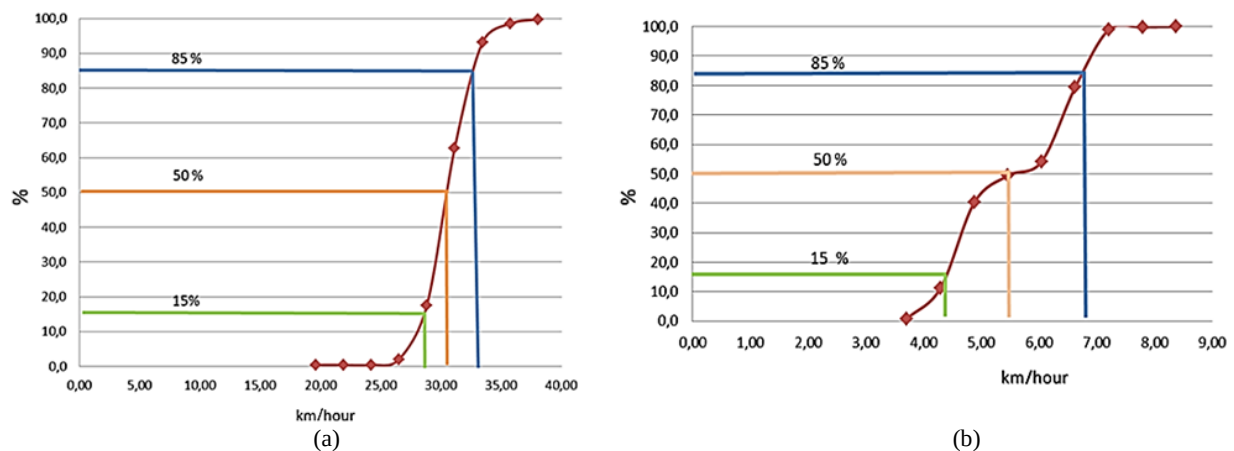


Figure 3 Motorcycles and passenger car's speed before crossing (a) and on speed bump (b)

The average speed (50th percentile) of motorcycles and passenger car on speed bump is 5.85 km/hour. The lower limit (15th percentile) of vehicle speed is 4.33 km/hour and the upper limit (85th percentile) is 6.92 km/hour. When compared with the minimum vehicle speed requirements on local roads, which is 15 km/hour. Speed humps were effective at significantly reducing vehicles speed for safe use by road users, from 85th speed percentile of 50–66 km/hour (30 metres upstream of the humps) to 85th speed percentile of 22–30 km/hour at the humps. The speed reduction was associated with hump height. The speed reduction was, however, transient as motorists accelerated at a higher rate after crossing the hump to 85th speed percentile of 41–56 km/hour, 30 metres downstream of the humps [25, 26]. Effective 85th percentile motorcycle and passenger car speed on speed bumps can be seen on Figure 3(b). The installation of speed bump effectively reduced vehicle speeds by 81.55% (reducing traffic speed according to its function and operational speed below 10 km/hour).

The presence of speed bumps can reduce vehicle speed. This result also supported with previous research [27, 28]. On local roads with a width of less than 5 meters, two-way traffic, and many houses, light vehicle travel at lower speeds than motorcycles to avoid conflicts with other vehicles and pedestrians. Therefore, when a passenger car goes over a speed bump, the vehicle's speed does not decrease significantly.

3.2 Traffic characteristics

The space mean speed of vehicles when passing over the speed bump experienced a maximum reduction of 82.639%, which occurred on Monday with a space mean speed of 5.536 km/hour. Meanwhile, the minimum reduction in space mean speed of 81.139% occurred on Tuesday with an SMS of 5.528 km/hour. The comparison of space mean speed of vehicle before speed bump and on speed bump locations is presented on Figure 4.

Low speeds and high vehicle volumes will increase density. This is evident at the point without a speed bump: the average space speed is 83% higher compared to when crossing a speed bump, thus density is at most 83% of the density at the speed bump point. When vehicles pass over a speed bump, the highest density occurs on Wednesday with a value of 12.765 vehicles/km/ln. The lowest density occurs on Tuesday, namely 11.329 vehicles/km/ln. Traffic density without speed bump is highest on Tuesday at 2.11 vehicles/km/ln and lowest on Wednesday at 2.061 vehicles/km/ln. The comparison of density without and with a speed bump is shown on Figure 5.

Relationship between speed and density (Figure 6), (green circle) without speed bumps, (red circle) with speed bumps. Free-flow speed is 37 km/hour and maximum density is 13 vehicles/km/ln. With the presence of a speed bump, speed decreases and density increases.

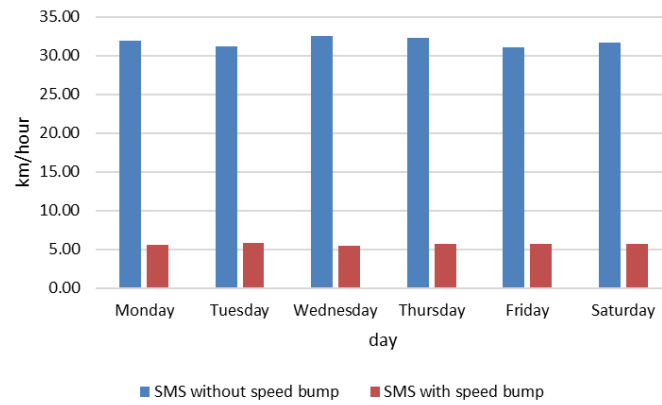


Figure 4 Space mean speed without and with speed bump

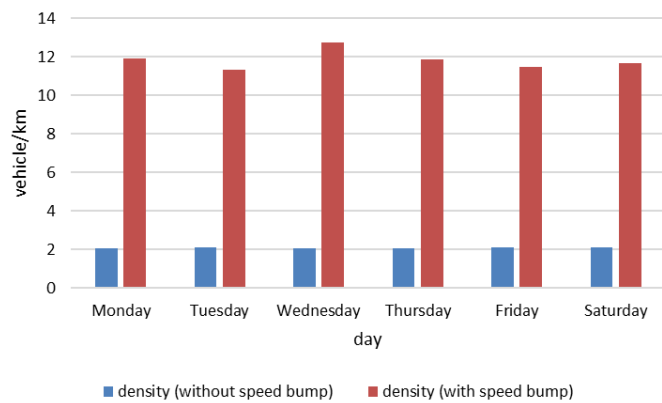


Figure 5 Density before and on speed bumps

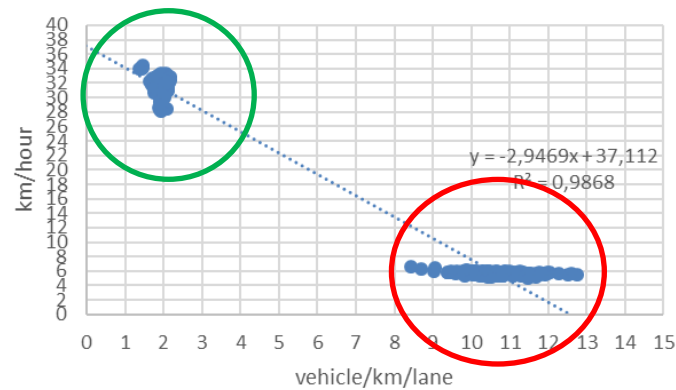


Figure 6 Relationship between space mean speed and density

3.3 Relationship between vehicle type proportion and speed

Regression equations are used to determine the relationship or influence between two parameters and to predict the value of the dependent parameter (Y) based on changes in the independent parameter. The proportion of motorcycles observed ranges from 44-100% of the total vehicles. The speed of motorcycle without speed bump starts from 30.571 km/hour to 65 km/hour. This speed range does not comply with local road geometric design regulation, which specify a speed of 15 km/hour. There is a decrease in motorcycle speed when crossing a speed bump, ranging from 5.865 km/hour to 8.002 km/hour. The elevation of speed bumps and the lower ground clearance of motorcycle compared to other type of motorized vehicles, makes motorcycle riders cautious when crossing speed bump. Such as diagonal technics for the front of motorcycle to prevent the rear tire does not receive a hard impact from the speed bump. The parts of the the motorcycle that are prone to getting stuck when going over speed bump are the low position of the exhaust, chassis, suspension, and engine cover. Relationship between motorcycle proportion and speed can be seen on Figure 7(a). The speed of passenger car decreases when crossing speed bump compared to segment before speed bump. The speed ranges on roads without speed bumps starts from 18.500 km/hour to 36.202 km/hour. The reduction in speed occurs when passenger car cross speed bump, ranging from 3.720 km/hour to 8.223 km/hour. The proportion of passenger car were 0 to 56% of the total vehicles. Relationship between passenger car proportion and speed can be seen on Figure 7(b).

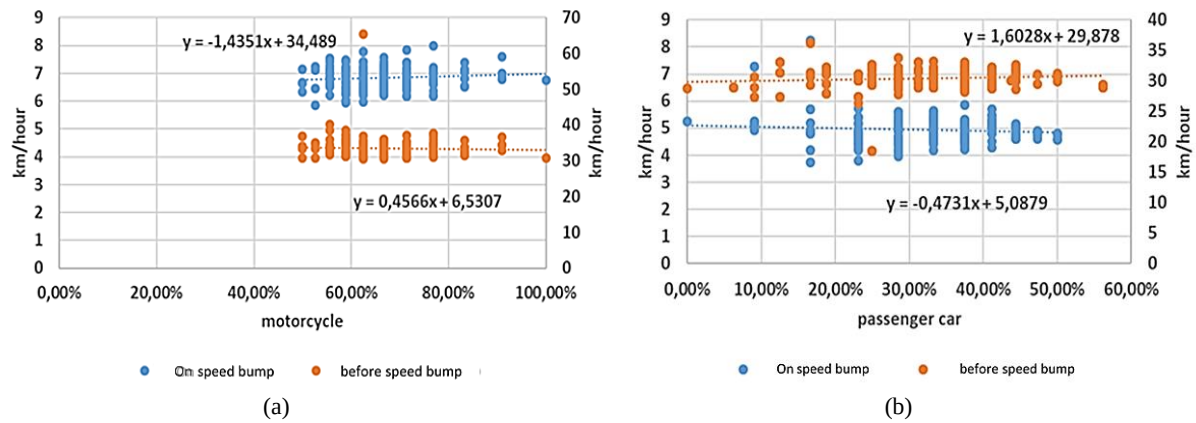


Figure 7 Relationship between speed and proportion of motorcycle (a) proportion of passenger car (b)

3.4 Relationship between proportion vehicle type to fuel consumption

The increasing proportion of passenger car will increase fuel consumption, conversely, the increasing proportion of motorcycles will decrease fuel consumption. Motorcycle fuel consumption when passing through a speed bump is 0.3768 litres/pcu to 0.3974 litres/pcu. Fuel consumption of passenger car ranges from 0 (passenger car proportion 0%) to 1.64189 litres/pcu. Passenger car with a high proportion traveling at almost constant and low speeds cause increased fuel consumption. Conversely, on the road segment before the speed bump, vehicle fuel consumption is lower: motorcycles and passenger cars, respectively 0.20065 litres/pcu – 0.46000 litres/pcu and 0 – 0.92166 litres/pcu. Other studies have revealed that fuel consumption comes from insufficient distance between speed bumps and speed bump geometrics that do not meet standards. [14]. Relationship between vehicle type proportion and fuel consumption on speed bump can be seen on Figure 8(a). On road segments before speed bumps, fuel consumption is influenced by the proportion of vehicle types. Relationship between vehicle type proportion and fuel consumption before speed bump can be seen on Figure 8(b).

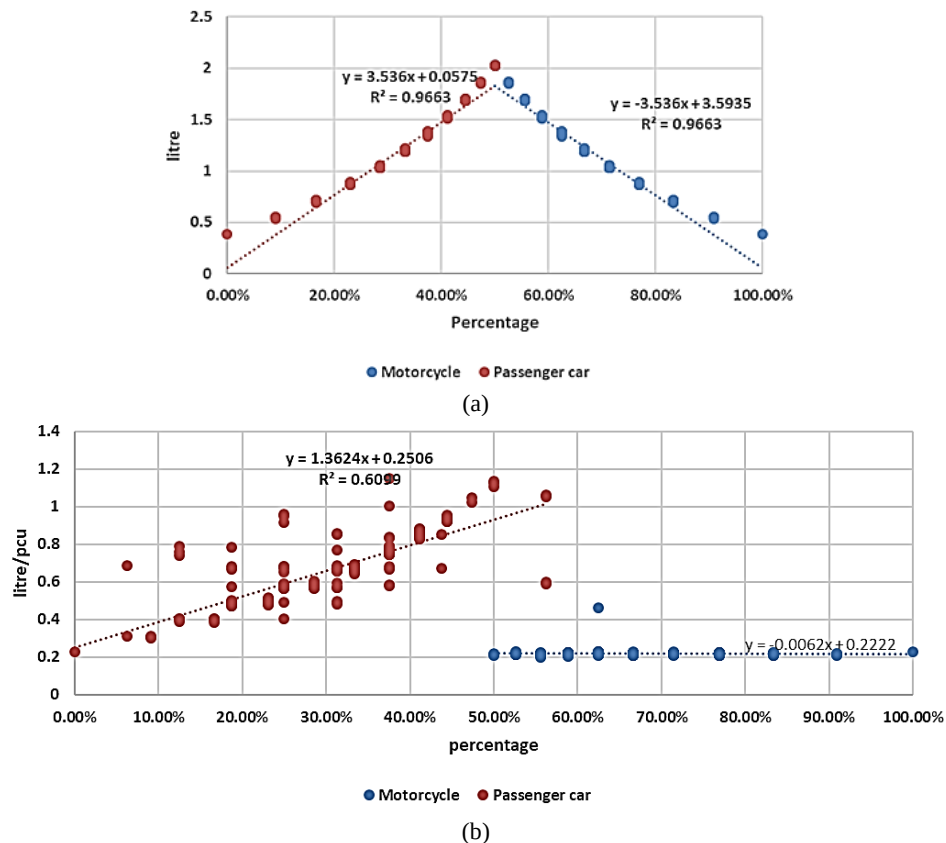


Figure 8 Relationship between vehicle type proportion and fuel consumption on speed bump (a), before speed bump (b)

3.5 Relationship between proportion of vehicle type to emission

Increasing the proportion of passenger car increases vehicle emissions, especially on speed bumps. The highest emissions due to proportion of passenger car on speed bump is 52,670.328 gram (0.0526 ton). Before speed bump condition, the highest proportion of passenger car causes emission is 8,903.863 gram (0.00890 ton). This is due to the decrease in vehicle speed to a near-constant level, which leads to increased fuel consumption and emissions.

In general, an increase in the proportion of motorcycles does not significantly raise emissions. Only when the motorcycle proportion is 62.5% on a road segment before a speed bump does emissions increase compared to lower or higher proportions than 62.5%.

Fuel consumption and emissions are better at a vehicle speed of 5.981 km/hour compared to speeds up to 6 km/hour. Relationship among emission, fuel consumption, and speed (on speed bump) can be seen on Figure 9(b).

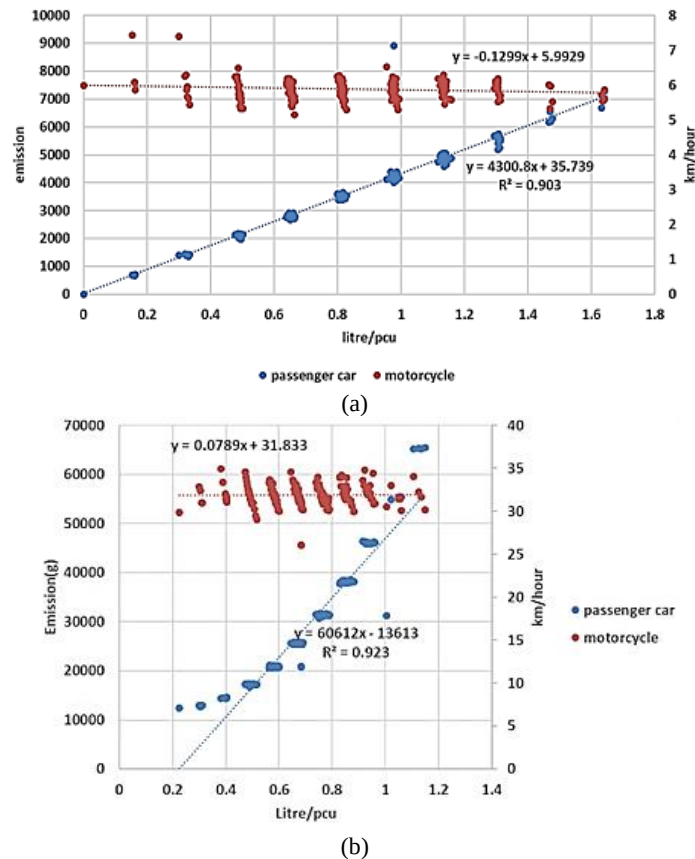


Figure 9 Relationship among emissions, fuel consumption, and speed (before speed bump) (a), on speed bump (b)

4. Discussion

Motorcycles tend to reduce their speed only when approaching speed bumps, unlike passenger car which slow down before reaching the speed bumps. Although the impact is not significant, increasing the proportion of motorcycles raises speed without speed bump. Conversely, motorcycle speeds decrease when crossing the speed bumps. This occurs because motorcycle movement on local road tend to form platoons, especially as the proportion of motorcycle increases. Previous research also stated that the decrease in motorcycle speed at speed bumps was up to 72.18% from the average normal speed of the road [29]. Additionally, the type of the land use conditions cause vehicle speeds to become relatively consistent. This supports the statement of previous study reveals that the “after” speeds were found to depend not only on the bump type and parameters but also on the direction of travel, vertical alignment of the street, parking location, and orientation of the parking space relative to the road axis [30]. Previous research also revealed that the deceleration rate on road segments with speed humps is influenced by vehicle speed before crossing the speed hump, the height of the speed hump, vehicle type, road width, distance from the speed hump to the intersection, and road gradient [31]. In addition, previous research has also revealed that the reduction in motorcycle speed at speed bumps is lower when the motorcycle carries a passenger [32].

Not all theories about applying speed bumps can improve rider safety, because based on the observation location, for the condition of motorcycles and passenger car that have modified clearance, it is necessary to be very careful through speed bumps. Low ground clearance compared to the vehicle manufacturer's standard clearance can cause the vehicle to get "stuck" on speed bumps and this can cause single accidents or accidents to other road users.

In contrast for motorcycles, as the proportion of passenger car increases, speed decreases on roads before speed bump. Conversely, speed increases as the proportion of passenger car increases when passing over speed bumps. On local roads without speed bumps, road width affects the speed of passenger car. Passenger car will travel at a slower speed than motorcycles to avoid conflicts with motorcycles moving in platoons. However, this condition causes passenger car to increase the speed when passing over speed bumps.

An increasing proportion of motorcycles reduces fuel consumption. Conversely, an increasing proportion of passenger car increases fuel consumption. This is due to the increased proportion of passenger car on roads less than 5 meters wide, reducing vehicle speeds. Meanwhile, motorcycles, being smaller than passenger car, can still maneuver better, even with the increased proportion. Therefore, lower speeds increase fuel consumption. The presence of a speed bump increases emissions from motorcycles by 83.12%. At a motorcycle proportion of 50%, emissions are at their highest. This is because when the motorcycle proportion decreases and passenger car increase, the maneuverability of motorcycles becomes limited.

The decrease in vehicle speed when crossing a speed bump causes increased fuel consumption. At high vehicle speeds, fuel consumption is low, and the emissions produced are also minimal. This is due to the pressure on the tires causing higher fuel consumption and emissions. Other research reveals that greater contact stress on the tires results in increased rolling resistance and fuel consumption [33]. Vehicle speeds below 6 km/hour result in the highest fuel consumption and emissions, because the vehicle undergoes

stop-and-go motion when passing over speed bumps. Fuel consumption reduction in vehicles can be achieved with an idle start–stop system [34]. In addition to affecting vehicles, speed bumps also affect pedestrians. At the observation location, it was seen that installing speed bumps would cause problems for pedestrians, due to the uneven road surface. Consequently, pedestrians need to be careful and not walk in a hurry. This is in accordance with the results of previous research, pedestrians and vehicle users agreed that poorly designed and constructed speed bumps posed a high risk to road users [35]. Table 2 shows impact of the proportion of motorcycles and passenger cars and speed bump on speed, fuel consumption, and emissions.

Table 2 Impact of the proportion of motorcycles and passenger cars and speed bump on speed, fuel consumption, and emissions

Condition	Variables	Motorcycle 44-100%	Passenger Car 0 - 56%
On speed bump	Speed	5.865 km/hour -8.002 km/hour	3.720 km/hour - 8.223 km/hour
	Fuel consumption	0.3768 litres/pcu - 0.3974 litres/pcu	0 - 1.64189 litres/pcu
	Emissions	0 - 0.0526 ton	
Before speed bump	Speed	30.571 km/hour - 65 km/hour	18,500 km/hour - 36.202 km/hour
	Fuel consumption	0.20065 litres/pcu – 0.46000 litres/pcu	0 – 0.92166 litres/pcu
	Emissions	0 - 0.00890 ton	

5. Conclusions

The reduction in vehicle speed when crossing a speed hump is 79.486% for motorcycles and 75.980% for passenger car. Finding of the this study is with the presence of a speed bump, there is a decrease in vehicle speed and an increase in fuel consumption, it leads to higher emissions. This effect is more noticeable when the proportion of passenger car increases compared to motorcycles. The limitation of this study is fuel consumption and emissions are estimates based on the model. Thus it is hoped that future research can investigate other variables that can generate a model for fuel consumption and emissions on speed bump.

6. Acknowledgements

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