

Passenger Car Equivalents at Signalized Intersections for Heavy and Medium Trucks and Animal Driven Carts in Gaza, Palestine.

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Abstract— Passenger Car Equivalent (PCE) or Passenger Car Unit (PCU) is used in highway capacity analysis to convert a mixed vehicle flow into an equivalent passenger car flow. PCE value for a vehicle is not constant but varies with traffic and roadway conditions around.

In this study, Passenger Car Equivalent values (PCE) for heavy trucks, medium trucks and animal-driven carts were developed at signalized intersections in Gaza City, Palestine. PCE data were collected at three signalized intersections; AL-Samer, Asqoula and Baghdad Intersections. A digital video camera was utilized for data collection, and the Headway method was used to calculate the PCE values. Local statistics show that heavy and medium trucks comprise from 1% to 16% of traffic flow on the main roads. However, the percentage of heavy vehicles reached more than 35% in some locations [1] [2]. On the other hand, there is no official record of animal driven carts in Gaza Strip. Some local traffic counts, conducted in Gaza city in 2011, indicated that the percentage of animal driven carts in traffic flow varies between less than 1% to more than 5% [1] depending on the location as well as land use.

This study concludes that in Gaza City, PCE values at traffic signals were found to be 2.23, and 1.43 for heavy and medium trucks, respectively. However PCE value for animal-driven carts was found to be 1.51.

Using appropriate statistical tests, to examine the significance of the differences among PCE values in Gaza, UK and India; it was found that there is no significant difference in PCE value for heavy and medium trucks between Gaza (2.23, 1.43) and UK (2.3, 1.5). However, it was found that there is a significant difference in PCE value for animal-driven carts between Gaza (1.51) and India (2.6).

Keywords—Animal driven carts, Gaza, heavy vehicles, medium vehicles, Palestine, passenger car equivalent, passenger car unit, signalized intersections.

I. INTRODUCTION

Passenger Car Equivalent (PCE) or Passenger Car Unit (PCU) is used in highway capacity analysis to convert a mixed vehicle flow into an equivalent passenger car flow. This calculation is relevant to capacity and level of service determination, lane requirements, and determining the effect of traffic on highway operations [3].

However, in the most recent Highway Capacity Manual (HCM) PCE values rely on a limited field database and extensive simulation runs based on this information; they were calibrated on steady-flow traffic operations [4].

Palestinian Central Bureau of Statistics mentioned that heavy and medium trucks comprise about 18% of the total number of vehicles registered in Gaza Strip in 2006 [5]. Local traffic surveys show that heavy and medium trucks comprise from 1% to 16% of traffic flow on the main roads, reaching more than 35% in some locations [1] [2]. However, there is no official record of animal driven carts in Gaza Strip. Some local traffic counts, conducted in Gaza in 2011, indicated that the percentage of animal driven carts in traffic flow varies between less than 1% to more than 5% [1] depending on the location as well as land use.

In practice, Palestinian engineers refer to other countries capacity manuals when designing local road facilities, including signalized intersections and un-signalized intersections, as well as other urban and rural transport facilities. This might not always be an appropriate practice as local traffic conditions might differ from traffic conditions in other countries. This leads to the need to carryout studies based on local traffic conditions in order to come up with local standards.

Therefore, this study about Passenger Car Equivalents (PCE) at signalized intersections has been carried out in Gaza city. It also comes as a complement to a previous study in Gaza city on PCE values of buses and animal driven carts. [6]

II. LITERATURE REVIEW

Highway Capacity Manual (HCM) paid special attention to passenger car equivalent factors (PCE), in its early edition in 1950 it stated that trucks on two-lane highways on level terrain have the same effect as two passenger cars. The recent edition of Highway Capacity Manual in 2010 [7] defines PCE as “the number of passenger cars that will result in the same operational conditions as a single heavy vehicle of a particular type under specified roadway, traffic, and control conditions”.

As a result of an investigation carried out by Martin and Voorhees Associates, Southampton University and the Transport and Road Research Laboratory, values of Passenger Car Equivalents have been proposed for use in the United Kingdom signal design. PCE value of a light vehicle (3 or 4 wheeled vehicles) equals 1.0. A medium commercial vehicle (2 axles but more than 4 wheels) equals 1.5 PCE, and a heavy commercial vehicle (vehicles with more than 2 axles) equals 2.3 PCE. A bus or a coach equals 2.0 PCE. However, a motorcycle equals 0.4 PCE and a pedal cycle equals 0.2. [8]

Saha et al, 2009 published a research on Passenger Car Equivalent (PCE) of through vehicles at signalized intersections in Dhaka Metropolitan City, Bangladesh. In this study, the headway ratio method was used for the calculation of PCE values. In this study, the PCE value for passenger car was 1.0, the PCE value for auto-rickshaw was 0.86, The PCE value for mini-bus was 1.42, and the PCE value for bus was 2.16. [9]

In 2012 Sarraj and Jadili [6] investigated the PCE for buses and animal-driven carts in Gaza city. Data were collected at three signalized intersections in Gaza; AL-Azhar, AL-Samer and Asqoula. Based on Headway method the PCE value for buses was 2.0 and the PCE value for animal driven carts was 1.6.

The following are some of the many factors on which the PCE values of different vehicle classes depend; dimensions, power, speed, acceleration and braking characteristics of the vehicle, road characteristics such as geometric characteristics including gradients, curves, access controls, type of road: rural or urban, and presence and type of intersection. [10]

Considering the recent studies on PCE value factors, Geistefeldt (2009) [11] estimated PCE based on capacity variability and simulate different factors affecting PCE values, where Al-kaisy et al. (2006) [12] investigated the limitations and appropriate use of HCM-PCE factors for heavy vehicles on freeways and multilane highways. Demarchi and Setti (2003) [13] studied the limitation of PCE derivation with more than one truck type.

In his study on measuring PCE for large vehicles at signalized intersections, Rahman [14] stated that headway ratio method is currently the most commonly used method for PCE estimation.

Rahman also stated that Greenshields et al. (1947) [15] estimated PCE value using the basic headway method expressed in Equation I.

Equation I

Basic Headway Method

$$PCE_i = \frac{h_i}{h_c}$$

Where, PCE_i = Passenger Car Equivalent of vehicle type i .

h_i = average headway (in seconds) maintained by type of vehicle i following passenger car.

h_c = saturation flow headway of passenger car following passenger car.

Values of PCE in Some Countries

Table 1 provides a summary of PCE values of trucks and animal-driven carts established in different countries such as UK, Malaysia and India.

III. OBJECTIVES

This research aimed to establish PCE values of heavy trucks, medium trucks and animal-driven carts at signalized intersections in Gaza, Palestine. The second objective is to compare the obtained values with established values used in other countries.

IV. METHODOLOGY

Based on random samples at signalized intersections and developing a statistical analysis for collected data, this research investigated PCE values of trucks and animal driven carts for Gaza Strip. The selection of the signalized intersections was based on the following criteria: High traffic volumes, significant queuing, no parking allowed at or close to the intersection and good mix of different vehicle types. Data was collected at three signalized intersections in Gaza city. Several methods may be used to collect data such as: manual method using a stop-watch, pressure-contact-strip method, sonic detectors and a digital video camera.

In this study, a digital video camera was used. Movements of vehicles were recorded by a digital camera that records and displays the accurate time of vehicles crossing the stop line.

TABLE I
PCE VALUES IN UK, MALAYSIA AND INDIA

| Types of Vehicles | UK TRRL [16] | India [17] | Malaysia [18] | UK [19] | Gaza, Palestine [6] |
|---------------------|--------------|------------|---------------|---------|---------------------|
| Heavy Trucks | 2.25 | - | 2.25 | 2.3 | - |
| Medium Trucks | 1.74 | - | 1.75 | 1.5 | - |
| Animal-driven Carts | - | 2.6 | - | - | 1.6 |

The selected random sample was representative with a statistically accepted size. The minimum sample size for each type of vehicle was not less than 30.

For the calculation of PCE values, the headway ratio method (Equation I) was used in this research. This method is considered as the most commonly used method to calculate PCE values at signalized intersections. It was selected for several reasons; it is easy, applicable and best suited to determine PCE value on level terrain at a low level of service.

Time headway is defined as the time difference between the same points (e.g. the front bumper) on two consecutive vehicles as they pass an observation point on the road. Time headway is calculated by measuring the consumed time to pass a longitudinal distance between one point on the lead vehicle and a second point on the following vehicle [20]. (Equation II) was used to compute the time headway in seconds.

Equation II
Time Headway

$$h_i = t_2 - t_1$$

Where, h_i = time headway in seconds.

t_1 = time for the first type of vehicles.

t_2 = time for the second type of vehicle (always taken car).

(Equation III) was used to compute the average time headway for all samples at each intersection.

Equation III
Average Time Headway

$$\text{Average time headway} = \frac{\sum h_i}{n}$$

Where, n = number of samples

Then PCE values were calculated for each vehicle type at each intersection using (Equation I).

A statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS). ANOVA test was used to compare the results of PCE values between the three selected intersections to evaluate the statistical differences of the PCE values between the intersections. The T-test was used to compare the results of PCE values for Gaza with values in the UK and India within the 95% confidence intervals for mean values.

V. DATA COLLECTION

The types of vehicle included in this study are passenger cars, trucks and animal-driven carts which can be defined as follows [21]:

Passenger Cars: can be defined as a motor vehicle with four wheels; usually propelled by an internal combustion engine. A micro-bus with less than ten passengers is also considered as a passenger car.

Trucks: can be divided up into any number of different categories. The most general truck classification is probably by gross weight, it is divided by the number of axles, and the most common categories are heavy trucks and medium trucks.



PASSENGER CAR



HEAVY TRUCK



ANIMAL DRIVEN CART



PASSENGER CAR



MEDIUM TRUCK



ANIMAL DRIVEN CART

Heavy trucks: are larger than passenger cars, which have more than two axles such as truck tractor, concrete mixer, dump truck and fire truck.

Medium trucks: are smaller than heavy trucks, with two axles one of them has double wheels such as city cargo van, beverage delivery truck and wrecker.

Animal-driven carts: can be defined as a vehicle for transport, using two or four wheels and normally pulled by one or a pair of draught animals.

This research studied three signalized intersections in Gaza city, namely; Asqoula, Baghdad and AL-Samer Intersections. These signalized intersections are saturated or have adequately saturated portions of the green interval. They have significant numbers of vehicle types being studied (passenger cars, animal driven-carts, heavy and medium trucks). Figure 1 shows the location of these selected intersections.

Asqoula Intersection is a four arm signalized intersection. The southern arm is Ahmed Yaseen Street, the eastern arm is AL-Maamadani Street, the western arm is Jamal Abed EL-Nasser (AL-Thalathiny) Street and the northern arm is AL-Hesba Street.

Baghdad Intersection is a four arm signalized intersection. The northern and southern arms are part of Salah AL-Deen Street whereas the western arm is AL-Wahda Street and the eastern arm is Baghdad Street.

AL-Samer Intersection is a four arm signalized intersection. The eastern and western arms form the extension of Omer AL-Mokhtar Street, the North arm is Bour Said Street and the South arm is Najm AL-Deen AL-Arabi Street.

At each intersection, a video camera was installed on the roof of a building located close to the intersection. The camera was used to collect the required data in the field. The data collection was made between February 12th and March 9th 2011. Data recording was for 90 to 120 minutes during the peak traffic conditions. Data were collected under dry and sunny weather condition and during morning and afternoon peak periods. The Recorded data was transferred later to a computer and then Movie Maker software was used to display the time in parts of a second. For vehicles in the queue, the entering headway was taken to be the elapsed time, front bumper to front bumper, as successive vehicles passed an intersection stop line.

The minimum sample size was selected to be 30 samples of each vehicle type at each intersection. Table II illustrates the number of the collected samples of each studied vehicle type at the three selected intersections.

During data collection process, the observers were faced by some problems, such as:

- Traffic signals were sometimes not working, either because of being out of order or because of power cut off.

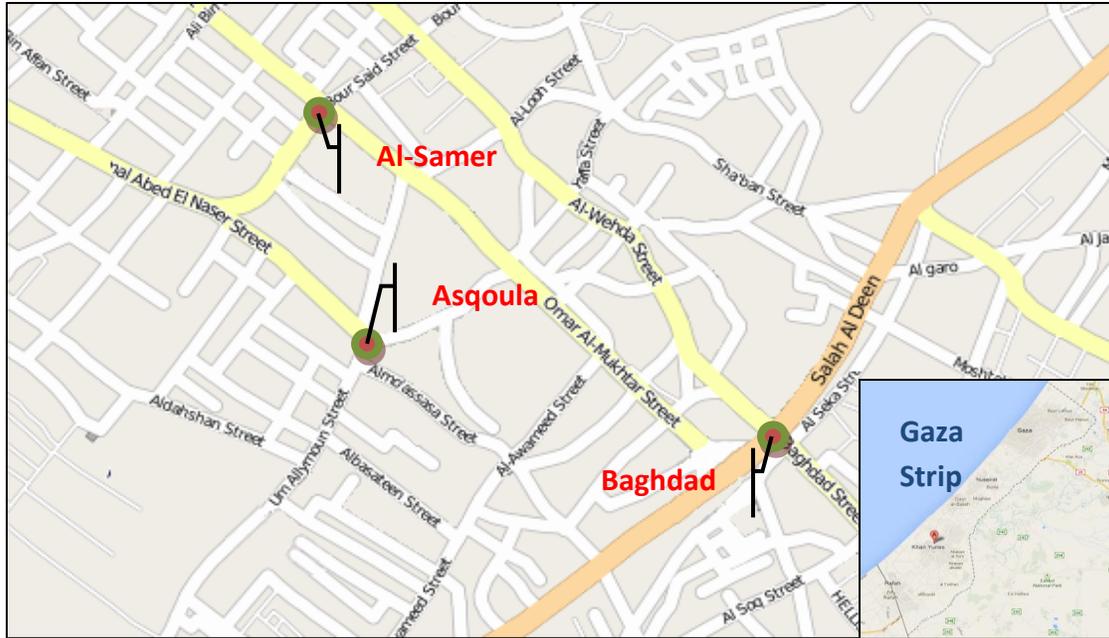


Figure 1 The Locations Of Selected Intersections In Gaza City, Palestine.

Source: www.igaza.ps and <https://maps.google.com>

- Some drivers don't always respect the traffic signals and animal-driven carts rarely followed traffic law.

Table II
The Number of Collected Samples of each Studied Vehicle Type at the Three Selected Intersections.

| Items | Asqoula Intersection | Baghdad Intersection | AL-Samer Intersection |
|---------------------|----------------------|----------------------|-----------------------|
| Passenger Cars | 100 | 117 | 140 |
| Heavy Trucks | 33 | 36 | 30 |
| Medium Trucks | 41 | 46 | 41 |
| Animal-driven Carts | 31 | 32 | 35 |

VI. DATA ANALYSIS

A. General descriptive statistics

The headway ratio method was used to calculate PCE values using (Equation I). Table III shows the calculated PCE values for the different studied vehicle types for the three intersections. Figure 2 reflects the variation of the PCE values for the three intersections considering heavy trucks, medium trucks and animal-driven carts.

B. Comparisons of the results at the three intersections

The analysis of variance (ANOVA) [22] was used to test the hypothesis that there is no significant difference between PCE values among the three intersections considering the studied vehicle types (as a null hypothesis). One-Sample Kolmogorov Smirnov [22] test was performed to check normality of each group of data. It was found that there is not sufficient evidence that the PCE values of vehicles does not have a normal distribution with Level of significance $\alpha = 0.05$. Also, Levene test [22] cleared that the homogeneity of the variances of the data groups is achieved at level of significance $\alpha = 0.05$.

Statistical result (Heavy trucks): Table IV shows the average PCE values for heavy trucks at the three intersections. ANOVA test shows p-value of 0.477 that is greater than the level of significance $\alpha = 0.05$. Thus there is no significant difference in PCE values for heavy trucks among the three intersections.

Table II
PCE Values for the Studied Types of Vehicle for the Three Selected Intersections.

| Vehicle Type | Asqoula Intersection | Baghdad Intersection | AL-Samer Intersection | Average Value of PCE |
|-----------------------------|----------------------|----------------------|-----------------------|----------------------|
| PCE for Heavy Trucks | 2.17 | 2.14 | 2.39 | 2.23 |
| PCE for Medium Trucks | 1.58 | 1.37 | 1.36 | 1.43 |
| PCE for Animal-driven Carts | 1.65 | 1.47 | 1.42 | 1.51 |

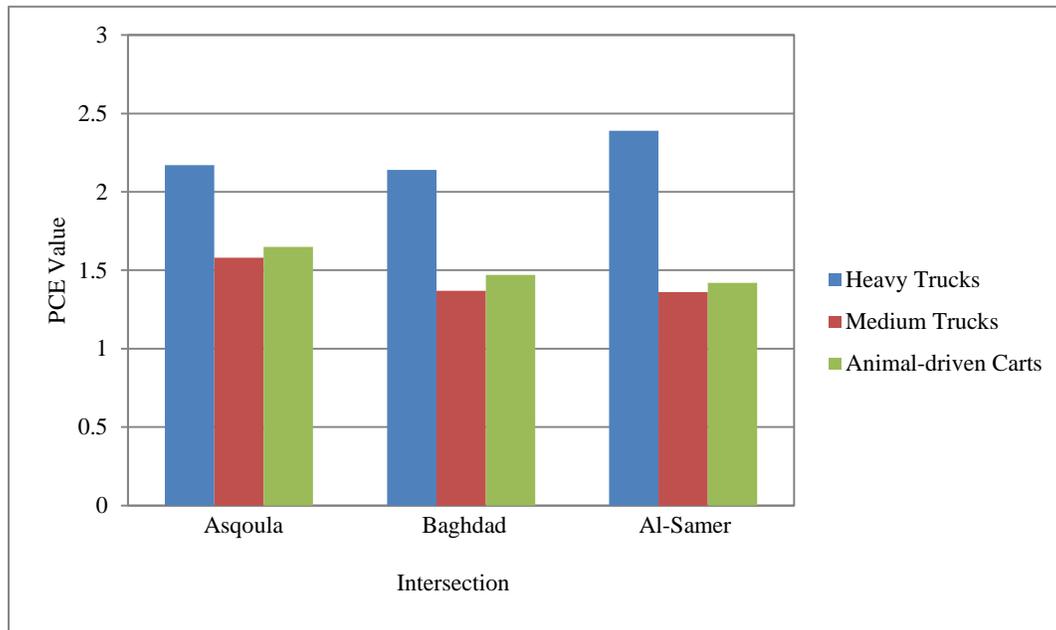


Figure 2 Values of PCE for Studied Types of Vehicle at the Three Selected Intersections

Table III
Descriptive Statistics of PCE for Heavy Trucks

| Group(Road Intersection) | Number of Samples | Average PCE Values | Standard Deviation |
|--------------------------|-------------------|--------------------|--------------------|
| Asqoula | 33 | 2.17 | 0.64868 |
| AL-Samer | 30 | 2.39 | 1.29705 |
| Baghdad | 36 | 2.14 | 0.67235 |

Figure 4 shows the variation of PCE values among the three intersections using Boxplot. Al-Samer intersection reflected higher deviation of PCE values than the other intersections, whereas Asqoula intersection gave the lowest deviation of PCE values. The higher the standard deviation of PCE values, the higher the variety of traffic conditions in the intersection.

Statistical result (Medium trucks): Table V shows the PCE values for medium trucks at the three sites. ANOVA test shows p-value of 0.012 that is smaller than the level of significance $\alpha = 0.05$. Thus there is a significant difference in PCE values for medium trucks among the three intersections.

The results from ANOVA test do not indicate which of the three intersections differ from the others. Therefore, it is of interest to follow the analysis with a post hoc test [22]. Post Hoc test detected that PCE value at Asqoula Intersection differs from the value at the other two intersections with level of significance $\alpha = 0.05$. This result means that Asqoula intersection has a specialty in terms of intersection capacity and/or traffic components. This study recommends further research to investigate the relation between different intersection characteristics and their response to the traffic conditions.

Table IV
Descriptive Statistics of PCE for Medium Trucks.

| Group (Road Intersection) | Number of Samples | Average PCE Values | Standard Deviation |
|---------------------------|-------------------|--------------------|--------------------|
| Asqoula | 41 | 1.58 | 0.37101 |
| AL-Samer | 41 | 1.36 | 0.41640 |
| Baghdad | 46 | 1.37 | 0.31602 |

Statistical result (Animal-driven Carts): Table VI shows the PCE values for animal-driven carts at the three sites. ANOVA test shows p-value of 0.120 that is greater than the

level of significance $\alpha = 0.05$. Thus there is no significant difference in PCE values for animal-driven carts among the three intersections.

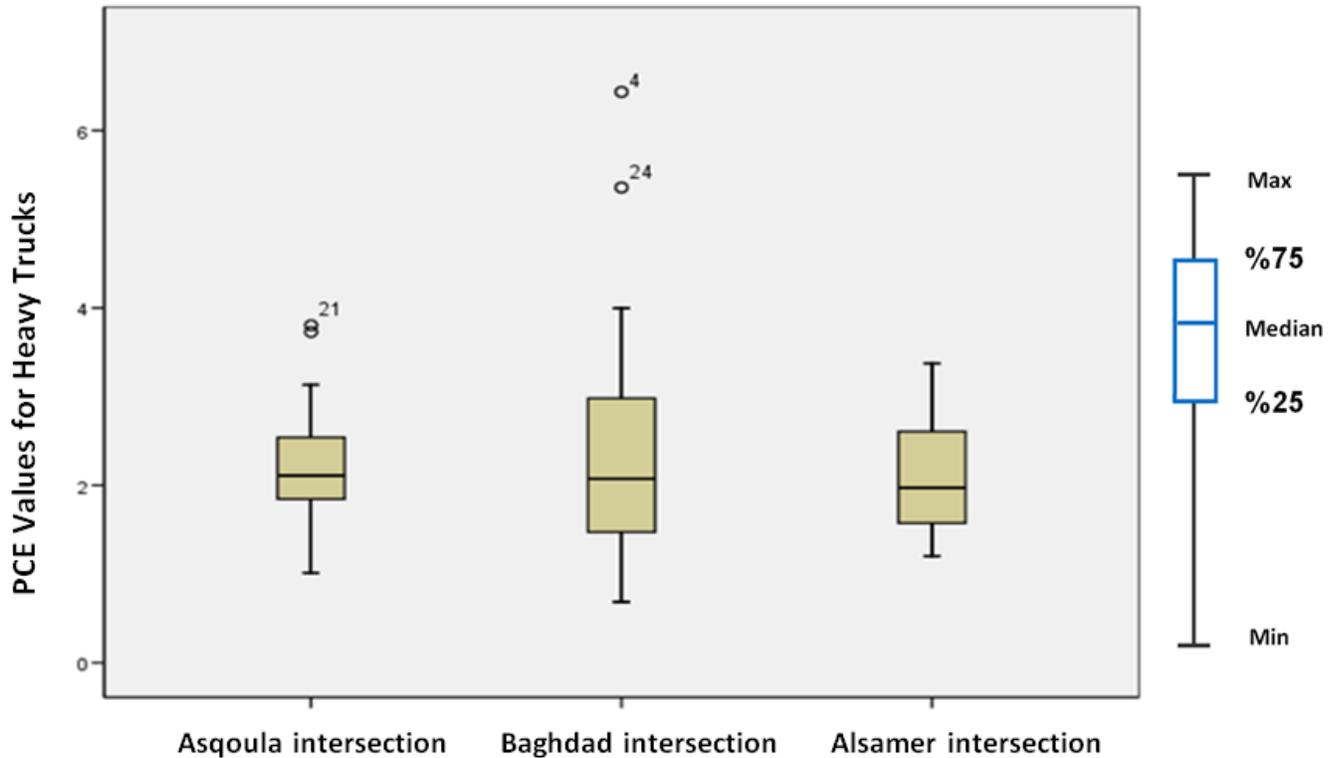


Figure 3 Boxplot Chart for PCE values for heavy trucks among the intersections

Table V
Descriptive Statistics of PCE for Animal-driven Carts.

| Group (Road Intersection) | Number of Samples | Average PCE Values | Standard Deviation |
|---------------------------|-------------------|--------------------|--------------------|
| Asqoula | 31 | 1.65 | 0.42811 |
| AL-Samer | 35 | 1.42 | 0.53468 |
| Baghdad | 32 | 1.47 | 0.44605 |

C. Comparisons of Results with Established Values in UK and India

The purpose of this analysis is to compare the results of PCE values of Gaza with established values in the UK and India. To achieve this purpose the analysis of one sample (T-test) [22] was performed.

Table VII and Figure 4 show a comparison between PCE values for the studied vehicle types in Gaza, UK and India.

Table VI
PCE Values for the Studied Types of Vehicles in Gaza, UK and India.

| PCE Values | Gaza (2011) | UK [19] | India [17] |
|---------------------|-------------|---------|------------|
| Heavy Trucks | 2.23 | 2.3 | - |
| Medium Trucks | 1.43 | 1.5 | - |
| Animal-driven Carts | 1.51 | - | 2.6 |

T-test results (Heavy Trucks): T-test was performed for heavy trucks to evaluate the difference of PCE values between Gaza and the UK. With P-value of 0.450 which is greater than the level of significance $\alpha = 0.05$; there is no statistically significant difference in PCE values of heavy trucks between Gaza (2.23) and UK (2.3).

T-test results (Medium Trucks): The same as before but for medium trucks with P-value of 0.064; there is no statistically significant difference in PCE values of medium trucks between Gaza (1.43) and UK (1.5).

T-test results (Animal-driven Carts): The results proved that there is a statistically significant difference in PCE values of animal-driven carts between Gaza (1.51) and India (2.6).

VII. CONCLUSIONS

The average PCE value for heavy trucks in Gaza was found to be 2.23, whereas it was 1.43 for medium trucks and 1.51 for animal-driven carts.

ANOVA shows that there is no significant difference in PCE values for heavy trucks among the three intersections as well as the animal-driven carts. But ANOVA shows that there is a significant difference in PCE values for medium trucks among the three intersections and Post Hoc test detected that Asqoula Intersection slightly differs from the other intersections.

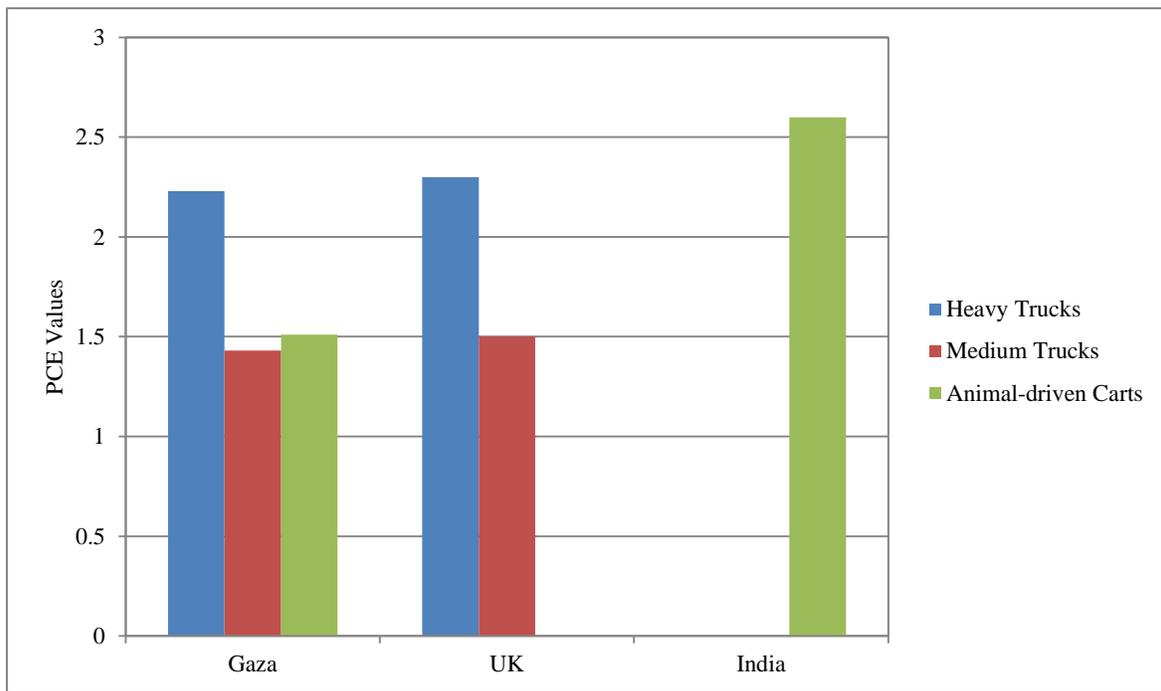


Figure 4 PCE Values for the Studied Types of Vehicle in Gaza, UK and India

Based on one way t-test for the mean, there is no statistically significant difference in PCE values of heavy and medium trucks between Gaza and UK.

For animal-driven carts and based on one sample t-test, there is a statistically significant difference in PCE values between Gaza and India. This variation might be due to the difference in animal types. Bullocks are used in India However, horses, mules or donkeys are used in Gaza.

It was noticed that the PCE value for animal driven carts in Gaza produced in 2008 [6] by Sarraj and Jadili, was 1.6. This value is slightly different from the value produced by this study (1.51). Therefore, the average value of the two results (1.56) is suggested to be used for PCE value for animal-driven carts in Gaza City.

Finally, the researcher recommends the use of the UK PCE values (2.3) and (1.5) for heavy and medium trucks.

This is because no significant difference was found between the locally established values and the UK values. For animal driven carts it is recommended to use the locally established value of 1.56 PCE's.

VIII. RECOMMENDATIONS

The researcher recommends conducting other studies for heavy and medium trucks to confirm the values which were established in this research as well as further researches to investigate PCE values under different traffic conditions. It is also recommended to investigate the PCE values for other types of vehicle used in Gaza Strip such as motorcycles, bicycle and the three-wheeler known locally as (toktok).

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