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Assessing Multifaceted Effects of Speed Humps and Bumps: Travel Time, Safety, and Environmental Considerations

Sayed A. Shwaly [1], Amal El-Ayaat [2], Reem Osman [2*]

[1] *Public Works Engineering Department, Faculty of Engineering, Mansoura University, Mansoura, Egypt.*

[2] *Department of Civil Engineering, Faculty of Engineering, Kafr El-Sheikh University, Kafr El-Sheikh, Egypt.*

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Abstract

This study focuses on investigating the significant impacts of speed breakers on various parameters, including travel time delays, vehicle speeds, fuel consumption, pavement maintenance costs, and vehicular exhaust emissions. Field data was collected and analyzed to assess the effects of different types of traffic calming measures on these parameters. The findings provide valuable insights into the implications of speed breakers on road safety, environmental pollution, and overall road infrastructure management. The results reveal that the implementation of speed humps, speed bumps, and triple bumps effectively slows down vehicles, as evidenced by considerable reductions in the 85th percentile speeds. The reduction percentages were 41.65% for speed humps, 73.52% for speed bumps, and 86.27% for triple bumps. This indicates the effectiveness of these traffic calming measures in improving road safety by reducing vehicle speeds. However, the presence of speed breakers also leads to increased travel time delays. On average, traversing stretches with speed humps, speed bumps, and triple bumps resulted in delays of 9.31, 16.42, and 29.51 seconds, respectively. While the individual delay times may appear relatively short, the cumulative effect of multiple speed obstacles along a road needs to be considered. Another significant impact observed is the increased fuel consumption associated with speed breakers. The study found that for every 100 km of travel, motorcycles and passenger cars consumed approximately 12.07 km and 27.37 km of additional fuel, respectively, when the density of speed breakers was 1.33/km. This translates to a fuel consumption increase of 13.73% for motorcycles and 37.74% for passenger cars. Furthermore, the presence of speed humps was found to contribute to pavement deterioration, as indicated by decreased Pavement Condition Index (PCI) values. The study also revealed that sections with speed humps incurred significantly higher maintenance costs compared to sections without speed humps. The increase in maintenance cost ranged from 100 to 264% across different road sections, with higher traffic volumes leading to greater cost escalation. Additionally, the study confirms that lower vehicle speeds, particularly between 0-15 km/hr, are associated with higher emissions of pollutants, including carbon monoxide (CO) and other pollutants. This highlights the environmental implications of speed breakers and their contribution to urban air pollution.

Keywords: Speed Humps; Speed Bumps; Travel Time Delays; Fuel Consumption; Pavement Maintenance; Exhaust Emissions.

1. Introduction

Traffic calming, as defined by the Institute of Transportation Engineers (ITE) subcommittee on traffic calming, refers to “a set of measures that aim to mitigate the negative effects of motor vehicle use, influence driver behavior, and create safer conditions for non-motorized road users” [1]. These measures typically involve physical alterations to road infrastructure, such as the installation of speed humps, bumps, chicanes, raised crosswalks, or narrowed lanes [2, 3]. The primary objective of traffic calming is to encourage drivers to reduce their speed and be more attentive while driving

* Corresponding author: mhzs3827@gmail.com

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[4]. By implementing these physical interventions, traffic calming measures can help achieve several outcomes, including reduced speeds, reduced volumes, collision severity reduction, and improved safety for non-motorized users [5, 6].

Traffic calming measures (speed breakers) can be broadly categorized into two main types: horizontal deflection and vertical deflection [7, 8]. Horizontal deflection measures involve introducing obstacles or changes to the road alignment, forcing drivers to maneuver around them, and creating a perception of narrower roads. This can lead to a natural reduction in speeds. Examples of horizontal deflection measures include chicanes, which introduce alternating curves, and roundabouts, which regulate traffic flow and reduce speeds at intersections [9]. On the other hand, vertical deflection measures focus on creating a sudden change in the height of the road surface [10]. These physical alterations aim to slow down vehicles by introducing discomfort or jarring experiences when driving over the raised surfaces [11]. Speed control bumps and humps are two common types of vertical deflection traffic calming measures that aim to reduce vehicle speeds [12, 13]. They have raised sections that span the entire width of the lane, forcing drivers to reduce speed to navigate over them. While both serve the same purpose, there are some differences in their design and effectiveness. Speed bumps are typically shorter and wider than speed humps. They are often rounded in shape and span the entire width of the roadway. Speed humps, on the other hand, are longer and narrower. They have a more gradual slope and often cover only a portion of the roadway, allowing larger vehicles to straddle them without significant discomfort. Speed tables are similar but longer and wider, often placed at pedestrian crossings or areas with high pedestrian activity.

Indeed, various studies have reported the effectiveness of speed humps and speed bumps in reducing vehicle speeds and accidents [10, 13–17]. Hallmark et al. [16] and Zech et al. [17] found that speed reductions of approximately 18-20% could be achieved with the use of speed humps. However, it is important to note that the degree of speed reduction can vary depending on factors such as driver behavior and site-specific conditions. Generally, speed reduction is the primary goal of speed humps [18]. A review of the various studies indicates that the magnitude of speed reduction depends on a number of factors, including the design and spacing, the circumambient environment, and vehicle type.

However, the disadvantages of speed humps and speed bumps include increased journey times, passenger discomfort, potential vehicle damage, elevated maintenance costs, and adverse effects on fuel efficiency and environmental pollution [6, 13, 19-22]. A study conducted by Bunte [21] found that each speed hump caused an average delay of 10 seconds. When multiple speed humps are installed in series along a road, the cumulative delay can become significant. In a study by Kiran et al. [6], they observed a delay of 13.44 seconds per hump installed. These delays can inconvenience drivers and add to overall travel times, particularly on routes with numerous speed humps. In terms of environmental impact, the study of Kiran et al. [6] found that vehicles experienced a decrease in fuel efficiency while traversing a stretch with a high density of speed humps. The test car in the study lost approximately 40% of its fuel efficiency on a road with a speed hump density of 1.66 per kilometer. This decrease in fuel efficiency contributes to increased emissions and environmental pollution, as more fuel is burned to cover the same distance. Also, Obregón-Biosca [23] confirmed this trend.

The physical characteristics of these interventions can lead to increased emissions of pollutants such as carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NO_x), and particulate matter (PM). The increase in exhaust emissions arises from the speed adjustments required to navigate over these traffic calming measures. The process of accelerating and decelerating to traverse speed humps or speed bumps can result in higher levels of fuel consumption and emissions. Vehicles driven at low average speeds, which are often associated with frequent stops, starts, and speed variations, tend to produce the highest emissions. A study conducted by Ahn and Rakha [22] found that traversing a stretch with speed humps led to an increase in emissions compared to an untreated stretch. The study reported a 51% increase in HC emissions, a 44% increase in CO emissions, a 110% increase in NO_x emissions, and a 52% increase in CO_2 emissions. Also, Januševičius & Grubliauskas [24] conducted a study on the impact of speed bumps and humps on CO_2 and NOx emissions. They measured emissions at pedestrian crossings with speed humps installed and found that concentrations of CO_2 and NOx increased near these traffic calming measures. The concentrations of NOx showed increments from 1 to 8 times, while CO_2 concentrations increased from 1 to 5 times compared to baseline measurements. These findings suggest that speed bumps and humps may contribute to higher emissions of CO_2 and NOx. Further research is needed to understand the broader environmental implications. Hu et al. [25] and AlKheder [26] confirmed this harmful impact.

Various studies have examined the effects of speed humps on different aspects such as traffic volume, noise level, ambulance delay, and pavement condition. Research has confirmed the harmful impacts of speed humps on these factors [27-31]. Additionally, studies have highlighted the negative effect of speed humps and bumps on pavement conditions, leading to increased maintenance costs [11, 30, 31]. Studies, such as the research conducted by Zakaria et al. [11], have reported a reduction ranging between 15% and 22% in Pavement Condition Index (PCI) values due to the presence of speed humps. A decrease in PCI indicates a decline in the overall condition of the pavement, which may necessitate more frequent repairs and maintenance to ensure road safety and usability. These findings emphasize the potential drawbacks associated with speed humps, including their impact on traffic flow, noise, emergency response times, and pavement deterioration.

Nevertheless, information provided in previous studies is not always consistent. Generally, the lack of consistent information in previous studies on the effects of speed humps can be attributed to variations in study design, contextual factors, objectives, and confounding factors. Conducting further research with standardized methodologies and considering a wide range of contextual factors is necessary to address these inconsistencies and provide more reliable and comparable results. The novelty of this paper lies in its focus on examining the critical impacts of speed beakers, specifically addressing potential travel time delays, the impact on 85th percentile speed, increased fuel consumption, the additional maintenance cost of the pavement, and elevated vehicular exhaust emissions. While there have been previous studies that have touched upon these aspects individually, this paper aims to provide a comprehensive analysis of the economic implications of speed humps by considering these factors collectively. In addition, the information presented in previous studies is not always compatible. Results can vary depending on factors such as driver behavior, site-specific conditions, and the practical methodology used.

2. Research Methodology

To fulfill the research objectives, the research methodology was divided into five main parts, including travel time and delay studies, 85th percentile speed studies, fuel consumption, exhaust emission, and road maintenance costs, as shown in Figure 1. The collected data and outcomes will be fully explained in the following sections.

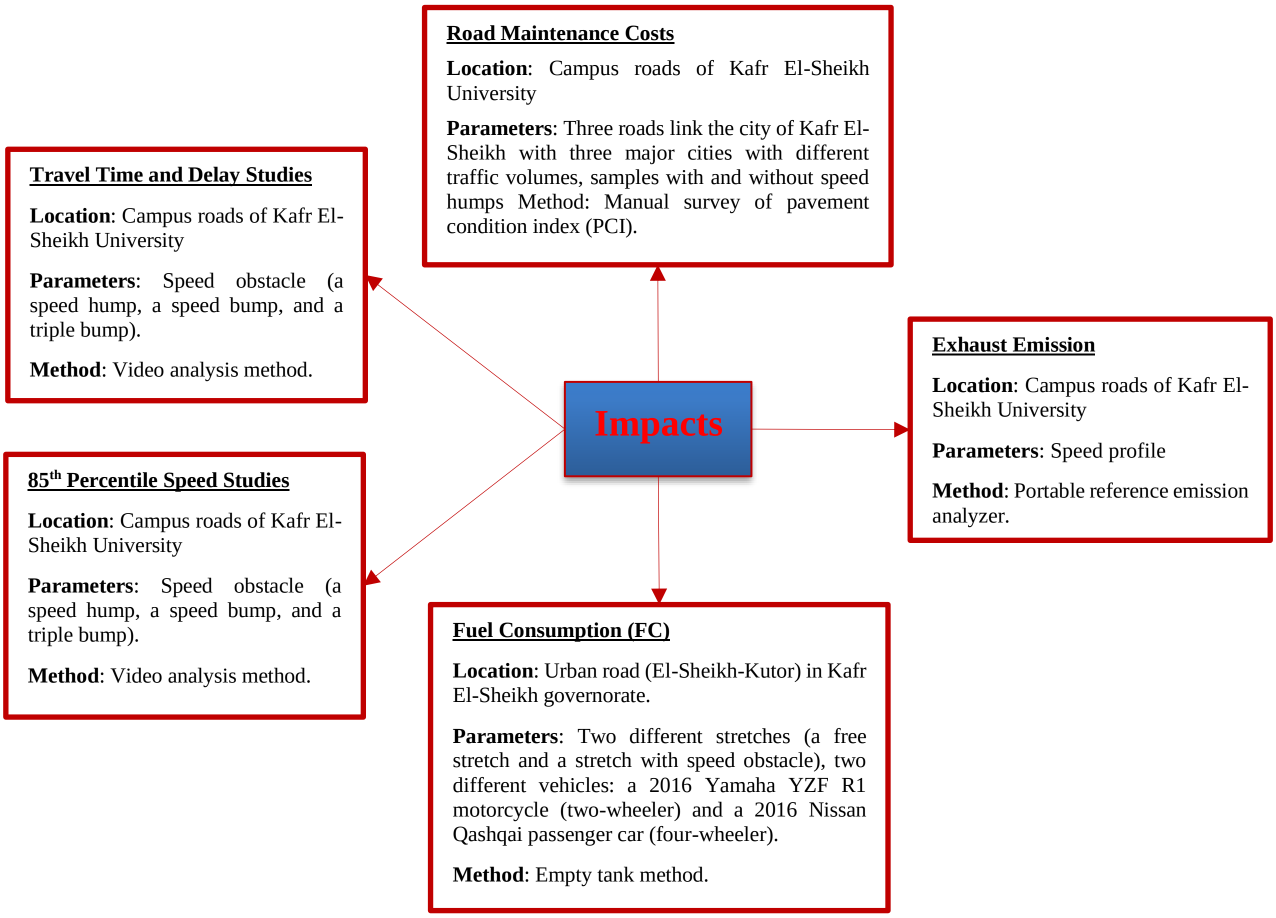


Figure 1. Summary of the main parts of the study

2.1. Study Area

The survey was conducted in Kafr El-Sheikh Governorate, situated in the northern region of the Arab Republic of Egypt. Spanning 100 kilometers along the Mediterranean coast, the governorate is positioned between the two branches of the Nile. The city of Kafr El-Sheikh serves as the capital of the governorate and is located approximately 134 kilometers north of Cairo, in the Nile Delta of Lower Egypt. Kafr El-Sheikh is the fourth largest city in the Nile Delta and is home to Kafr El-Sheikh University, which houses various educational and research institutions, as well as a hospital that attracts numerous students, employees, and patients on a daily basis. Most of the measurements for this study were conducted within the Kafrelsheikh University campus, a public university offering a diverse range of academic programs in fields such as medicine, dentistry, engineering, agriculture, veterinary medicine, pharmacy, commerce, arts, science, education, and physical education. The university campus is well-equipped with modern facilities, including classrooms, laboratories, libraries, sports facilities, student dormitories, and other infrastructure. Refer to Figure 2 for the locations of Kafr El Sheikh Governorate and Kafr El Sheikh University within the region.

(a) (b)

Figure 2. Locations of (a) Kafr El Sheikh Governorate and (b) Kafr El Sheikh University campus

3. Influence of Speed Humps/Bumps on Different Parameters

Several drawbacks of speed bumps and humps were hypothesized in the introductory section. There are a number of drawbacks to consider, such as the possibility of travel time delays, effects on the 85th percentile speed, higher fuel consumption (as shown by mileage studies), and elevated vehicular exhaust emissions.

3.1. Travel Time Delays

In a study conducted on the campus roads of Kafr El-Sheikh University, travel time and delay studies were conducted to assess the level of service in the selected sections. Reasons for choosing the roads on Kafr El-Sheikh University's campus for the research include the relatively low volume of traffic and the presence of strategically placed speed barriers. A variety of speed obstacles, including a speed hump, a speed bump, and a triple bump, were considered for the three separate lengths. Figure 3 depicts the road layout and the locations of the speed impediments; it also contains a description of these sections. Studies on travel time and delays were carried out employing the video analysis approach. Installing a camera as seen in Figure 4 allowed for data collection for a brief period of one hour when traffic flowed freely. Using the Logger Program software, spot speed was determined from the recorded movies for each station. Figure 3 shows that before beginning the video recording, it is essential to know the reference distance between two certain spots. These spots are predefined and marked on the pavement. When analyzing the data, this distance will be utilized to confirm the logger software's speed readings.

The vehicles' average travel time was utilized to determine the travel time for each segment. Each of the chosen stretches was structured so that, once through the speed breaker stretch, there would be a free stretch of the same length. The design made it possible to compare the travel timings of the speed breaker stretch to those of the subsequent free stretch in a straightforward manner. A reasonable approximation of the delays induced by the speed breaker installation was achieved by comparing the travel times on the free stretch and the stretch with the speed breaker. The average delay caused by the speed breaker is the difference in travel time between the two segments. To evaluate the delays caused by the placement of the speed breakers, this method offers a quantitative evaluation of the speed barriers' effect on travel time. The average delay (D_{avg}) can be calculated based on the travel times for the speed obstacle path (T_{ss}) and the free path (T_{fs}). The formula for average delay is (Equation 1):

$$Davg. = [T_{fs} - T_{ss}] \tag{1}$$

A comparison of the average travel time and average delay for various speed impediments is shown in Table 1 (a sample size of at least 50 and preferably 100 vehicles are usually obtained). Results showed that crossing the sections with a speed hump, a speed bump, and a triple bump each caused an average delay of 9.31, 16.42, and 29.51 seconds, respectively. While these individual delay times may appear relatively short, it is important to consider the cumulative effect when multiple speed humps are installed in series along a road. When speed humps are placed close to each other, the total delay experienced by vehicles can increase significantly. This can have implications for overall travel time and traffic flow along the road. Additionally, it is worth noting that the installation of traffic calming devices like speed humps and bumps can also impact public transport. Public transport vehicles, such as buses, may experience increased journey times due to the need to slow down and navigate over these road features. This can result in longer travel durations for commuters relying on public transportation. Generally, delays in travel time can lead to productivity loss for individuals and businesses. Kiran et al. [6] concluded that there were average delays of 13.44 seconds, 17.46 seconds, and 31.32 seconds when traversing stretches with different types of speed obstacles. Specifically, the delays occurred on a speed hump stretch (500m), a speed bump stretch (400m), and a double bump stretch (700m), respectively. The differences in the average delay times can be attributed to several factors, including the sample size, specific study conditions, driver behavior, and variations in the design and characteristics of the speed obstacles.

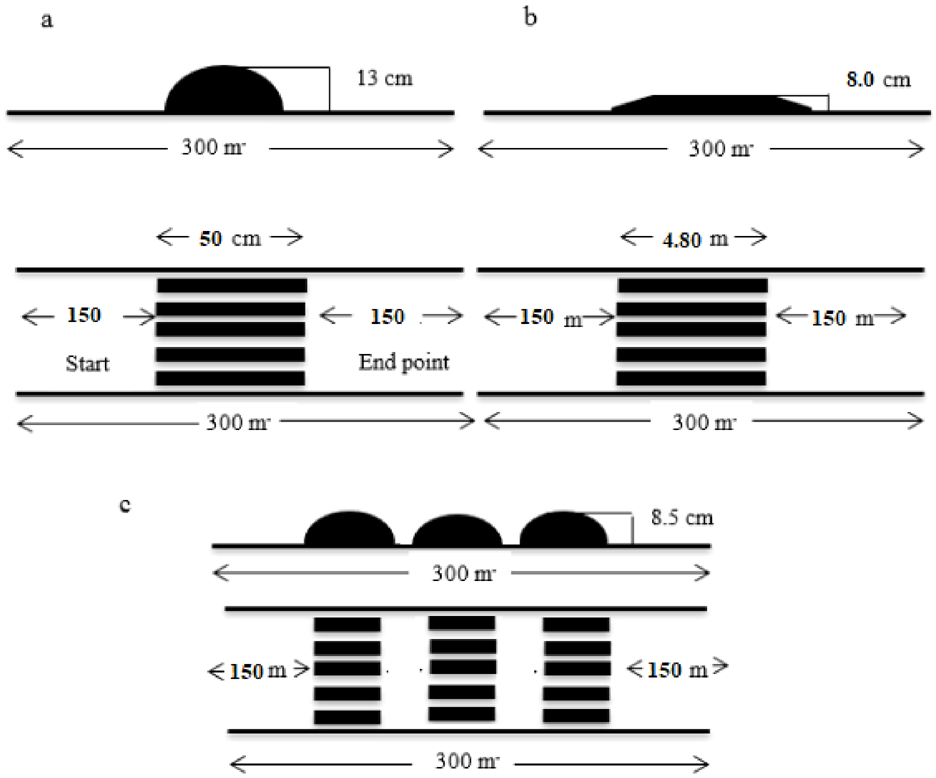


Figure 3. Visual representations of (a) speed bump; (b) speed hump; (c) triple speed bumps

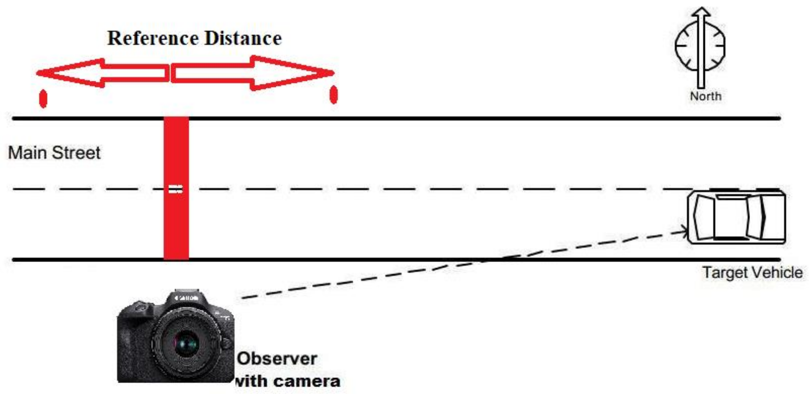


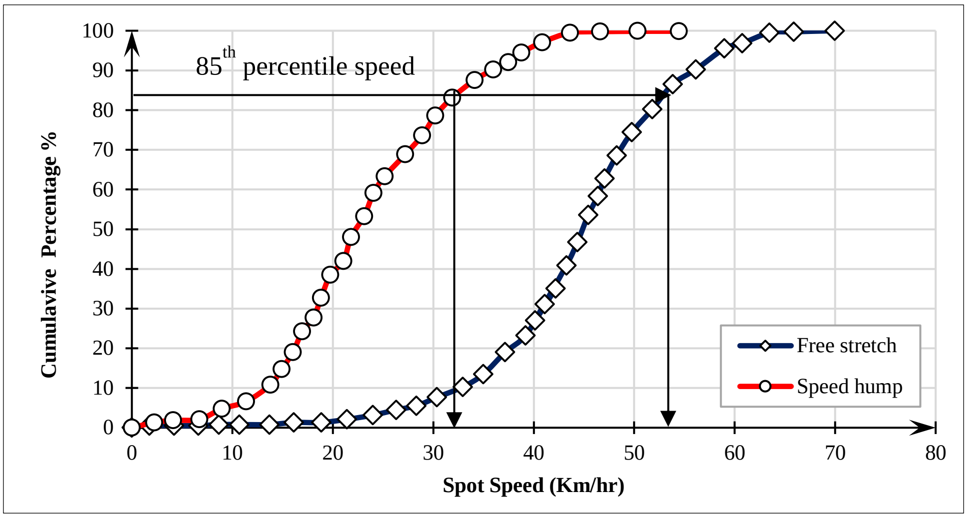
Figure 4. Setting up the digital camera at the site of the hump/bump

Table 1. Analyzing average travel times and delays

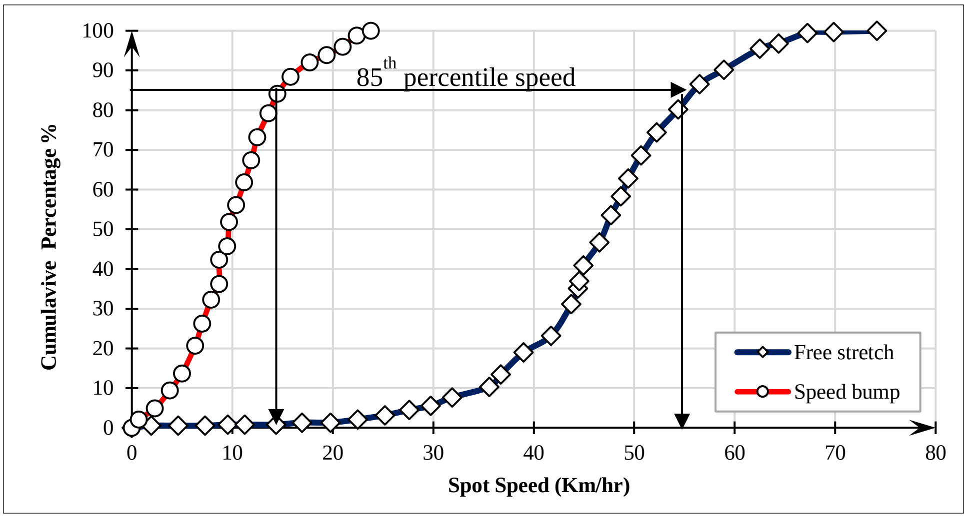
	Avg. Travel Time (sec)		Avg. Delay (sec)
	Speed Breaker Stretch	**Free Stretch**	
Bump	35.93	19.51	16.42
Hump	27.83	18.52	9.31
Triple bump	50.02	20.51	29.51

3.2. Impact on 85th Percentile Speed/Operating Speed

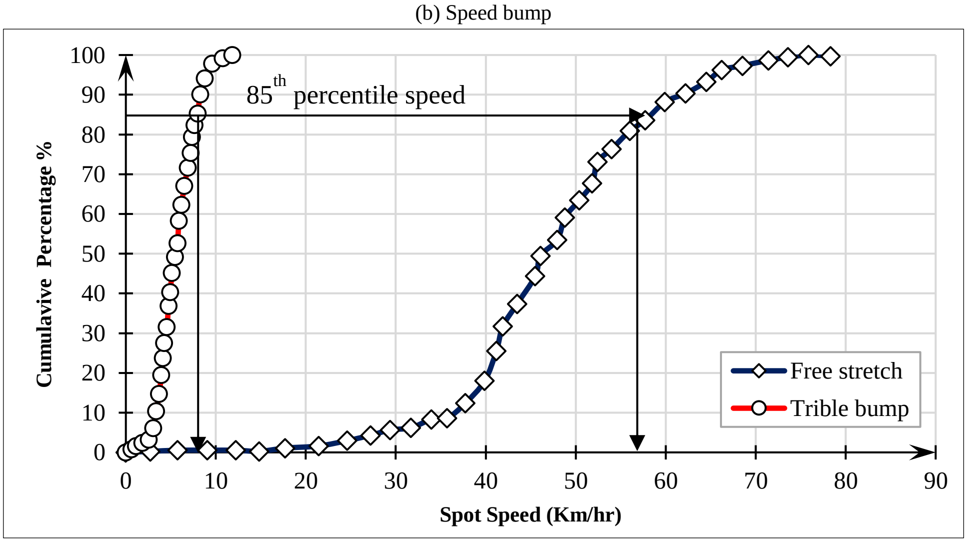
Research was carried out to assess the impact of speed bumps and humps on the 85th percentile speed. The approach used in the study included choosing a free stretch devoid of speed obstacles and stretches with various forms of speed obstacles, such as triple bumps, speed hump, and speed bumps. The 85th percentile speed is a common measure used in traffic studies to assess the prevailing speed at which 85% of the vehicles are traveling below or at that speed. The speeds were obtained in the vicinity of the selected speed humps' locations using Logger Program software. Figure 5 shows the 85th percentile speed curves for selected cases.



(a) Speed hump



(b) Speed bump



(c) Triple bump

Figure 5. Determination of 85th percentile speed for passenger cars

The 85th percentile speeds on the stretches with these traffic calming measures were significantly lower compared to the free stretch without any obstacles. The 85th percentile speeds (calculated from the above graphs) were reduced from 53.85 Km/hr on free stretch to 31.42 Km/hr in case of a speed hump, from 56.32 Km/hr on free stretch to 14.91 Km/hr for a speed bump and from 58.15 Km/hr on free stretch to 7.98 Km/hr for triple bumps (Figure 6). The 85th percentile speed decreased by 41.65% for a speed hump, 73.52% for a speed bump, and 86.27% for triple bumps (Figure 6). These reductions indicate that the traffic calming measures were effective in slowing down vehicles and improving road safety. However, it is important to consider the potential trade-off between reduced speeds and any economic impacts, such as increased travel time or costs.

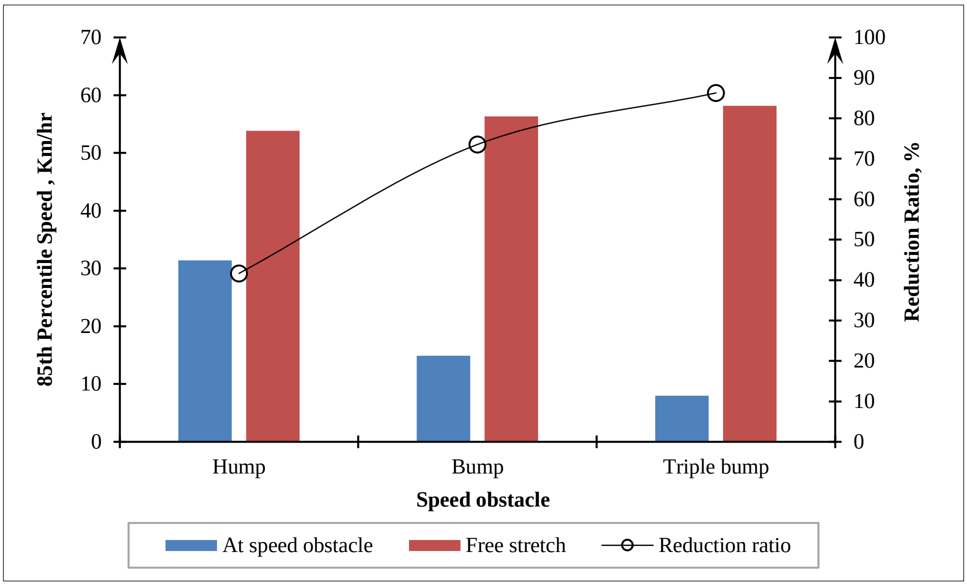


Figure 6. Effect of speed obstacle type on the 85th percentile speed

3.3. Effect on Fuel Consumption (FC)

Fuel Consumption (FC) or mileage is indeed a measure of the distance a vehicle can travel per unit of fuel, and it can be expressed in various units such as kilometers per liter (KM/L) or miles per liter. The maximum mileage a vehicle can achieve is typically influenced by several factors. The power of the engine plays a role, as a more powerful engine may consume more fuel. The thermal efficiency of the engine, which refers to how effectively it converts the chemical energy of fuel into mechanical output, can also impact mileage. The overall design of the engine, including factors such as its efficiency and aerodynamics, can affect fuel efficiency as well. Other factors that can influence mileage include the usage patterns of the vehicle, such as driving conditions (e.g., city driving versus highway driving), driving style (e.g., aggressive driving with frequent acceleration and braking), and vehicle maintenance. The age and condition of the vehicle can also play a role, as older or poorly maintained vehicles may have reduced fuel efficiency. Additionally, external factors such as the condition of the roads, traffic conditions, and the presence of speed humps or bumps can affect fuel consumption. This study aims to determine the impact of speed humps on fuel consumption by examining the loss in travel distance caused by traversing these obstacles. The study used the empty tank method, where the fuel tank is completely emptied, a predetermined quantity of fuel is added, and the vehicle is driven until the fuel is exhausted. This allows researchers to measure the fuel consumption under specific conditions. Generally, the FC can be given by the following equation (Equation 2):

$$FC = (\text{Travel distance}/\text{Fuel consumed}) \tag{2}$$

In the present study, two different stretches were selected: a free stretch and a stretch with a speed obstacle. The study involved two different vehicles: a 2016 Yamaha YZF R1 motorcycle (two-wheeler) and a 2016 Nissan Qashqai passenger car (four-wheeler). To measure the mileage for each vehicle on the free stretch, 6.0 trials were conducted for each vehicle type. During these trials, the vehicles were driven on the free stretch while approximately maintaining an average speed of 50 km/hr. The vehicles were driven on the free stretch until the fuel was exhausted. The distance covered during each trial was recorded, and the mileage was calculated by dividing the distance traveled by the amount of fuel consumed. By analyzing the data obtained from these trials, the average mileage for the motorcycle and the passenger car on the free stretch at an average speed of 50 km/hr was recorded in Table 2. The average FC in the free stretch was found to be 48.27 km/l for the motorcycle and 12.59 km/l for the passenger car.

Table 2. Fuel consumption data for free stretch

No.	Motorcycle			Passenger car		
	Distance	Fuel	Mileage	Distance	Fuel	Mileage
	km	ml	km/l	km	ml	km/l
1	3.91	80.00	48.93	10.00	800.00	12.50
2	4.42	90.00	49.08	11.20	900.00	12.44
3	4.80	100.00	47.98	12.51	1000.00	12.51
4	5.27	110.00	47.93	14.05	1100.00	12.77
5	5.74	120.00	47.82	15.42	1200.00	12.85
6	6.22	130.00	47.87	16.21	1300.00	12.47
Average	5.06	105.00	48.27	13.23	1050.00	12.59

In the stretch with speed humps, the speed hump density was determined to be 1.33 per kilometer, which means there was approximately one-speed hump for every 750 meters along the stretch. The specific data obtained from these trials, shown in Table 3, include the distance covered by each vehicle on the speed breaker stretches and the corresponding fuel consumption. The average FC in speed breaker stretch was found to be 42.44 km/l for the motorcycle and 9.14 km/l for the passenger car.

Table 3. Fuel consumption data for stretch with speed humps

Trail	Motorcycle			Passenger car		
	Distance (km)	Fuel (ml)	Mileage (km/l)	Distance (km)	Fuel (ml)	Mileage (km/l)
1	3.55	80.00	44.38	7.25	800.00	9.06
2	3.84	90.00	42.67	8.15	900.00	9.06
3	4.22	100.00	42.20	9.14	1000.00	9.14
4	4.44	110.00	40.36	9.75	1100.00	8.86
5	5.20	120.00	43.33	11.21	1200.00	9.34
6	5.42	130.00	41.69	12.22	1300.00	9.40
Average	4.45	105.00	42.44	9.62	1050.00	9.14

The loss in fuel, expressed as kilometers per 100 kilometers, can be obtained using the formula:

$$\text{Loss in fuel } (F_w) = 100 \times (1.0 - [FC_{ss} / FC_{fs}]) \tag{3}$$

where FC_{ss} represents the FC on the speed breaker stretch (in kilometers per liter or miles per liter), FC_{fs} represents the mileage on the free stretch (in kilometers per liter or miles per liter). Accordingly, the fuel loses approximately 12.07, and 27.37 km of fuel for every 100 km of travel when the density of speed breakers is 1.33/km for the motorcycle and passenger car respectively.

To calculate the additional fuel consumption caused by the speed breaker stretch, the following formula can be employed:

$$\text{Additional fuel consumption} = [((100/FC_{ss})-(100/FC_{fs}))/ (100/FC_{fs})] \times 100 \tag{4}$$

Figure 7 presents the loss in fuel and additional fuel consumption for two types of vehicles. The additional fuel consumption was found to be 13.73, and 37.74% for motorcycles and passenger cars respectively.

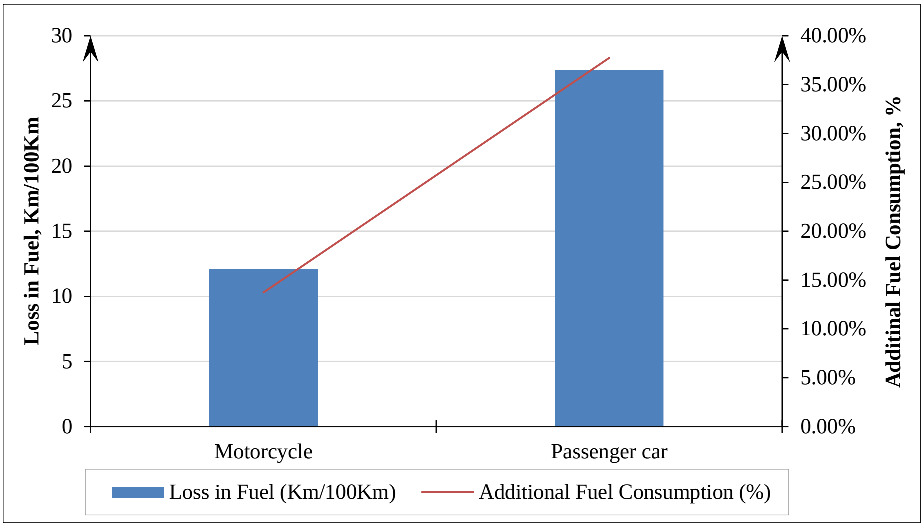


Figure 7. Supplementary fuel consumption and fuel loss

3.4. Effect on Road Maintenance Costs

Three main cities that are part of the Kafr El-Sheikh Governorate, Egypt, are connected to the city of Kafr El-Sheikh via three routes, which were selected for PCI calculations. Several characteristics are represented by these roads, such as population density (densely populated areas vs. sparsely populated areas), road type (divided vs. undivided), and traffic volume. Table 4 displays the details of these roadways. Noting that this portion of the research was an extension of the investigation carried out in the year 2019 by Zakaria et al. [10].

Table 4. Description of chosen roadways

Road Name	Length (km)	Width (m)	Geometric Type	No. of lanes	Type
Kafr El-Sheikh - Biyala	24	7.1	Undivided	2	Rural
Kafr El- Sheikh - Sidi Salem		7.70			
Kafr El-Sheikh - Baltim	20	7.5/Dir.	Divided	4	

3.4.1. Traffic Volume

The days of Sunday and Thursday were chosen for the traffic counts because, being the beginning and end of the week, respectively, are predicted to have increased traffic congestion. The morning hours (8:00 am to 10:00 am) and the evening hours (3:30 pm to 5:00 pm) are usually the busiest. The PHV is the basis for calculating the daily traffic volume. The level of traffic on a road has a major influence on its overall condition. The roadways included in the investigation have limited access to traffic statistics. Figure 8 displays sample data for each vehicle class during the afternoon rush hour on the Kafr El-Sheikh-Biala route. The proportion of heavy trucks is also included in the figure. Table 5 provides a synopsis of the traffic metrics taken on each route.

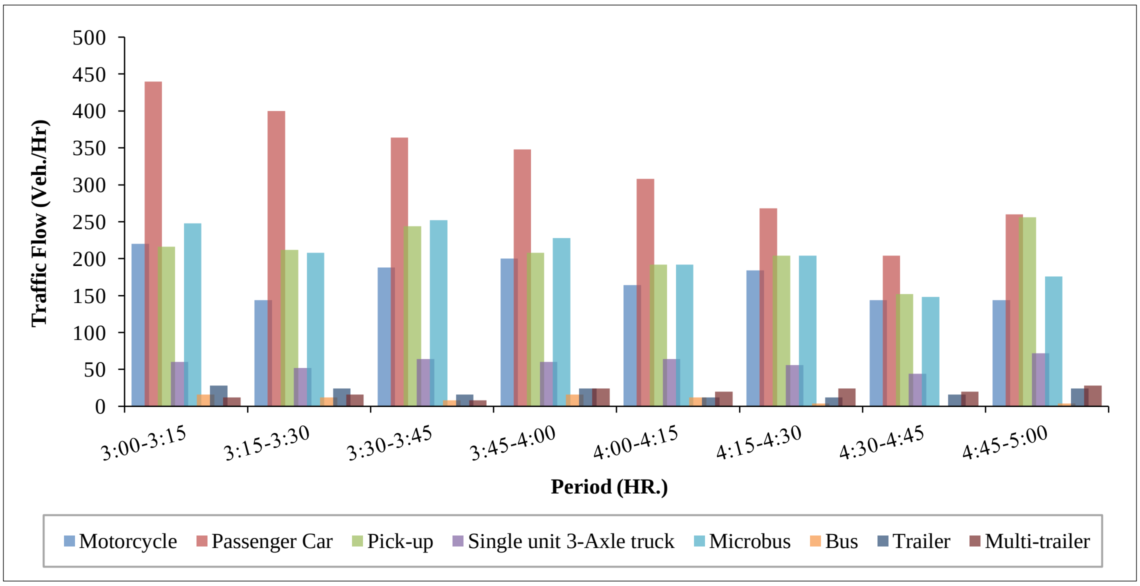


Figure 8. Registration of vehicles on Kafr El-Sheikh-Biala road from 3:00 to 5:00 pm

Table 5. The study's findings on traffic volumes

	Kafr El-Sheikh - Sidi Salem	Kafr El-Sheikh - Biyala	Kafr El-Sheikh - Baltim
Peak hour traffic volume, (veh/hr) am	1518	1381	1523
Peak hour traffic volume, (veh/hr) pm	1422	1421	1639
K-factor		0.15	
Daily Traffic (veh/day)	10144	9611	11100/direction

3.4.2. Pavement Condition Survey

The chosen roadways were surveyed manually. Parts of each route were used as samples. In order to determine the amount of each sort of distress, the authors visually examined the pavement sample units and determined its type and degree. As part of the sample inspection process, the inspector documented the types and intensity of distress on an inspection sheet. Following the recording of inspection data on the inspection sheets, an assessment of surface distress was computed using a numerical rating system ranging from 0 to 100. Lastly, the PCIs were computed in the same way as previously indicated. The computation was executed with the help of the Micro PAVER program [32]. As illustrated in Table 6, the pavement condition rating provides a description of the pavement's state based on the PCI value, which ranges from excellent to failed. Figures 9 to 11 show the locations of the examined samples of the selected roads.

Table 6. Various pavement condition indices and the state of pavement [33]

Pavement's State	PCI	
	Upper limit	Lower limit
Excellent	100	86
Very Good	85	71
Good	70	56
Fair	55	41
Poor	40	24
Very Poor	25	11
Failed	10	0

Figure 9. The GPS coordinates of the chosen roadway samples along the Biyala-Kafr El-Sheikh route

Figure 10. The GPS coordinates of the chosen roadway samples along the Sidi Salem-Kafr El-Sheikh route

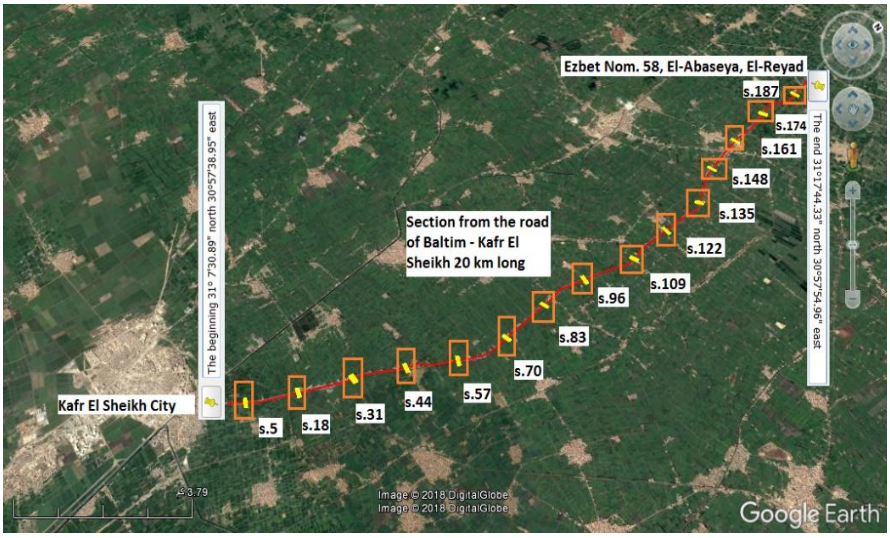


Figure 11. The GPS coordinates of the chosen roadway samples along the Kafr El-Sheikh-Baltim route

There are four degrees of analysis. Level one consists of a road condition evaluation that does not take speed humps into account. The second stage involves evaluating the road's surface only in the areas that include speed humps. Level three involves testing how speed humps affect the values of PCI. Level four involves using Figure 12 to establish a correlation between the road's pavement index and the anticipated cost of repair. By comparing the average condition of segments with and without speed humps along the same road, this effect can be ascertained.

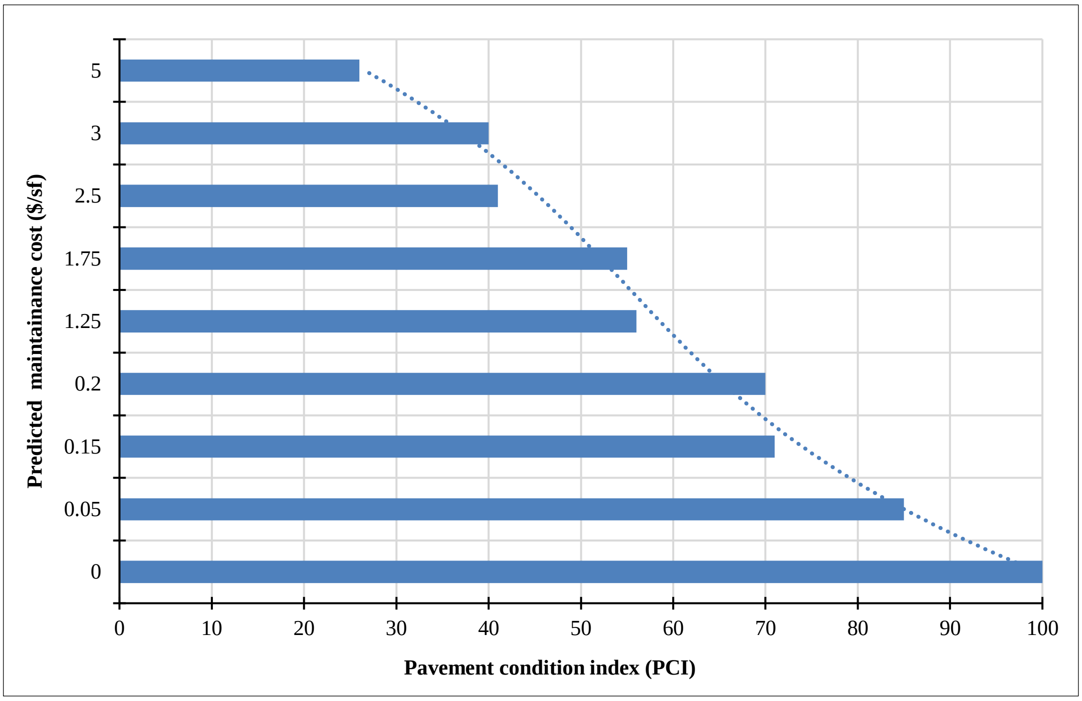


Figure 12. Relation between PCI and predicted maintenance cost according to Naimi & Karimi [34]

Tables 7 and 8 show details of selected samples on Kafr El-Sheikh- Sidi Salem road. The average value of PCI of all samples is 62.33%, and 44.9%, which means that the pavement condition is good and fair for sections without and with speed humps respectively. Generally, the values of PCI are reduced in the case of sections with speed humps from other sections. Also, the average predicted total maintenance cost was increased in the presence of speed humps by 124% compared to sections without speed humps. Where the approximate maintenance cost per unit area was 10.96$, and 27.1$ for sections without and with speed humps.

Table 7. Details of Sections without Speed Humps on Kafr El-Sheikh- Sidi Salem

No.	Sample ID.	Sample unit area, m^2	PCI	Rating	Approx. cost per unit area, $	Total cost/section, $
1	2	890	71	Very good	5.00	4453.682
2	18	820	59	Good	12.36	10140.65
3	34	790	48	Fair	22.65	17898.13
4	50	810	70	Good	5.46	4425.64
5	66	775	50	Fair	20.53	15913.24
6	82	805	69	Good	5.95	4790.84
7	98	790	72	Very good	4.57	3612.27
8	114	880	67	Good	7.01	6169.26
9	130	750	48	Fair	22.65	16991.89
10	146	750	55	Fair	15.71	11787.28
11	162	790	72	Very good	4.57	3612.27
12	178	810	68	Good	6.46	5238.23
13	194	790	55	Fair	15.71	12415.93
14	210	750	65	Good	8.18	6136.23
15	226	775	66	Good	7.58	5876.121
Average PCI of sections			62.33	Good	10.96	8630.78

Table 8. Details of Sections with Speed Humps on Kafr El-Sheikh- Sidi Salem

No.	Sample ID.	Sample unit area, m^2	PCI	Rating	Approx. cost per unit area, $	Total cost/section, $
1	H1	750	48	Fair	22.66	16991.89
2	H2	750	50	Fair	20.53	15399.91
3	H3	780	29	Poor	48.40	37755.26
4	H4	810	39	Poor	33.59	27210.37
5	H5	800	49	Fair	21.58	17264.43
6	H6	790	47	Fair	23.76	18769.73
7	H7	790	52	Fair	18.52	14632.79
8	H8	750	43	Fair	28.45	21339.16
9	H9	790	31	Poor	45.22	35722.27
10	H10	740	62	Good	10.15	7509.67
11	H11	750	39	Good	33.59	25194.79
12	H12	790	51	Fair	19.51	15415.96
13	H13	750	45	Fair	26.05	19537.29
14	H14	750	51	Fair	19.51	14635.41
15	H15	750	38	Poor	34.95	26211.17
Average of sections			44.9	Fair	27.10	20906.01

Tables 9 and 10 show details of selected samples on Kafr El-Sheikh-Biala Road. The average value of PCI of all samples is 56.33%, and 41.67% which means that the pavement condition is good and fair for sections without and with speed humps respectively. Generally, the values of PCI are reduced in the case of sections with speed humps from other sections. Also, the average predicted total maintenance cost was increased in the presence of speed humps by 100% compared to sections without speed humps. Where the approximate maintenance cost per unit area was 15.14$, and 31.24$ for sections without and with speed humps.

Table 9. Details of Sections without Speed Humps on Kafr El-Sheikh- Biala Road

No.	Sample ID.	Sample unit area, m^2	PCI	Rating	Approx. cost per unit area, $	Total cost/section, $
1	5	850	59	Good	12.36	10511.65
2	21	840	55	Fair	15.71	13201.75
3	37	810	46	Fair	24.89	20161.26
4	53	850	61	Good	10.85	9230.744
5	69	790	53	Fair	17.55	13871.73
6	85	800	61	Good	10.85	8687.759
7	101	840	64	Good	8.80	7399.708
8	117	850	52	Fair	18.52	15744.14
9	133	790	69	Good	5.95	4701.575
10	149	810	44	Fair	27.27	22061.95
11	165	840	55	Fair	15.71	13201.75
12	181	850	59	Good	12.36	10511.65
13	197	790	49	Fair	21.58	17048.63
14	213	850	59	Good	12.36	10511.65
15	229	800	59	Good	12.36	9893.316
Average of sections			56.33	Good	15.14	12449.28

Table 10. Details of Sections with Speed Humps on Kafr El-Sheikh- Biala Road

No.	Sample ID.	Sample unit area, m^2	PCI	Rating	Approx. cost per unit area, $	Total cost/section, $
1	H1	810	41	Fair	30.97	25083.00
2	H2	750	39	Poor	33.59	25194.79
3	H3	780	28	Poor	50.04	39030.59
4	H4	810	37	Poor	36.33	29428.43
5	H5	800	48	Fair	22.66	18124.69
6	H6	790	42	Fair	29.70	23459.40
7	H7	790	47	Fair	23.76	18769.73
8	H8	800	44	Fair	27.24	21789.58
9	H9	790	31	Poor	45.22	35722.27
10	H10	840	53	Fair	17.56	14749.69
11	H11	840	33	Poor	42.14	35400.87
12	H12	850	55	Fair	15.72	13358.91
13	H13	840	38	Poor	34.95	29356.51
14	H14	750	51	Fair	19.51	14635.41
15	H15	750	35	Poor	39.18	29386.25
Average of sections			41.67	Fair	31.24	24899.34

Tables 11 and 12 show details of selected samples on Kafr El-Sheikh-Baltim Road. The average value of PCI of all samples is 71.93%, and 49.60% which means that the pavement condition is very good and fair for sections without and with speed humps respectively. Generally, the values of PCI are reduced in the case of sections with speed humps from other sections. Also, the average predicted total maintenance cost was increased in the presence of speed humps by 264% compared to the section without speed humps. Where the approximate maintenance cost per unit area was 6.0$, and 22.21$ for sections without and with speed humps. Figure 13 shows the reduction in PCI values and increase ratios of maintenance costs due to humps

Table 11. PCI Values of the Sections without Speed Humps on Kafr El-Sheikh- Baltim Road

No.	Sample ID.	Direction	Sample unit area, m^2	PCI	Rating	Approx. cost per unit area, $	Total cost/section, $
1	5	Going Dir.	850	71	Very Good	5.00	4253.52
		Coming Dir.	830	76	Very Good	3.13	2594.44
2	20	Going Dir.	840	61	Good	10.86	9122.15
		Coming Dir.	810	74	Very Good	3.79	3072.49
3	35	Going Dir.	810	50	Fair	20.53	16631.90
		Coming Dir.	850	80	Very Good	2.13	1807.90
4	50	Going Dir.	850	72	Very Good	4.57	3886.63
		Coming Dir.	850	77	Very Good	2.83	2409.01
5	65	Going Dir.	790	53	Fair	17.56	13871.73
		Coming Dir.	850	72	Very Good	4.57	3886.63
6	80	Going Dir.	800	70	Very Good	5.46	4371.00
		Coming Dir.	800	84	Very Good	1.58	1260.67
7	95	Going Dir.	840	71	Very Good	5.00	4203.48
		Coming Dir.	800	83	Very Good	1.67	1337.31
8	110	Going Dir.	850	61	Good	10.86	9230.74
		Coming Dir.	840	77	Very Good	2.83	2380.67
9	125	Going Dir.	790	70	Very Good	5.46	4316.37
		Coming Dir.	840	83	Very Good	1.67	1404.17
10	140	Going Dir.	810	62	Good	10.15	8220.05
		Coming Dir.	810	83	Very Good	1.67	1354.02
11	155	Going Dir.	840	72	Very Good	4.57	3840.90
		Coming Dir.	810	74	Very Good	3.79	3072.49
12	170	Going Dir.	850	69	Good	5.95	5058.66
		Coming Dir.	790	86	Very Good	1.47	1159.87
13	185	Going Dir.	790	55	Fair	15.72	12415.93
		Coming Dir.	790	76	Very Good	3.13	2469.41
14	200	Going Dir.	850	59	Good	12.37	10511.65
		Coming Dir.	840	93	Excellent	1.97	1657.34
15	215	Going Dir.	800	76	Good	3.13	2500.67
		Coming Dir.	840	68	Good	6.47	5432.24
Average Values of Samples				71.93	Very Good	6.00	4924.47

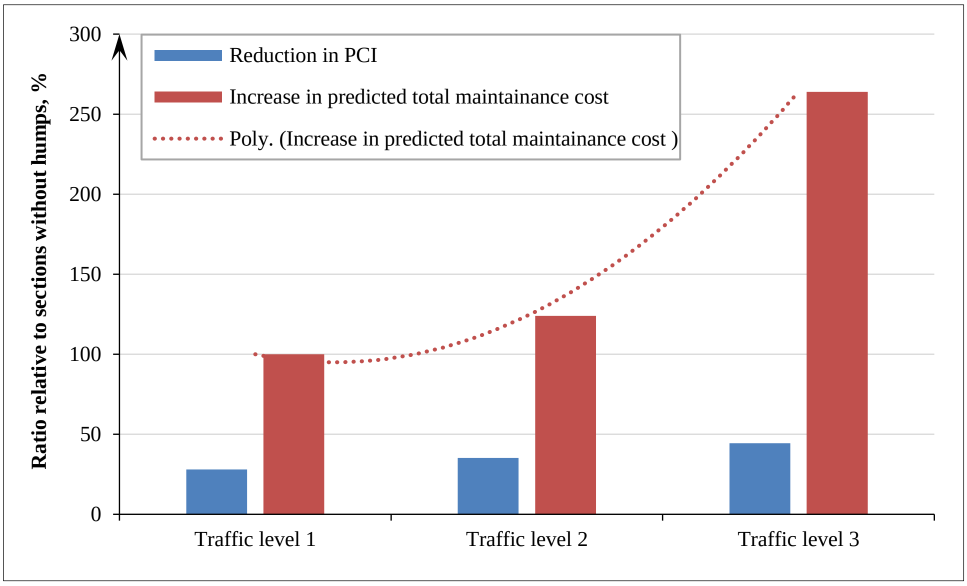


Figure 13. Reduction in PCI values and increase ratios of maintenance costs due to humps

Table 12. PCI Values of the Sections with Speed Humps on Kafr El-Sheikh- Baltim Road

No.	Sample No.	Direction	Sample unit area, m^2	PCI	Rating	Approx. cost per unit area, $	Total cost/section, $
1.00	H1	Going Dir.	810.00	41.00	Fair	30.97	25083.00
2.00	H2	Going Dir.	750.00	42.00	Fair	29.70	22271.59
3.00	H3	Going Dir.	780.00	29.00	Poor	48.40	37755.26
4.00	H4	Going Dir.	810.00	39.00	Poor	33.59	27210.37
5.00	H5	Going Dir.	800.00	49.00	Fair	21.58	17264.43
6.00	H6	Going Dir.	790.00	61.00	Good	10.86	8579.16
7.00	H7	Going Dir.	790.00	52.00	Fair	18.52	14632.79
8.00	H8	Going Dir.	800.00	44.00	Fair	27.24	21789.58
9.00	H9	Going Dir.	790.00	61.00	Good	10.86	8579.16
10.00	H10	Going Dir.	840.00	53.00	Fair	17.56	14749.69
11.00	H11	Going Dir.	840.00	49.00	Fair	21.58	18127.66
12.00	H12	Going Dir.	850.00	55.00	Fair	15.72	13358.91
13.00	H13	Going Dir.	840.00	38.00	Poor	34.95	29356.51
14.00	H14	Going Dir.	750.00	51.00	Fair	19.51	14635.41
15.00	H15	Going Dir.	750.00	35.00	Poor	39.18	29386.25
16.00	H16	Coming Dir.	840.00	49.00	Fair	21.58	18127.66
17.00	H17	Coming Dir.	840.00	57.00	Good	13.99	11747.85
18.00	H18	Coming Dir.	820.00	53.00	Fair	17.56	14398.50
19.00	H19	Coming Dir.	840.00	47.00	Fair	23.76	19957.69
20.00	H20	Coming Dir.	840.00	57.00	Good	13.99	11747.85
21.00	H21	Coming Dir.	820.00	35.00	Fair	39.18	32128.97
22.00	H22	Coming Dir.	850.00	51.00	Fair	19.51	16586.79
23.00	H23	Coming Dir.	840.00	52.00	Fair	18.52	15558.92
24.00	H24	Coming Dir.	800.00	64.00	Good	8.81	7047.34
25.00	H25	Coming Dir.	800.00	56.00	Good	14.84	11869.57
26.00	H26	Coming Dir.	780.00	56.00	Good	14.84	11572.83
27.00	H27	Coming Dir.	790.00	31.00	Poor	45.22	35722.27
28.00	H28	Coming Dir.	790.00	64.00	Good	8.81	6959.25
29.00	H29	Coming Dir.	850.00	57.00	Good	13.99	11887.70
30.00	H30	Coming Dir.	850.00	60.00	Good	11.60	9859.30
Average of sections				49.60	Fair	22.21	17931.74

3.5. Effect on Exhaust Emission

Urban air pollution is a significant environmental issue in many cities around the world. The high level of urban air pollution particularly in the form of CO, SO_2, NO_2, PM (Particulate Matter), and RSPM (Respirable Suspended Particulate Matter). It is caused by various factors, including industrial emissions, residential heating and cooking, and transportation. Among these sources, the transport sector is a major contributor, accounting for approximately 70% of the pollution [6]. In the context of vehicle emissions, carbon monoxide (CO) is a significant pollutant. CO is produced when fossil fuels, such as gasoline or diesel, are burned incompletely. It is a colorless and odorless gas that can be harmful to human health when present in high concentrations. The information you provided suggests that CO contributes about 90% of all emissions from the transport sector.

In order to get the effect of mean traveling speed on emission levels a portable reference emission analyzer was employed (Figure 14). The study was conducted on campus roads of Kafr El-Sheikh University by using a 2016 Nissan Qashqai passenger car (four-wheeler). The results of the emission factor were taken at different speeds by the emission analyzer device. The concentration of different pollutants as a function of vehicle speed was plotted in Figure 15. This study supports the observation that vehicle emissions, including CO and other pollutants, are highest when vehicles are traveling at lower speeds, specifically between 0-15 km/hr. The findings were in accordance with the study by Bahar et al. (2009) [27]. This finding can be explained by several factors. Firstly, when vehicles approach speed humps or encounter traffic congestion, they often shift gears and reduce speeds. These frequent gear shifts and speed reductions can result in increased energy consumption and fuel usage, leading to higher emissions. Secondly, vehicles tend to use more fuel when traveling at lower speeds due to increased idling and longer periods of acceleration. This can contribute to higher emissions of pollutants, including CO. Thirdly, continuous accelerations and decelerations caused by a series of speed humps or traffic conditions can have an adverse impact on vehicular emissions. Rapid changes in speed require more fuel and can lead to inefficient combustion, resulting in increased emissions. It's worth noting that the concentration of pollutants mentioned (CO, SO_2, NO_2, PM, and RSPM) can vary depending on various factors such as vehicle type, age, maintenance, and the quality of fuel used. Additionally, other factors, such as weather conditions and geographical features, can also influence the dispersion and accumulation of pollutants in urban areas.

Figure 14. Portable reference emission analyzer

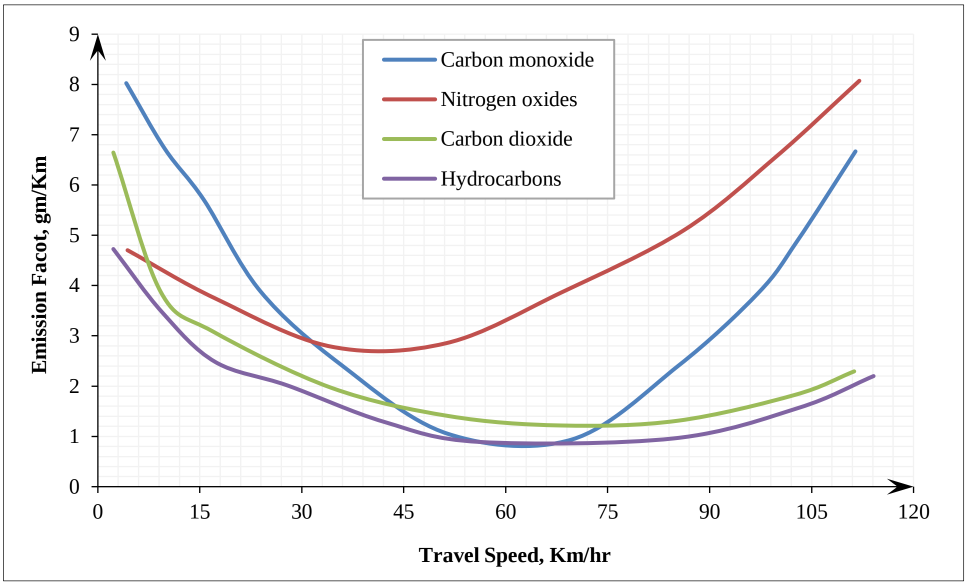


Figure 15. The concentration of different pollutants as a function of vehicle speed

4. Conclusions

This study primarily focuses on investigating the significant impacts of speed breakers. It specifically examines several key parameters, including potential travel time delays, the impact on the 85th percentile speed, increased fuel consumption, the additional maintenance cost of the pavement, and elevated vehicular exhaust emissions. These parameters were examined by using field data. Based on the analysis of the study, the following conclusions were drawn:

- The 85th percentile speeds experienced significant reductions compared to free stretches without any obstacles, with reductions of 41.65%, 73.52%, and 86.27% for speed humps, speed bumps, and triple bumps, respectively. These results highlight the efficacy of traffic calming measures in slowing down vehicles and creating safer road conditions.
- The presence of speed humps, speed bumps, and triple bumps led to average delays of 9.31, 16.42, and 29.51 seconds, respectively. Although these delays may seem short individually, it is crucial to consider their cumulative impact when multiple speed obstacles are present on a road.
- The fuel loses approximately 12.07, and 27.37 km of fuel for every 100 km of travel when the density of speed breakers is 1.33/km for motorcycles and passenger cars respectively.

- The additional fuel consumption due to speed breakers was found to be 13.73, and 37.74% for motorcycles and passenger cars respectively.
- The study found that the presence of speed humps is associated with a decrease in Pavement Condition Index (PCI) values, which signifies a deterioration in pavement condition.
- The average predicted total maintenance cost was significantly higher in sections with speed humps compared to sections without speed humps. The increase in maintenance cost ranged from 100% to 264% across the different road sections, and the rate develops with increasing traffic volume.

The lower vehicle speeds (at humps locations), particularly between 0-15 km/hr, are associated with higher emissions of pollutants, including carbon monoxide (CO) and other pollutants.

5. Declarations

5.1. Author Contributions

Conceptualization, S.S. and A.E.; methodology, S.S., A.E., and R.O.; investigation, R.O.; writing—original draft preparation, S.S., A.E., and R.O.; writing—review and editing, S.S., A.E., and R.O. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

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