An Investigation of Vehicle Travel Characteristics on Rural Arterials of Pakistan

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Submitted By

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Dedicated to my parents for their unfaltering support and my sister Laiba Khan

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ABSTRACT

With ever increasing transportation demand, highway agencies are struggling to provide reliable level of service (LOS) to the road users. Knowledge of capacity of existing highway system is an important input for capacity enhancement decision making. In order to determine capacity and level of service, existing methodologies make use of concept of passenger car equivalent (PCE). PCE is used to convert a mixed traffic stream into a base stream (passenger cars only) for the determination of traffic density and highway capacity/LOS. Most of the existing PCE values are based on research carried out in USA and other developed countries. Pakistan being a developing country has traffic composition and vehicles travel characteristics considerably different from those of developed countries. Consequently, standard traffic parameters practiced in developed countries may not be appropriate for Pakistan. In present research, an effort has been made to develop PCE values for different vehicle classes on the rural arterials of Pakistan using the concept of lagging headway ratios. Video data were collected from four different locations on Grand Trunk Road (N-5) and software package "Traffic Tracker" was used for the extraction of necessary information from video clips of 10-minute duration. Three-stage-least-squares (3SLS) regression model was developed to estimate the lagging headways for passenger car (PC), passenger van (PV), single unit truck (SUT) and combination truck (CT). The PCE values estimated for PV, SUT, and CT are 0.94, 0.87 and 1.03 respectively. Study results revealed that passenger van has similar travel characteristics as that of passenger car (almost similar speed and headway). Also, there is no conclusive evidence that SUT and CT have large headways under stable stream conditions. However, additional efforts are required to refine the estimated PCE values for different vehicle classes on rural arterials of Pakistan using data from different geographical locations/ highways.

CHAPTER 1. INTRODUCTION

1.1 Background

In a typical traffic stream, different types of vehicles are present such as passenger cars, passenger vans, buses, single unit trucks and combination trucks. The distribution of these vehicles is greatly influenced by time and location. Passenger cars and heavy vehicles have considerable different operational and physical characteristics which result in different travel behavior. Also, due to maneuvering difficulties and larger size, heavy vehicles have psychological effect on adjacent lanes drivers as well as physical impact on other vehicles (Krammes and Crowley, 1986; Al-Kaisy et al., 2002). The performance and physical gaps between passenger cars and trucks require that both types of vehicles should be accounted for in a different manner while taking into account the design and analysis purposes.

In general, level of service (LOS) is used for the qualitative measurement of traffic operational performance under prevailing traffic and roadway conditions. LOS amalgamates various factors such as driver comfort, density, lateral restraints, etc. (TRB, 2000). The present Highway Capacity Manual (HCM) uses density for LOS gradation by providing six different levels ranging from A (free flow conditions) to F (total congestion) (HCM, 2010). However, for freeway sections, vehicle density is the governing factor in estimating LOS. As density is measured in PC per kilometer per lane, a need arises to convert heterogeneous traffic flow into homogeneous traffic flow which is comprised of passenger cars only. Therefore, passenger car equivalent (PCE) was introduced which sets a common basis for assessing different vehicle types. Using PCEs, passenger car density and LOS can be computed for various conditions.

Density being the governing factor in LOS calculation, it is sensible to primarily specify PCEs from vehicle density perspective. Spatial lagging headway (distance from rear bumper to rear bumper between the leading vehicle and following vehicle) provides density surrogate for PCE calculation. In a heterogeneous traffic stream, different vehicles keep different distances from the leading vehicle while taking into account various factors. The measurement of these spacings can assist in determination of average space occupied by particular vehicle class (Elefteriadou et al., 1997). Thus, a particular vehicle class contribution to density and LOS can be determined by adding the spacings consumed by individual vehicles. As density and inter-vehicle spacing are inversely related, measurement of spacing using headways directly provides density which is the basic step in LOS calculation.

In recent edition of Highway Capacity Manual 2010, single PCE value is provided for all truck types on freeways (HCM, 2010). However, the impact of different truck types on traffic stream can be different. Moreover, HCM provides no allowances for the regional conditions variation. Two roads with similar traffic volume and geometry may have different operational characteristics like vehicle headway due to different driving culture, design standards and land use pattern.

1.2 Problem Statement

In developing countries, like Pakistan, transportation sector is facing many challenges and lack of traffic management on both urban and rural highways is one of them. Most challenging issues in highway design, planning and management are estimation of traffic density, capacity and LOS under heterogeneous traffic conditions for which knowledge of PCE is a primary input. The PCE values recommended in Highway Capacity Manual are generally used in the analysis of traffic operations and highway capacity estimation (TRB, 2000). Use of PCE values estimated for USA may not be applicable for Pakistan as traffic conditions in Pakistan are totally different from USA and other developed countries. The truck fleet in Pakistan is relatively old and has different physical and operational characteristics compared to developed countries. In this exploratory study, an effort has been made to estimate PCE values using spatial lagging headways for three different vehicle classes i.e. passenger van (PV), single unit truck (SUT) and combination truck (CT) at rural arterials of Pakistan.

1.3 Study Objectives

In order to address the key aspects of identified problem, the objectives set for this study are:

a. To establish PCE values for different vehicle classes (passenger van, single unit truck and combination truck) on the rural arterials of Pakistan.

b. To compare estimated PCE values with those provided in the Highway Capacity Manual.

1.4 Overview of Study Approach

To achieve the study objectives, a detailed methodology (Figure 1.1) was developed and the following research tasks were identified:

- Literature review of the previous research findings regarding PCE values estimation.
- Identification and selection of different sites on Grand Trunk road (N-5) for video data collection.
- Video data collection and processing using software package “Traffic Tracker”.
- Estimation of lagging headway for different vehicle classes using three-stage-least-squares (3SLS) regression model.
- Estimation of PCE values for different vehicle classes using headway ratio methodology.
- Comparison of predicted and Highway Capacity Manual provided PCE values.
- Lastly, synopsis of the research, conclusions and recommendations are presented.

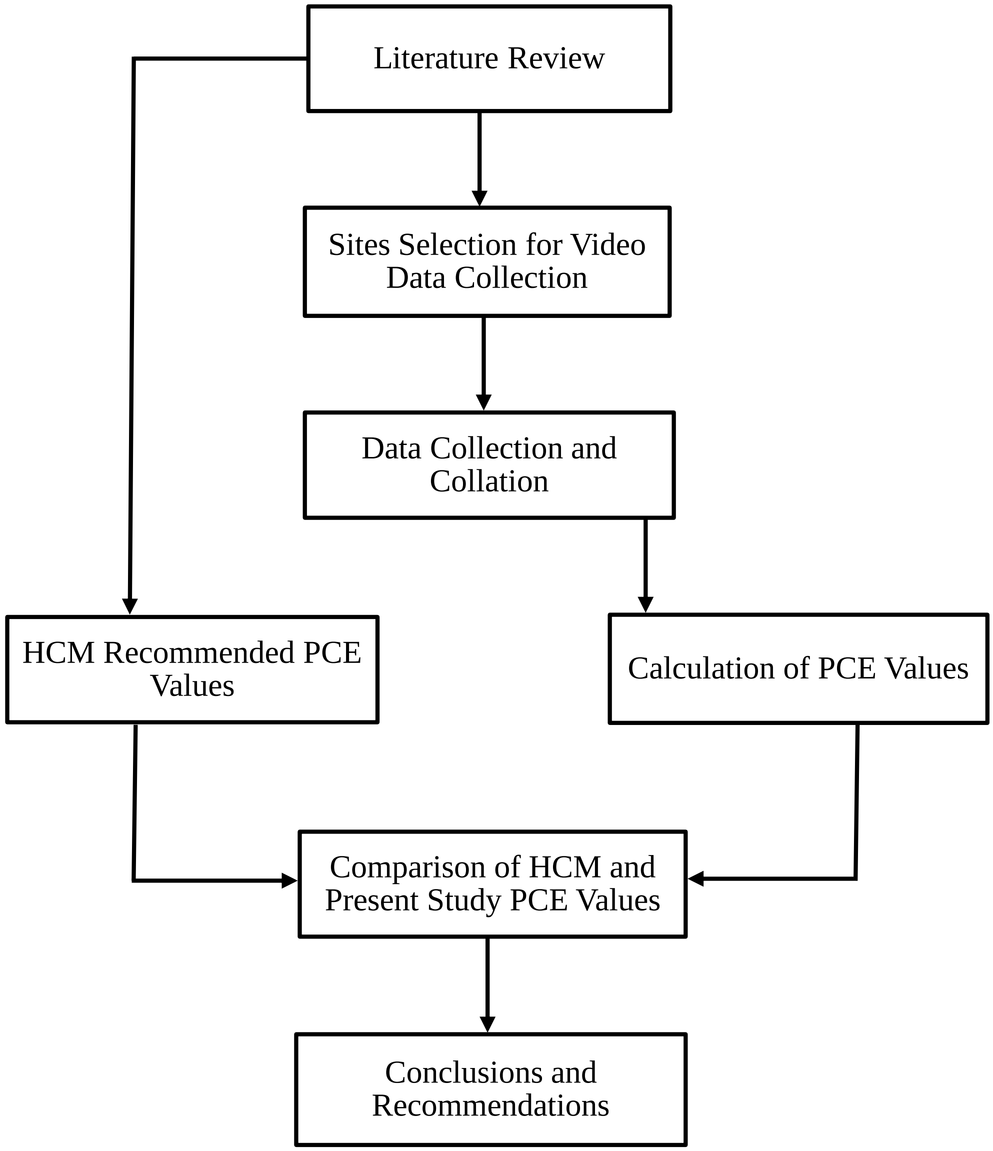


Figure 1. 1: Overview of study approach

1.5 Study Outline

This study has five chapters. Chapter 1 briefly discusses the research problem along with the study motivation and objectives. Chapter 2 presents the literature review in PCEs area which is organized on the basis of methods used, classification of vehicles and traffic flow theory. Chapter 3 explains the collection and collation of video recorded data. The basic methodology adopted for estimating PCEs in the current study is also described in chapter 3. Chapter 4 presents and discusses the four-equation three-stage-least-squares (3SLS) regression model as well as estimated PCE values for passenger van, single unit truck and combination truck. Conclusions and recommendations are present in Chapter 5.

CHAPTER 2. LITERATURE REVIEW

In developing countries the road networks, traffic stream composition, and travel characteristics are different from those in developed countries. Due to these variations, a need arises that different traffic operational performance parameters should be determined which can be used by local transportation network. PCE is an important traffic parameter which is used in estimation of density and LOS.

2.1 Historical Review of PCE Development

Before the 1965 edition of Highway Capacity Manual (HCM), there was no concept of the term "passenger car equivalent". In the 1950 version of HCM, truck equivalencies were introduced for the first time in which a value equivalent to two passenger cars was arbitrarily allotted to all types of trucks for two-lane highways (level terrain). The basis for this estimate was volume of PC passing trucks compared to volume of PC passing PC. It was the 1965 HCM edition which properly used the term "passenger car equivalent" and defined it as "the number of passenger cars displaced in the traffic flow by a truck or a bus, under the prevailing roadway and traffic conditions" (HRB, 1950; HRB, 1965). The 1985 HCM edition used a methodology based on volume to capacity ratio approach, basically formulated by Linzer et al. (1979), for PCE values estimation. The 2000 edition of HCM used PCEs for trucks conversion into passenger cars and defined it as "the number of passenger cars that are displaced by a single heavy vehicle of a particular type under prevailing roadway, traffic, and control conditions" (HCM, 2000). In 2000 and 2010 editions of HCM, different PCE values have been provided for different highway facilities but a single PCE value is assigned to both SUT and CT on freeways regardless of LOS.

In the present edition of HCM (TRB, 2000), LOS calculation requires estimation of traffic stream density which consists of passenger cars only. For the conversion of vehicles other than PC, PCEs are used. The PCE values provided in the HCM 2000 vary while taking into account various factors such as trucks percentage, intensity of grade and grade length. The formula used by HCM in PCEs estimation procedure is presented in equation 2.1. Where f_{HV} is the factor for heavy vehicle, Pi is the vehicle type i proportion, and E_i is the value of PCE for i type vehicle class. The equivalent flow of passenger cars can be obtained from the division of passenger car flow by f_{HV}.

$$f_{HV} = \frac{1}{1+\sum P_i\left(E_i - 1\right)} \tag{2.1}$$

For PCEs estimation, appropriate performance measure must be considered while using any methodology. In past studies, a number of methodologies have been carried out to derive PCEs for different types of highway facilities. In all these studies, most researchers used traffic simulation while a few used actual field data for PCEs derivation. In this study, a focus has been kept on rural arterials with free flow conditions and it is worth noting that critical characteristics of such facility are different from urban two-lane highway and signalized arterials. There are various factors which govern LOS of such facility but the most dominating factor is density (TRB, 2000).

2.1.1 PCEs Based on Density and Flow Rates

Huber (1982) derived an equation for PCE values estimation by using simulations under three different conditions; density and speed of mixed and base (only passenger cars) streams, and speed of passenger car in mixed and base streams. He then compared flow rate of mixed stream, q_M, with flow rate of base stream, q_B, with both having same flow impedance (Huber, 1982). His procedure is applicable only when only one type of heavy vehicle is present in a traffic stream. Huber's equation is as follows:

$$\mathrm{PCE} = \frac{1}{\mathrm{P_T}}\left(\frac{\mathrm{q_B}}{\mathrm{q_M}} - 1\right) + 1 \tag{2.2}$$

where P_T is truck proportion in mixed traffic stream.

Sumner et al. (1984) used simulations to further develop the Huber's method by incorporating different types of trucks in a mixed traffic flow, as shown in Equation 2.3:

$$\mathrm{PCE}_s = \frac{1}{\Delta_\mathrm{P}}\left(\frac{\mathrm{q_B}}{\mathrm{q_S}} - \frac{\mathrm{q_B}}{\mathrm{q_M}}\right) + 1 \tag{2.3}$$

where Δ_P is the subject vehicles proportion, and q_S is subject vehicle flow rate. In first simulation, traffic flow comprised base stream (q_B), mixed flow in second simulation (q_M), and mixed flow in which PC were replaced with Δ_P% of interest vehicles in third simulation. Flow was plotted against delay in vehicle-hours for three different simulations.

Demarchi and Setti (2003) found various issues in the procedure developed by Sumner et al (1984). Therefore, they derived a formula (Equation 2.4) for PCE estimation by accounting interaction between different types of trucks in order to eradicate the potential error for mixed heavy vehicles in a heterogeneous traffic stream.

$$\mathrm{PCE}_s = \frac{1}{\sum_i^n \mathrm{P_i}}\left(\frac{\mathrm{q_B}}{\mathrm{q_M}} - 1\right) + 1 \tag{2.4}$$

where P_i is the proportion of type i trucks out of n trucks in a heterogeneous traffic stream. All other terms are as defined previously.

2.1.2 PCEs Based on Headways

Headways have been used by a number of researchers PCEs calculation. The pioneering work of Greenshields et al. (1947) developed PCU values by introducing basic headway method which is as follows:

$$\mathrm{PCU}_i = \frac{\mathrm{H_i}}{\mathrm{H_c}} \tag{2.5}$$

where PCU_i is the passenger car unit of type i vehicle, H_i is the average headway of type i vehicle, and H_c is the average headway of PC.

Werner and Morrall (1976) also used the headway ratio concept for estimating PCEs on highways with level terrain. Authors developed relationship (Equation 2.6) for PCEs estimation which provided generalized PCE values for recreational vehicles (RVs), buses and trucks on two lane highways.

$$\mathrm{PCE} = \left(\frac{\mathrm{H_M}}{\mathrm{H_{PC}}} - \mathrm{P_{PC}}\right) / \mathrm{P_T} \tag{2.6}$$

where H_M is the entire traffic stream average headway, H_{PC} is the headway of passenger car, and P_T and P_{PC} are trucks and passenger car proportions respectively.

Cunagin and Chang (1982) used time headway to determine the effect of heavy vehicles presence on freeway traffic flow based on seven different measured headways combinations of vehicle class “k” followed by vehicle class “m”. They concluded that the trucks presence may increase vehicle's average headway. Seguin et al. (1982) also used the spatial headway methodology to calculate PCEs.

Elefteriadou et al. (1997) suggested that comparative amount of space occupied by vehicle could be used as base for PCEs estimation. With an assumption that following vehicle size affects the spatial lagging headway of vehicle, they developed a formula which is as follows:

$$\mathrm{PCE_{ij}} = \frac{\mathrm{H_{ij}}}{\mathrm{H_{pcj}}} \tag{2.7}$$

where PCE_{ij} is the value of PCE of type i vehicle under j conditions, H_{ij} is the following vehicle lagging headway under j conditions, and H_{pcj} is the lagging headway of PC under j conditions.

Van Boxel et al. (2010) used spatial lagging headway to determine PCE values through exploratory study for collection of data from single microloop detector. Also, Ahmed et al. (2011) used the concept of spatial lagging headway to calculate PCE values for three different vehicle classes i.e. passenger car, single unit truck and combination truck. They developed two sets of three-stage-least-squares (3SLS) regression models using actual field data.

2.1.3 PCEs Based on Speed

Speed is another measure which has been used by a number of researchers for PCE values estimation. Van Aerde and Yagar (1983) estimated PCE values using relative rates of speed for each vehicle type and all combined vehicle types travelling in the main and opposing direction, respectively. They concluded that PCE value decreases with the increase in speed percentiles. The formula used for speed analysis is as follows:

$$\begin{aligned} \text{Percentile speed} = \text{free flow speed} &+ C_1\,(\textit{number of passenger cars}) \\ &+ C_2\,(\textit{number of passenger trucks}) \\ &+ C_3\,(\textit{number of RVs}) + C_4\,(\textit{number of other vehicles}) \\ &+ C_5\,(\textit{number of opposing vehicles}) \end{aligned} \tag{2.8}$$

where C_1 to C_5 are coefficients of speed reductions for each type of vehicle. Using the coefficients of speed reduction, the PCE value for type "n" vehicle can be calculated as:

$$E_n = \frac{C_n}{C_1} \tag{2.9}$$

where C_n and C_1 are coefficients of speed reduction for type n vehicle and passenger car, respectively. E_n is the PCE of truck.

Zhao (1998) proposed a methodology for heavy vehicles, based on delay of passenger car equivalents, at signalized intersections. He estimated PCE values by using the headway data as follows:

$$D - PCE_i = 1 + \frac{\Delta d_i}{d_o} \tag{2.10}$$

where $D-PCE_i$ is the delay based PCE for type i vehicle, Δd_i is additional delay due to type i vehicle, and d_o is the PC queue average delay.

2.1.4 PCEs Based on Delays

The delay has been described by HCM as additional travel time experienced by pedestrian, passenger, or a driver (HCM, 2010). Craus et al. (1979) estimated PCE values for trucks using the ratio of delay time due to single truck to the delay time due to single passenger car. This method considers the traffic in opposite lane. The disturbance and delay instigated by various trucks to the other traffic can be determined by the equation as follows:

$$E = \frac{d_{kt}}{d_{kp}} \tag{2.11}$$

where E is the PCE value of truck while d_{kt} and d_{kp} are the average delay caused by single truck and single passenger car, respectively.

Cunagin and Messer (1983) determined PCE values based on distribution of speed, vehicle types, and traffic volumes. For PCEs derivation, authors used the ratio of delay caused by non-passenger vehicles to a single passenger car to the delay caused by other passenger cars to a single passenger car.

$$E_T = \frac{D_{ij} - D_{base}}{D_{base}} \tag{2.12}$$

where E_T is the PCE of type i vehicle under j conditions, D_{ij} is the delay experienced by passenger cars due to type i vehicle under j conditions, and D_{base} is the delay experienced by standard passenger cars due to slower passenger cars.

2.1.5 PCEs Based on V/C Ratio

Since the 1985 HCM edition publication, PCEs calculation using constant v/c method has been subsided because LOS is now determined primarily in terms of density. With same v/c ratio, traffic streams may not certainly have same speed and density and therefore LOS. However, Fan (1990) used this methodology to develop PCEs for expressways in Singapore. Author argument was that even though freeway LOS is determined by vehicles density, yet v/c ratio is desirable to be used for capacity analysis. Study focused on v/c ratio between 0.67 to 1.0, corresponding to congested flow conditions (LOS D or E) and stated that PCE values computation at uncongested flow conditions is not necessary. Author concluded that PCE values for commercial vehicles such as buses, trucks, and trailers are higher than PCEs used in UK and US.

2.1.6 PCEs Based on Queue Discharge Flow

When the vehicles move slowly or is stationary, queue formation occurs by the upstream vehicles accumulation at a bottleneck. It happens when the demand of passing vehicles exceeds existing highway capacity. Al-kaisy et al. (2002) determined PCE values using queue discharge flow with an assumption that if the traffic stream is comprised of passenger cars only and uniform, queue discharge flow capacity observation may experience minimum variation. They concluded that on a freeway, heavy vehicles effect is much greater when they operate under oversaturated conditions. Author found that both during the roadside maintenance work and rainy or dry days, PCE values are not significantly different.

2.1.7 PCEs Based on Hourly Vehicle Volume

Hourly volumes of traffic is used to determine the magnitude and length of peak periods, capacity evaluation, and traffic control and geometric design assessment. Sumner et al. (1984) developed a methodology for estimating PCE values on urban arterials by considering signalized intersections through microscopic simulation. Authors found that better LOS experience lower PCE values, precisely PCE values at LOS D are greater than the PCE values at LOS B.

2.2 Effect of Heavy Vehicles on PCEs

To observe the heavy vehicles (HV) effect on the movement of heterogeneous traffic stream, Sarvi (2009) studied the performance of 240 vehicles out of which 120 were PC-following-PC and PC-following-HV while 120 were HV-following-PC under congested traffic conditions. For the detail analysis of each vehicle-following case, a 700 meters segment was selected over which the position and speed of each vehicle were recorded. The author found that a significant difference was observed in the HV and PC vehicle-following behavior (HV were keeping longer spacings and headways while trailing other vehicles). He also observed that HV presence in a leading position negatively affects the trailing vehicles headways (longer headways by trailing vehicles).

Y. Tanaboriboon et al. (1990) carried out study for the evaluation of vehicle size effect on highway capacity in Thailand using field data and stated that their study conclusions should be considered in the PCEs development. Rakha et al. (2007) made an effort to determine the heavy vehicles impact on mixed traffic flow and found that in the mixed traffic stream, increase in heavy vehicles percentage results in decreased PCEs.

2.3 Chapter Summary

The overview of past research revealed that the term “Passenger Car Equivalent” was used for the first time in the 1965 HCM. Before that, a concept of truck equivalency was used in the 1950 HCM. Since then number of researchers have adopted various procedures such as simulation, equivalent delay, and headway ratio to quantify PCEs. Both the 2000 and 2010 HCM editions recommend single PCE value for all types of trucks on freeways. However, the HCM recommended PCE values are not suited for regional use as it does not consider the regional traffic stream variations. The past research also revealed that for Pakistan, no studies have been carried out to estimate PCEs for heavy vehicles especially on rural arterials with free flow conditions. Moreover, Adnan (2014) carried out a case study for Karachi, Pakistan by using actual field data from 12 different urban arterials and calculated PCE values for different vehicle classes.

CHAPTER 3. DATA COLLECTION

In the present study, after the literature review, various sites were identified for video data collection but four of them were selected. The video data were collected at selected sites and processed accordingly. A four simultaneous-equations three-stage-least-squares (3SLS) regression model was developed for spatial lagging headway estimation. PCE values for three different vehicle classes i.e. passenger van, single unit truck, and combination truck were calculated and compared with HCM recommended PCE values.

There are number of methods that have been developed by different researchers to calculate PCE values. However, headway ratio concept may be attractive alternative to the methodology used by HCM. Headways being reciprocal of density - a governing factor of freeway LOS, are very useful. This study uses the basic headway equation to determine PCE values.

$$\mathrm{PCU}_i = \frac{\mathrm{H}_i}{\mathrm{H}_c} \tag{3.1}$$

where PCU_i is the passenger car unit of type i vehicle, H_i is the average headway of type i vehicle, and H_c is the average headway of PC.

3.1 Headway Measurement

This research used spatial lagging headway (distance from rear bumper to rear bumper between the leading vehicle and trailing vehicle) methodology for PCEs estimation (Figure 3.1). The headway was measured in meters. The spatial lagging headway computation requires a dataset which gives both the individual vehicle speed and a time stamp of when vehicle touches a specific reference line. With this type of available data, spatial leading headway can be computed as follows:

$$LH_i^* = 0.278V_i\,(t_i - t_{i-1}) \tag{3.2}$$

where LH_i^* is the type i vehicle leading headway (in meter), V_i is the vehicle speed in kilometers per hour (kmph), t_i is the type i vehicle timestamp in seconds, t_{i-1} is the previous vehicle timestamp. The lagging headway can be obtained from leading headway by the subtraction of leading vehicle length and addition of trailing vehicle length as follows:

$$LH_i = LH_i^* - L_{i-1} + L_i \quad (3.3)$$

where LH_i is the vehicle type i lagging headway, L_{i-1} is the leading vehicle length, and L_i is the vehicle type i length.

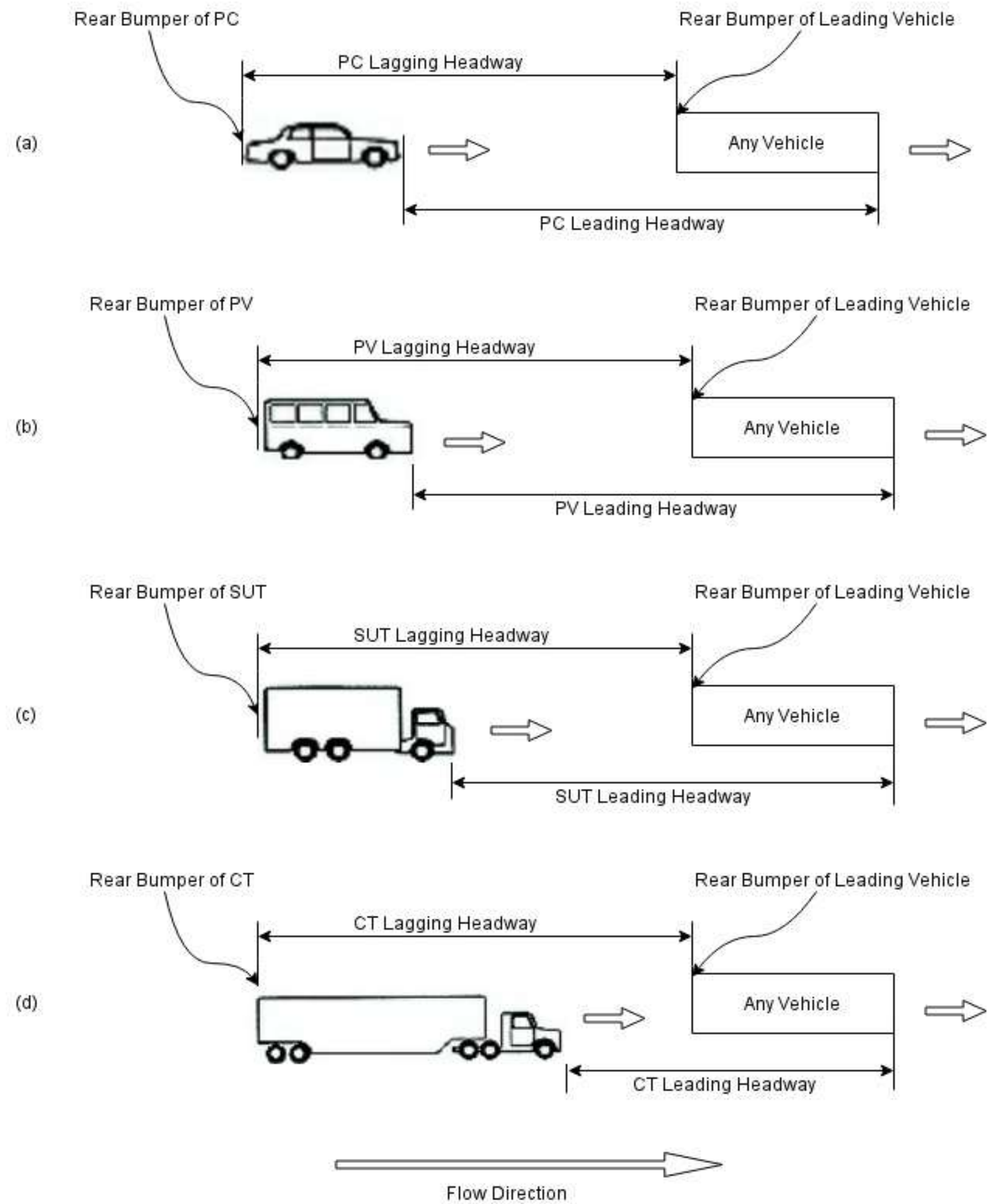


Figure 3. 1: Schematic spatial headway diagrams

For vehicle classification system, the Federal Highway Administration (FHWA) suggests 13 different vehicle classes. However, in many cases the source of data does not possess this much information. Vehicles classification offers a realistic and simple basis for calculations but it may not be as reliable as FHWA vehicle classification system. Therefore, the current study stratified vehicles into limited number of classes while taking into account the vehicle length. The vehicles have been stratified into four different classes i.e. passenger car (PC), passenger van (PV), single unit truck (SUT), and combination truck (CT) as presented in Table 3.1. Our aim was to calculate the spatial lagging headway for each of four vehicle classes in order to estimate PCE values separately for PV, SUT, and CT.

Table 3. 1: Vehicle classification by length

Vehicle type	Length (m)	Included Vehicles
Passenger Car	5.49	Car, Jeep, Suzuki carry
Passenger Van	6.1	Van, Hiace, Double cabin pickup
Single Unit Truck	10.67	Trucks with single frame body
Combination Truck	21.34	Trucks with multi frame body

3.2 Data Collection Sites

Determining the number and nature of data collection sites that yield necessary information regarding roadway geometry and traffic characteristics is the first step in collection of video data. In order to assess the traffic parameters, single road segment might be acceptable but data collection time span should be at least of numerous days. However, one should endeavor to select data collection site with sufficient traffic conditions variability. A number of data collection sites at various highways segments would not be critical but better. However, a large variety of locations becomes vital while assessing geometric impacts. For each section, information about highway geometry (length, number of lanes, grade, lane width, etc.) is essential to understand the geometric impacts. Similarly, data from different sites would be required to test the geographic factors that may affect PCEs.

Figure 3. 2: Video data collection sites

In this study, taking into consideration the HCM recommendations of free flow conditions and level terrain, four different sites were chosen along the Grand Trunk Road (N-5) near Islamabad, Pakistan: Two of the sites (Hassan Abdal and Faqeerabad) were located East and two sites (Mandra and Ghungrilla) were located South-West of the Islamabad (Figure 3.2). The details of individual sites can be seen in Figure 3.3 through Figure 3.6.

Figure 3. 3: Video data collection – Site 1

Figure 3. 4: Video data collection – Site 2

Figure 3. 5: Video data collection – Site 3

Figure 3. 6: Video data collection – Site 4

3.3 Collection of Video Data

Video recording is a method which is used to extract useful information such as vehicle counts and individual vehicle speed that are required for headway model development. In this study, video-recorded data has been utilized to develop a headway model. A digital video camera was used for the video recording. Arrangement was made by setting a video camera on the camera stand. The camera was adjusted such that it covered all the traffic lanes in order to capture the vehicles when they approached the camera. Figure 3.7 shows the setup for video data collection at one of the sites i.e. Ghungrilla.

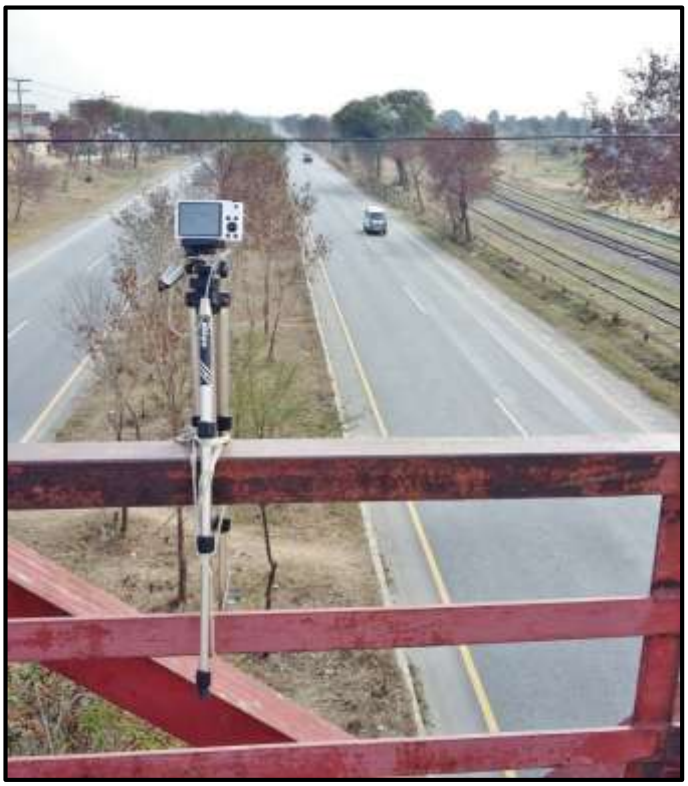


Figure 3. 7: Video camera setup at site 4 (Ghungrilla)

3.4 Data Description

The data used in this study was extracted from simple video clips. Each clip is of 10-minutes duration with enormous amount of information such as individual vehicle class, speed, spatial lagging headway, total vehicle flow, and number of lanes in which vehicles were travelling. For a specific study, video clips can be rerun to extract the necessary information. As the current study deals with spatial lagging headway estimation, only the essential information was extracted. A total of 2,480 lane-minutes video data were collected from four different locations from March 2014 to October 2014.

3.5 Chapter Summary

This chapter explained the headway ratio methodology adopted in the current study for PCEs estimation. In order to calculate the spatial lagging headways for different vehicle classes, they were grouped into four different classes on the basis of their length (passenger car, passenger van, single unit truck and combination truck). For field data collection, a digital video camera was used. The video data were collected at four different locations i.e. Faqeerabad, Hassan Abdal, Mandra and Ghungrilla. There were free flow traffic conditions at all the four selected sites with minimum grade.

CHAPTER 4. RESULTS AND DISCUSSION

4.1 Video Data Processing

The data used in present study were extracted from 10-minutes video clips. As the current study deals with spatial lagging headway estimation, only the essential information was extracted. Specifically, time stamp, speed, and vehicle's class (based on the stratified groups used in this study) were required. The recorded videos do not yield the required information automatically, so this information needs to be extracted through suitable tool. For this purpose, a software package "Traffic Tracker" was used. In all the video clips, each traffic lane was analyzed separately. For example in a video clip, if a road segment had two lanes, then same video clip was processed eight times for the extraction of required information (vehicle's class, vehicle count for each class, and time stamp to calculate the lagging headway) i.e. four times for lane-1 and four times for lane-2 for four different vehicle classes. Similarly, the same process was repeated for each video clip.

Before starting the process of data extraction, a software package Traffic Tracker was initialized and process was started. In the subsequent stage, two reference points/lines at known distance apart were selected from the video clip screen shot and referred as entry and exit points. When individual vehicle reached these reference points (time at which the individual vehicle front bumper touches the entry point and time at which the same individual vehicle front bumper touches the exit point), their time stamp was recorded. The start and end points of roadway lane markings (white broken line used for travel lanes separation in the same direction) were used as reference points for the individual vehicles entry and exit. Reference points at each location, based on the recorded video quality, can be established by measuring length of broken lines and space between them. The advantage of using these roadway markings as reference points is that it eliminates the requirement of actually gauging ground distances for each site. Entry and exit reference points are presented in Figure 4.1. The ends of two white markers and two spacings, successively, were demarcated as reference points. A distance of 120 feet (36.576 meters) was fixed between the two selected reference points.

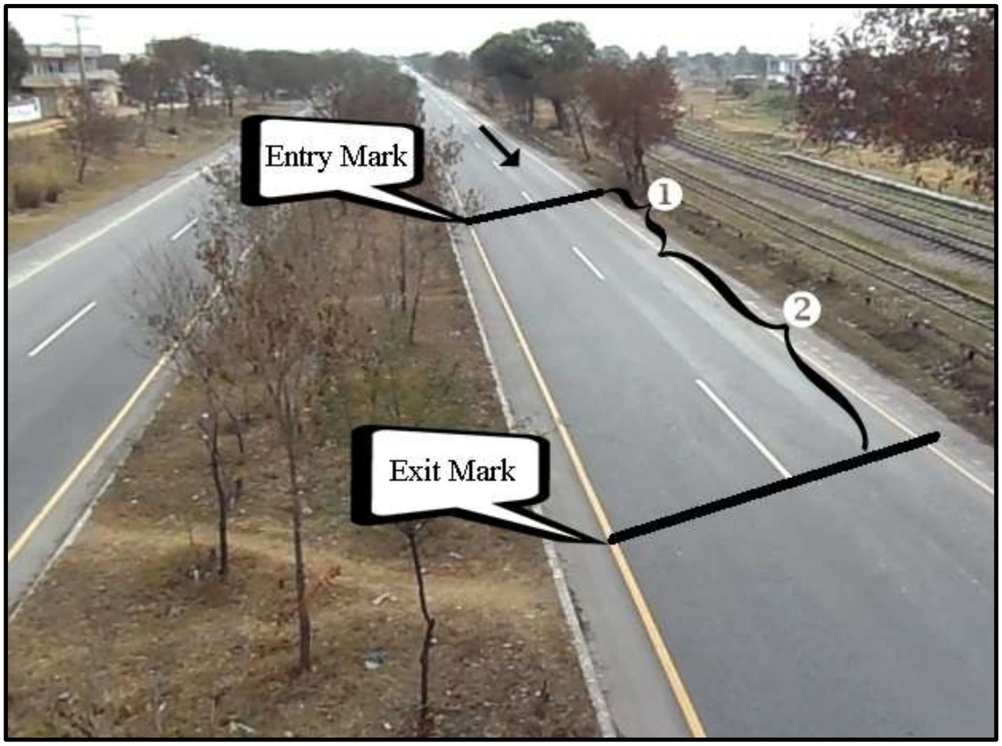


Figure 4. 1: Data extraction – vehicle entry and exit points

Traffic Tracker software does not recognize vehicles automatically but through different keyboard clicks. To fulfill this purpose, vehicles were grouped into four classes: passenger car, passenger van, single unit truck, and combination truck. For this specific assignment, eight different keys were used according to user comfort; one each for a vehicle (of a specific class) entry point and one for vehicle exit point. The different keys assigned to various vehicle classes are shown in Figure 4.2.

To obtain maximum accuracy during the keys recording process, 10-minute video clips were run at lower speed – half of their normal speed. The assigned entry key was pressed when a specific class vehicle reached first reference point and assigned exit key was pressed when the same specific class vehicle reached second reference point. Similarly, same process was repeated for other classe’s vehicle.

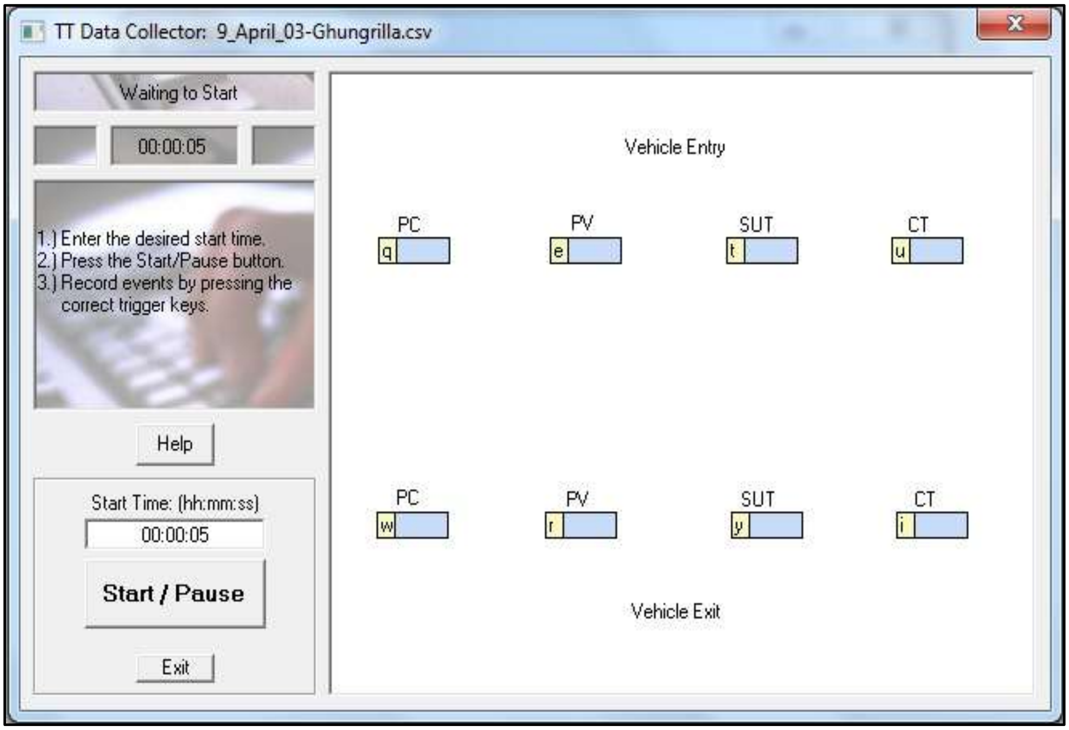


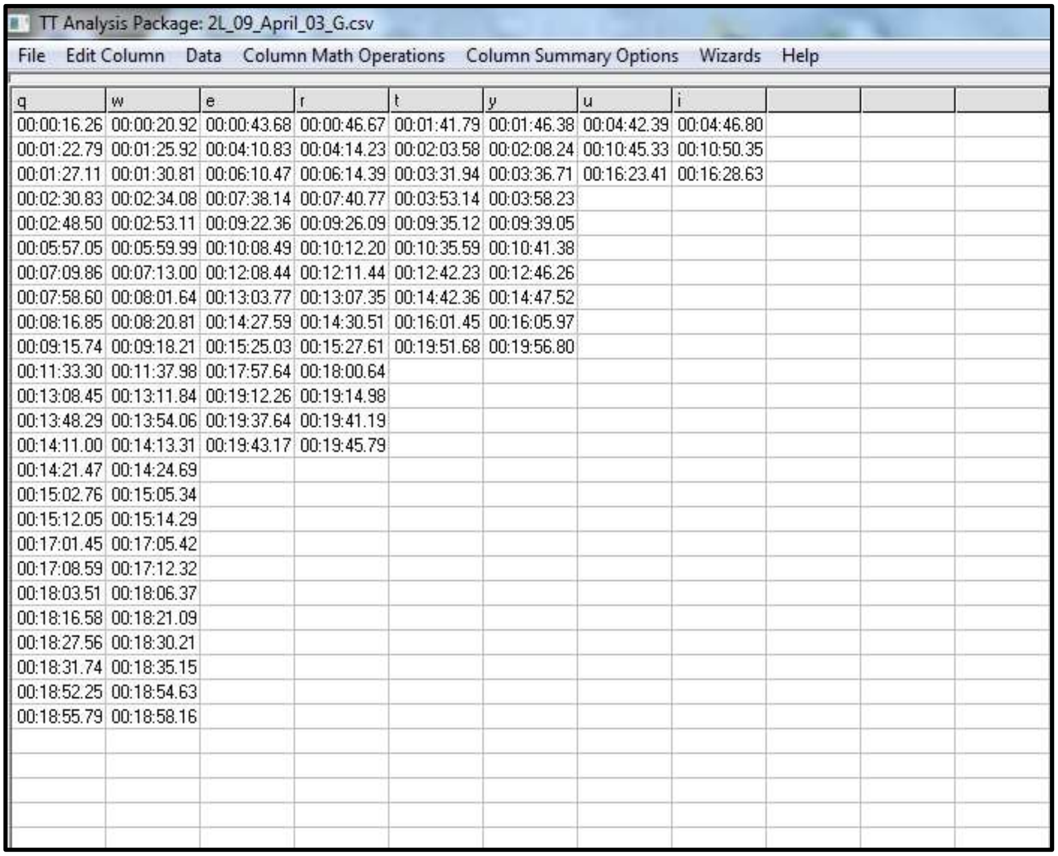
Figure 4. 2: Key designations of Traffic Tracker software

This procedure was repeated for each roadway lane for each 10-minute video. Keystroke data showing each vehicle class as well as entry and exit times was shifted into a worksheet at the completion of each video. Figure 4.3 shows the output (spreadsheet) from the software; various columns show individual vehicles entry and exit time.

The analysis focus then shifts to calculate the lagging headways. The total time consumed by individual vehicle between the entry and exit reference points can be obtained from the time difference when vehicle's front bumper touches entry point and when it touches the exit point. In order to get the actual time spent by individual vehicle in traversing first and second reference points, the time differences for individual vehicle were divided by two because videos were run at half of their normal speed. As total distance between first and second reference points is known, individual vehicles speed S_i can be calculated as follows:

$$S_i = \frac{L_{ST}}{(t_2 - t_1)} \quad (4.1)$$

where L_{ST} is the distance between two reference points while t_1 and t_2 are times when a vehicle reaches first and second reference points, respectively.



q	w	e	r	t	y	u	i
00:00:16.26	00:00:20.92	00:00:43.68	00:00:46.67	00:01:41.79	00:01:46.38	00:04:42.39	00:04:46.80
00:01:22.79	00:01:25.92	00:04:10.83	00:04:14.23	00:02:03.58	00:02:08.24	00:10:45.33	00:10:50.35
00:01:27.11	00:01:30.81	00:06:10.47	00:06:14.39	00:03:31.94	00:03:36.71	00:16:23.41	00:16:28.63
00:02:30.83	00:02:34.08	00:07:38.14	00:07:40.77	00:03:53.14	00:03:58.23		
00:02:48.50	00:02:53.11	00:09:22.36	00:09:26.09	00:09:35.12	00:09:39.05		
00:05:57.05	00:05:59.99	00:10:08.49	00:10:12.20	00:10:35.59	00:10:41.38		
00:07:09.86	00:07:13.00	00:12:08.44	00:12:11.44	00:12:42.23	00:12:46.26		
00:07:58.60	00:08:01.64	00:13:03.77	00:13:07.35	00:14:42.36	00:14:47.52		
00:08:16.85	00:08:20.81	00:14:27.59	00:14:30.51	00:16:01.45	00:16:05.97		
00:09:15.74	00:09:18.21	00:15:25.03	00:15:27.61	00:19:51.68	00:19:56.80		
00:11:33.30	00:11:37.98	00:17:57.64	00:18:00.64				
00:13:08.45	00:13:11.84	00:19:12.26	00:19:14.98				
00:13:48.29	00:13:54.06	00:19:37.64	00:19:41.19				
00:14:11.00	00:14:13.31	00:19:43.17	00:19:45.79				
00:14:21.47	00:14:24.69						
00:15:02.76	00:15:05.34						
00:15:12.05	00:15:14.29						
00:17:01.45	00:17:05.42						
00:17:08.59	00:17:12.32						
00:18:03.51	00:18:06.37						
00:18:16.58	00:18:21.09						
00:18:27.56	00:18:30.21						
00:18:31.74	00:18:35.15						
00:18:52.25	00:18:54.63						
00:18:55.79	00:18:58.16						

Figure 4. 3: Traffic Tracker worksheet

Once individual vehicles speed and time stamp are known, the leading and lagging headways of individual vehicles can be calculated as discussed in section 3.1. Now, the spatial lagging headway, LH_i, for individual vehicle i, is bounded as below:

$$Length_i \leq LH_i \leq (SSD_i + Length_i) \quad (4.2)$$

where $Length_i$ is the vehicle length in meter and SSD_i is the stopping sight distance required for vehicle "i". Both bounds are extremum of traffic congestion. The lower bound for lagging headway, LH_i, of individual vehicle "i" is the following vehicle length (complete congestion) while the upper bound is sum of stopping sight distance (SSD_i) and following vehicle length. In a traffic stream vehicle is not considered to be "following" leading vehicle, if the lagging headway of vehicle exceeds the upper limit. Such conditions, when vehicle's lagging headway physically exceeds the upper limit, suggest that vehicle's headway is not affected by low traffic. One can easily calculate SSD using following equation (AASHTO, 2001):

$$\text{Stopping Sight Distance}, SSD = 0.278Vt + \frac{0.039V^2}{a} \quad (4.3)$$

where V is the vehicle initial speed in kmph, t is the perception-reaction time, usually 2.5 sec, and a is the deceleration constant, 3.4 m/sec^2.

The collected data presents some challenges which are beyond modeling framework. Some of the 10-minutes video clips in the data do not contain vehicles from a specific class. Though the data processing structure provides a value of zero to average lagging headway of that vehicle class. Obviously, headway measurement is not possible for vehicles which do not exist. All such entries need to be removed from the dataset. To yield data for each class headway modeling, every observation must contain at least one vehicle from the interested class.

In this study, another challenge arises from the temporal data use. Although the collected data is split into 10-minutes durations, it is still possible that the previous average headway may affect the current average headway. This is termed as serial correlation. Washington et al. (2011) states that, generally, ignoring price of this effect is not grave: variables in ordinary least squares (OLS) become insignificant but are otherwise unbiased. However, the remaining variables may result in biasness due to the elimination of otherwise significant variables. To measure the magnitude of serial correlation, Durbin-Watson (DW) statistic is used (Durbin and Watson, 1951). There is no serial correlation if the DB value is close to 2. To cater for this issue, one has various options. One way is to include the serial correlation into disturbance term and converting the dependent variables to incorporate lagged (segment of previous time) variables (Washington et al., 2003). This is very striking as it directly addresses the issue; however, its application in simultaneous equation framework may be intensive. Another tractable method is to include exogenous variables that resolve serial correlation. In temporal data, time of day can be such a substitute. Once these challenges are resolved, a 3SLS regression model should be reliable and accurately specified. Table 4.1 presents the statistics summary of data collected.

Table 4. 1: Summary of the video recorded data

Variable	Unit	Mean	Standard deviation
PC Flow	PC/10 min	21.153	12.384
PV Flow	PV/10 min	7.274	4.807
SUT Flow	SUT/10 min	10.701	5.399
CT Flow	CT/10 min	2.177	1.459
Traffic Volume	Vehicles/10 min	41.306	13.793
Percent PC	Percentage	48.904	13.322
Percent PV	Percentage	16.751	7.925
Percent SUT	Percentage	28.675	15.412
Percent CT	Percentage	5.667	3.724
PC average speed	kmph	71.925	8.563
PV average speed	kmph	74.812	9.917
SUT average speed	kmph	52.136	6.444
CT average speed	kmph	50.093	9.395
PC average headway	meter	63.642	21.513
PV average headway	meter	67.417	32.762
SUT average headway	meter	56.172	17.311
CT average headway	meter	64.593	15.940

*Note: 1 meter = 3.2808 feet; 1 kmph = 0.6213 mph

4.2 Modeling framework

In the present study, a methodology has been adopted which calculates spatial lagging headway through statistical approach for four different classes of vehicles: passenger car, passenger van, single unit truck and combination truck. In the model for each vehicle class, the spatial lagging headways are dependent variables. Using the three-stage-least-squares (3SLS) regression, four equations were simultaneously modeled as the dependent variables are considered to have an impact on each other i.e. endogenous variables. To put it another way, the vehicles lagging headway of one vehicle class have direct influence on the vehicles lagging headway of other vehicle class. Strictly speaking, if single-equation appraisals like ordinary least squares regression would have been used for endogenous variables, the resulting findings would have serious biasness due to the presence of correlation between randomly correlated variables and random error terms (Washington et al., 2011). Moreover, for the positive values of lagging headways, models were formulated to estimate the natural logarithm of lagging headways. The mathematical structure of regression models is developed as follows:

$$Ln(H_{pc}) = \alpha_1 + \gamma_{pc} X_{pc} + \lambda ln(H_{pv}) + \tau ln(H_{sut}) + \delta ln(H_{ct}) + \varepsilon_{pc} \quad (4.4)$$

$$Ln(H_{pv}) = \alpha_2 + \gamma_{pv} X_{pv} + \alpha ln(H_{pc}) + \varphi ln(H_{sut}) + £ln(H_{ct}) + \varepsilon_{pv} \quad (4.5)$$

$$Ln(H_{sut}) = \alpha_3 + \gamma_{sut} X_{sut} + \Omega ln(H_{pc}) + \mu ln(H_{pv}) + \beta ln(H_{ct}) + \varepsilon_{sut} \quad (4.6)$$

$$Ln(H_{ct}) = \alpha_4 + \gamma_{ct} X_{ct} + \eta ln(H_{pc}) + \psi ln(H_{pv}) + \xi ln(H_{sut}) + \varepsilon_{ct} \quad (4.7)$$

where $ln(H_i)$ is the natural logarithm of type i vehicle average lagging headway, γ_i is a vector of estimable parameters, X is a vector of known traffic data (e.g. total vehicle flow, individual vehicle class flow, average speed of vehicle class, and percent PC, PV and trucks), λ, τ, δ, α, φ, £, Ω, μ, β, η, ψ, and ξ are estimable scalars, and ε_i is the error term.

The relationship nature between the dependent variables helps in the selection of system equation method. In this situation $ln(H_{pc})$, $ln(H_{pv})$, $ln(H_{sut})$, and $ln(H_{ct})$ are endogenous variables which means that influential variables set of $ln(H_{pv})$, $ln(H_{sut})$, and $ln(H_{ct})$ includes $ln(H_{pc})$. In the same way $ln(H_{pc})$ and $ln(H_{pv})$ belong to the independent variables set of $ln(H_{sut})$, and $ln(H_{ct})$ and so on. Thus, the 3SLS regression is felicitous for the simultaneous estimation of equations parameters while taking into account the endogeneity among the dependent variables and correlation of the disturbance terms (Anastasopoulas**,** 2009).

The 3SLS regression is an extension of conventional techniques such as two-stage least squares (2SLS) regression. There are two stages in 2SLS. In stage 1, each endogenous variable (average lagging headway of class, H_i's) is regressed using all exogenous variables (traffic variables, X's). In stage 2, headways predicted in stage 1 are used as instruments for endogenous terms for each equation through ordinary least square

(OLS) estimation. According to Washington et al., (2003), the 2SLS results (in this specific case) are consistent but biased.

The 3SLS regression offers unbiased solution. In 3SLS, the first stage is to calculate 2SLS parameter estimates. In stage 2, these results are used for the estimation of cross-equation disturbance-term correlations. Generalized least squares (GLS) is used in stage 3 for computation of parameter estimates. The outputs of this GLS computation comprise the final results of 3SLS estimation. 3SLS provides more effective parameter estimates and knowledge about their impact on dependent variables.

4.3 Headway Model Results

The study developed a four-equation three-stage-least-squares (3SLS) regression model using 124 observations. Each observation represents average value that is extracted from a single 10-minutes video clip. All 124 observations are only those observations in which four different vehicle's lagging headways were measured. The results of four equations 3SLS regression model are displayed in Table 4.2. The first column contains the descriptive list of various dependent variables while the second column contains list of significant variables. The third column contains the calculated exploratory factors. Last column hosts significance of each variable; a $|\text{t-stat}| \geq 1.96$ represents the 95% confidence interval.

The results for passenger car lagging headway show that PC average speed and lagging headway of CT are significant variables. The positive sign for PC average speed indicates that with increase in PC average speed, the lagging headway of PC also increases. This is intuitive as vehicles at higher speed require larger stopping distance and drivers prefer to keep more distance between their vehicle and the leading vehicle. The lagging headway of CT has a significant negative relationship with PC lagging headway which may be due to difference between two vehicle classes travel behavior.

The CT flow (CT/10 minutes) and average PV speed have significant positive relationship with the passenger van lagging headway. The PV lagging headway increases with the increase in CT flow rate which may be due to the reason that PV drivers become more cautious in the presence of CT and keep greater distance from the leading vehicle when more CT are added to the traffic stream. The positive relationship of average PV speed with the PV lagging headway is also intuitive as at higher speed, drivers become cautious and prefer to keep greater distance from the vehicle ahead of them. Moreover, the endogenous variable SUT lagging headway is positively significant; meaning an increase in SUT lagging headway is accompanied by increase in passenger van lagging headway.

The equation for SUT lagging headway suggests that both the PC flow and SUT flow are important variables which possess significant negative relationship with the lagging headway of SUT. This is intuitive; as addition of vehicles to the traffic stream is accompanied by more spatial constraints and thus, vehicles reduce their lagging headway. The results also show that increase in SUT speed is accompanied by increase in the lagging headway of SUT. It means that SUT drivers exercise caution at higher speeds and keep greater distance between themselves and the vehicle ahead of them.

The value of adjusted R^2 for CT equation is 0.534 which is highest among all the four equations. The result suggests that both the average speeds of PC and CT are important variables which affect the CT lagging headway. An increase in both the speeds of PC and CT results in an increase in CT lagging headway; meaning that CT prefer to have more space in front of them at higher speeds and feel comfortable with fast travelling PC. In addition, the endogenous variable SUT lagging headway has positive significant relationship with CT lagging headway. Possibly, this could be due to some unobserved similarities in travel pattern of these two vehicle classes.

Table 4. 2: Estimated four-equation 3SLS regression model results

Elements	Significant Variables	Coefficients	t-stat
Ln(PC Lagging Headway)	Constant	4.840	8.703
	PC speed (kmph)	0.023	5.781
	Ln(CT headway (m))	-0.575	-4.026
Adjusted R^2		0.216	
Durbin-Watson statistic		1.971	
Ln(PV Lagging Headway)	Constant	1.429	2.248
	CT flow (CT/10 min.)	0.064	2.088
	PV speed (kmph)	0.015	3.473
	Ln(SUT headway (m))	0.342	2.379
Adjusted R^2		0.129	
Durbin-Watson statistic		1.952	
Ln(SUT Lagging Headway)	Constant	3.489	15.305
	PC flow (PC/10 min.)	-0.011	-4.294
	SUT flow (SUT/10 min.)	-0.020	-3.735
	SUT speed (kmph)	0.018	4.328
Adjusted R^2		0.201	
Durbin-Watson statistic		2.000	
Ln(CT Lagging Headway)	Constant	2.478	12.075
	PC speed (kmph)	0.004	2.396
	CT speed (kmph)	0.016	9.491
	Ln(SUT headway (m))	0.145	3.023
Adjusted R^2		0.534	
Durbin-Watson statistic		1.500	
N		124	

*Note: 1 meter = 3.2808 feet; 1 kmph = 0.6213 mph

The Mean Absolute Percent Error (MAPE) can be used for the measurement of prediction accuracy of developed model by using the following equation (Washington et al., 2011):

$$\text{MAPE} = \left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{A_i - P_i}{A_i}\right)\right] * 100 \qquad (4.8)$$

where A_i and P_i are the actual and predicted headway for observation i, respectively.

The MAPE results for respective vehicle class are presented in Table 4.3 for four-equation 3SLS regression model. Greater accuracy is inferred from MAPE values closer to zero. For instance, a MAPE value of 0.014 (as for the CT average headway) signifies that on average, model overestimates or underestimates the actual values by 1.4%. The predicted over the actual headway estimates by vehicle class are presented in Figure 4.4 through Figure 4.7 and graphically shows that the four-equation 3SLS regression model predictive accuracy is satisfactory. In Figure 4.4 through Figure 4.7, the equivalence of predicted and actual estimates are represented by the straight line.

Table 4. 3: MAPE values for different vehicle classes

Vehicle Class	MAPE values
Average headway of PC	0.086
Average headway of PV	0.087
Average headway of SUT	0.033
Average headway of CT	0.014

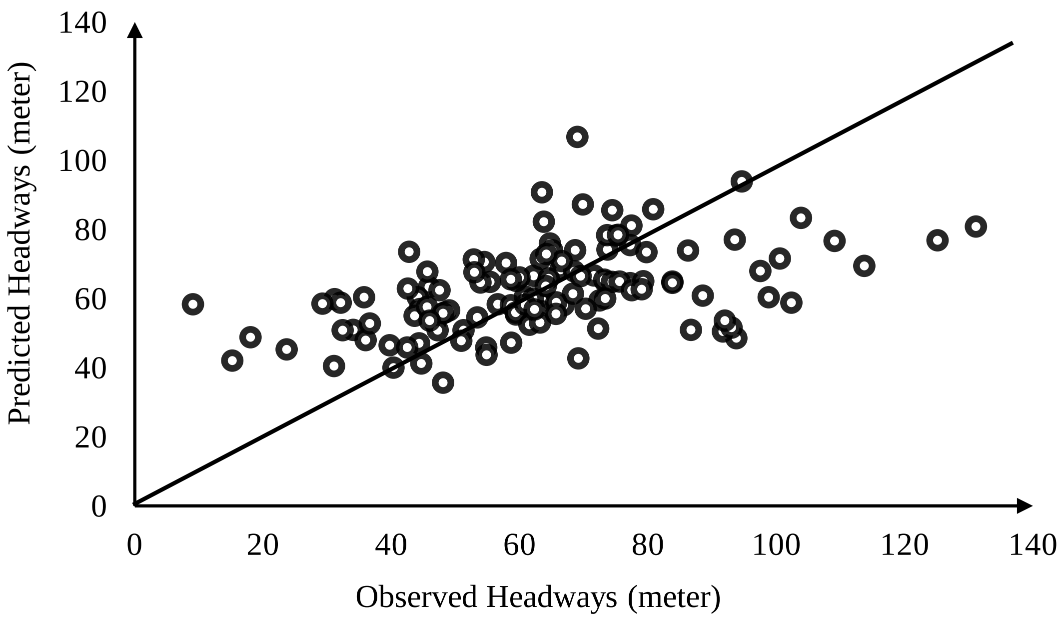


Figure 4. 4: Predicted vs observed headways of passenger car

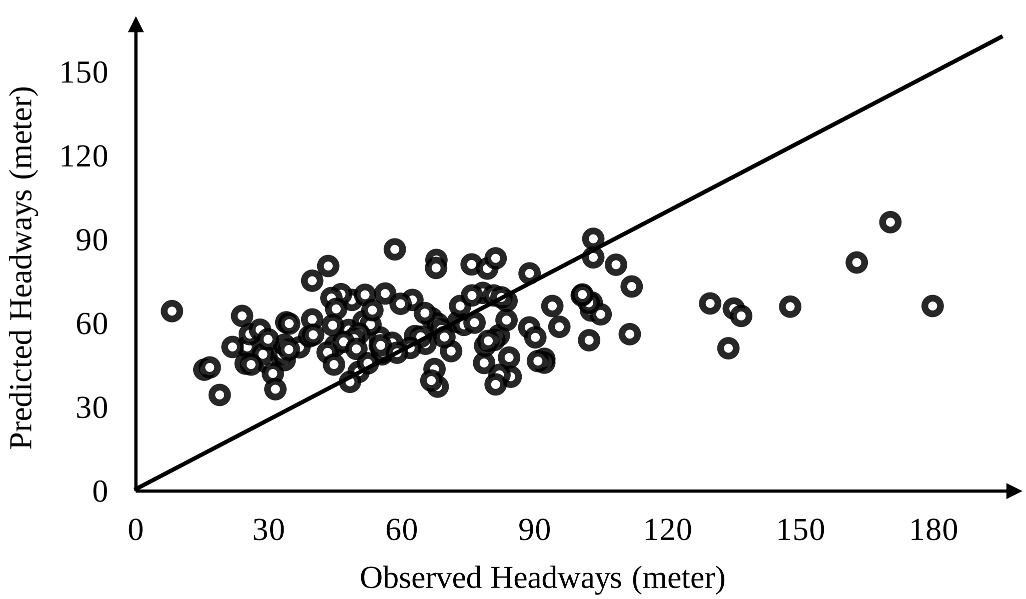


Figure 4. 5: Predicted vs observed headways of passenger van

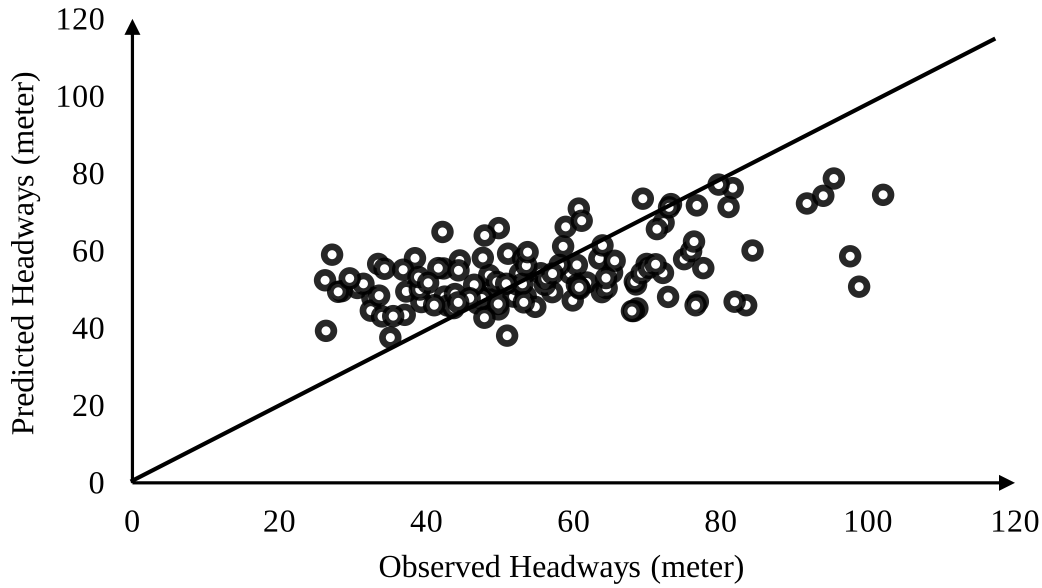


Figure 4. 6: Predicted vs observed headways of single unit truck

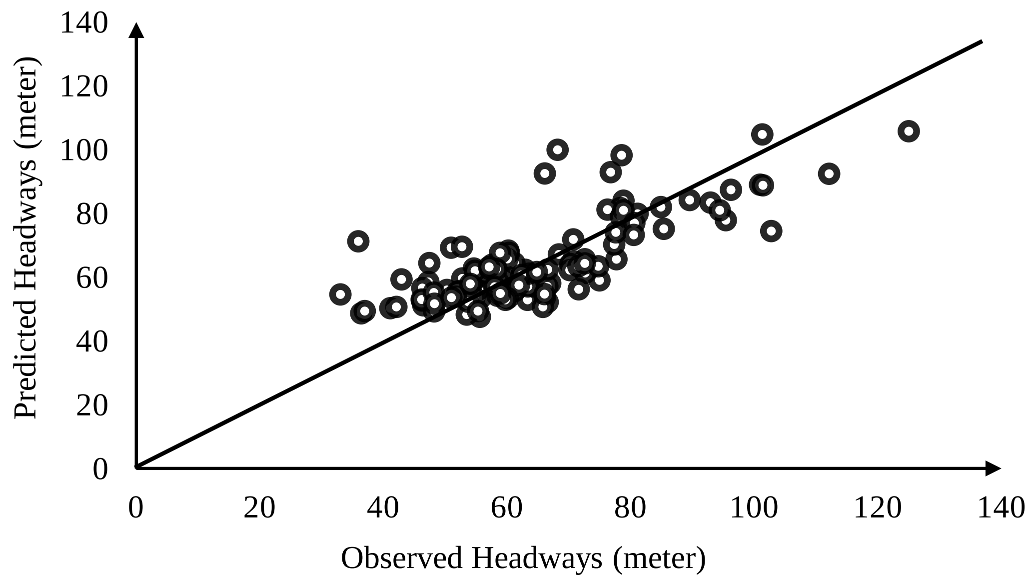


Figure 4. 7: Predicted vs observed headways of combination truck

The lagging headway measured for passenger car came to be 63.642 meters, 67.417 meters for passenger van, 56.173 meters for single unit truck and 64.593 meters for combination truck. The longest lagging headway was observed for passenger van as they exercise highest speed among the all four vehicle classes. The single unit truck and combination truck do not keep longer headways under stable stream conditions as both the vehicle classes exercise lower speeds. The headways directly predicted by four-equation 3SLS regression model, using Equations 4.4 to 4.7, are 62.352, 58.762, 54.209, and 64.188 meters for passenger car, passenger van, single unit truck and combination truck respectively. Table 4.4 contains the comparison between measured and predicted headways using four-equation 3SLS regression model along with the percent deviation of predicted values from the actual values.

Table 4. 4: Comparison of observed and predicted headways

Headway Type	Observed Headway (m)	Predicted Headway (m)	% Deviation
Passenger Car Average Lagging Headway	63.642	62.352	2.027%
Passenger Van Average Lagging Headway	67.417	58.762	12.838%
Single Unit Truck Average Lagging Headway	56.173	54.209	3.496%
Combination Truck Average Lagging Headway	64.593	64.188	0.627%

*Note: 1 meter = 3.2808 feet

4.4 Calculation of PCE Values

PCE values possess the potential to appropriately and accurately convert the mixed traffic flow into passenger car stream. Different PCE value estimates are obtained by using different methodologies which ultimately leads to different densities of traffic and level of service. The ratio of PV, SUT or CT spatial lagging headways to PC spatial lagging headway results in PCEs for each vehicle class. The PCE values obtained in the present study for passenger van, single unit truck and combination truck are 0.94, 0.87 and 1.03 respectively. Table 4.5 presents the comparison of predicted PCEs estimates with those recommended by HCM. The predicted PCE values delivered by four-equation 3SLS regression model using actual observations for three different vehicle classes differ from HCM provided PCE values. As presented in the Table 4.5, predicted PCE values vary from HCM recommended PCE values between 45 percent and 75 percent for single unit truck and combination truck respectively, while 6 percent for passenger van. The PCE values provided by the current study for single unit truck and combination truck vary by greater percentage. Other locations may experience greater or lesser disparity between the actual traffic measurements based PCE values and HCM recommended single PCE values depending upon the volume of traffic flow.

Table 4. 5: Comparison between present study and HCM provided PCE values

Vehicle Class	Predicted PCE values (Present study)	HCM provided PCE values	% Deviation
Passenger Van	0.94	1.0	-6.38%
Single Unit Truck	0.87	1.5	-72.41%
Combination Truck	1.03	1.5	-45.63%

4.5 Chapter Summary

This chapter presented analysis of video collected data and model results. The video data were collected at four different locations. Using software package "Traffic Tracker", 10-minutes video clips were processed to extract necessary information. A four-equation 3SLS regression model was developed as a function of various traffic variables for the spatial lagging headway prediction of different vehicle classes i.e. passenger car, passenger van, single unit truck and combination truck. To check the model goodness of fit, calibration of model was performed. In addition, the developed PCE values were compared with PCE values recommended by HCM. The results showed that the PCE values developed in the current study for rural arterials greatly vary from HCM provided PCE values for single unit truck and combination truck.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Synopsis of the Research

The focus of this study was to investigate vehicle travel characteristics on rural arterials of Pakistan through establishment of PCE values for different vehicle classes including PV, SUT and CT. Firstly, a detailed review of literature at both the national and international level was carried out regarding various methodologies used for PCEs establishment. Review of the international researches helped to classify different methodologies used in different countries for estimating PCE values. The various issues during video data collection and collation were also highlighted in the literature review. Also, review of various national studies helped to identify the methodologies used by different researchers for urban and rural locations. After the literature review and selection of video data collection sites, video data were collected from four different locations on rural arterial (Grand Trunk Road N-5) near Islamabad, to develop a four-equation three-stage-least-squares (3SLS) regression model to estimate lagging headways for passenger car, passenger van, single unit truck and combination truck. The current study, using headway ratio methodology, estimated PCE values of 0.94, 0.87 and 1.03 for passenger van, single unit truck, and combination truck respectively. Moreover, the present study revealed that not only different classes of vehicle maintain different headways, but the headway of one vehicle class directly depends on the headway of other vehicle class. The passenger vans maintain greater lagging headway (67.417 m) among the four vehicle classes i.e. PC, PV, SUT and CT. Besides low speed (50.09 kmph), the average lagging headway of combination trucks was found to be 64.593 m which may be due to the reason that CT drivers prefer to keep greater distance from the leading vehicle due to their vehicle size.

The 3SLS regression model predicted headways on the basis of actual field data provide reliable estimation of PCE values for PV, SUT and CT. The estimated model predicted lagging headway within 2, 12.8, 3.5 and 1 % of the actual observed headway for PC, PV, SUT and CT respectively. The current study revealed that various traffic variables such as vehicles speed and flow rates have substantial effect on the spatial headway of vehicle. Lastly, the estimated PCE values for different vehicle classes were compared with the HCM provided PCE values. The comparison revealed significant difference between the present study and HCM provided PCE values especially for SUT and CT.

5.2 Conclusions

A detailed review of the previous national research revealed that in Pakistan, no serious effort has been made to estimate PCE values for different vehicle classes at rural arterials while for urban arterials, few studies have been carried out. Different researchers carried out studies using limited data from different urban arterials of few big cities like Karachi and Lahore. Literature review also confirmed that there is significant difference among PCE values estimated for same vehicle class by different researchers. This might be attributed to the differences in data sets and PCE estimation methodologies adopted by different past studies.

With the aforementioned lack of established PCE values for different vehicle classes at rural arterials of Pakistan, the present study estimated PCE values using headway ratio methodology for three different vehicle classes (PV, SUT and CT). The study results showed that there is no significant difference in the travel behavior of two vehicle classes (PC and PV) as they exercise almost similar speed and headway. This suggests that the two vehicle classes can be grouped together in various traffic operational analysis. The study results also showed that the traffic stream on rural arterials is highly non-homogenous with some extremely slow moving vehicles especially CT. This study did not find any conclusive evidence that SUT headway is considerably different from CT headways. Lastly, the estimated PCE values for different vehicle classes were then compared with the Highway Capacity Manual provided PCE values. The comparison showed a significant difference between the present study and HCM provided PCE values for both SUT and CT.

5.3 Recommendations

In the present study, although, an attempt has been made to establish PCE values for different vehicle classes by using headway ratio methodology, yet additional efforts are needed to further refine and polish the study results. Further efforts should be made to expand the data collection base for both the urban and rural arterials of Pakistan. If useful information such as shoulder width, lane width, number of lanes, segment grade, length of segment, day of month and climatic conditions are available for each highway segment, then the developed model can cater for varying traffic, geometry and climate. Also in future research, expert's opinions should be sought to establish PCE values for different vehicle classes.

REFERENCES

AASHTO, (2001), 4th edition. “Policy on Geometric Design of highways and Streets”, American Association of State Highway and Transportation Officials, Washington, DC.

Adnan, M. (2014). “Passenger car equivalent factors in heterogeneous traffic environment-are we using the right numbers?” Procedia Engineering, 77, pp. 106-113.

Ahmed, A., Van Boxel, D., Volovski, M., Anastasopoulos, P., Labi, S., and Sinha, K. C. (2011). “Using Lagging Headways to Estimate Passenger Car Equivalents on Basic Freeway Sections.” Journal of Transportation of the Institute of Transportation Engineers, 2(1).

Al-Kaisy, A., Hall., F. L., and Reisman, E. S. (2002). “Developing passenger car equivalents for heavy vehicles on freeways during queue discharge flow.” Transportation Research Part A: Policy and Practice, 36(8), pp. 725-742.

Anastasopoulos, P. (2009). “Infrastructure asset management: A case study on pavement rehabilitation.” Ph.D dissertation, Purdue University.

Craus, J., Polus, A., and Grinberg, I. (1979). “A revised method for the determination of passenger car equivalencies.” Transportation Research Part A: General, 14(4), pp. 241-246.

Cunagin, W. D., and Chang, E. C. (1982). “Effects of trucks on freeway vehicle headways under off-peak flow conditions.” Transportation Research Record No. 869. Transportation Research Board. Washington, DC.

Cunagin, W. D., and Messer, C. J. (1983). “Passenger car equivalents for rural highways (Discussion).”

Demarchi, S., and Setti, J. (2003). "Limitations of passenger-car equivalent derivation for traffic streams with more than one truck type." Transportation Research Record: Journal of the Transportation Research Board(1852), pp. 96-104.

Durbin, J., and Watson, G. S. (1951). "Testing for serial correlation in least squares regression. II." Biometrika, pp. 159-177.

Elefteriadou, L., Torbic, D., and Webster, N. (1997). "Development of passenger car equivalents for freeways, two-lane highways, and arterials." Transportation Research Record: Journal of the Transportation Research Board(1572), pp. 51-58.

Fan, H. S. (1990). "Passenger car equivalents for vehicles on Singapore expressways." Transportation Research Part A: General, 24(5), pp. 391-396.

Greenshields, B. D., Schapiro, D., and Ericksen, E. L. (1947). "Traffic performance at urban street intersections." Technical report No. 1. Bureau of highway traffic, Yale University.

Highway Research Board. (1950). "Highway Capacity Manual: Practical Applications for Research." Department of Traffic and Operations, Committee on Highway Capacity, United States Government Printing Office, Washington, DC.

Highway Research Board. (1965). "Special Report 87, Highway Capacity Manual, National Research Council," Department of Traffic and Operations, Committee on Highway Capacity, Washington, DC.

Highway Capacity Manual. (2000). TRB, National Research Council, Washington, DC.

Highway Capacity Manual. (2010). TRB, National Research Council, Washington, DC.

Huber, M. J. (1982). "Estimation of passenger-car equivalents of trucks in traffic stream (discussion and closure)." Transportation research record, (869).

Krammes, R. A., and Crowley, K. W. (1986). "Passenger car equivalents for trucks on level freeway segments." Transportation Research Record(1091), pp. 10-17.

Linzer, E. M., Roess, R. P., and McShane, W. R. (1979). “Effect of trucks, buses, and recreational vehicles on freeway capacity and service volume.” Transportation Research Record(699), pp. 17-24.

Rakha, H., Ingle, A., Hancock, K., and Al-Kaisy, A. (2007). “Estimating truck equivalencies for freeway sections.” Transportation Research Record: Journal of the Transportation Research Board(2027), pp. 73-84.

Saha, P. M., Iqbal, H., Quazi S., and Islam, M. Z. (2009). “Passenger car equivalent (PCE) of through vehicles at signalized intersections in Dhaka Metropolitan City, Bangladesh.” IATSS research, 33(2), pp. 99-104.

Sarvi, M. (2009). “Freeway Operation Characteristics of Heavy Commercial Vehicle Traffic.” Paper presented at the Transportation Research Board 88th Annual Meeting.

Seguin, E., Crowley, K., and Zweig, W. (1982). “Passenger Car Equivalents on Urban Freeways.” Report DTFH61-80-C-00106, Institute for Research State College, Pennsylvania.

Sumner, R., Hill, D., and Shapiro, S. (1984). “Segment passenger car equivalent values for cost allocation on urban arterial roads.” Transportation Research Part A: General, 18(5), pp. 399-406.

Tanaboriboon, Y. and Aryal, R. (1990). “Effect of vehicle size on highway capacity in Thailand.” Journal of Transportation Engineering, 116(5), pp. 658-666.

Van Aerde, M., and Yagar, S. (1983). “Capacity, Speed and Platooning Vehicle Equivalents for Two-Lane Rural Highways.” Transportation Research Record: Journal of the Transportation Research Board, 971, pp. 58-67. Washington, DC.

Van Boxel, D., Sinha, K. C., Bullock, D. M., and Mannering, F. L. (2010). “An Exploratory Study of Vehicle Class Headway Ratios as Passenger Car Equivalence Values Using Three Stage Least Squares Estimation.” Paper presented at the Transportation Research Board 89th Annual Meeting.

Washington, S. P., Karlaftis, M. G., and Mannering, F. L. (2011). "Statistical and econometric methods for transportation data analysis." Boca Raton, FL: Chapman and Hall/ CRC press.

Werner, A. and Morrall, J. F. (1976). "Passenger car equivalencies of trucks, buses, and recreational vehicles for two-lane rural highways." Transportation Research Record, 615, pp. 10-17.

Zhao, W. (1998). "Delay-based passenger car equivalents for heavy vehicles at signalized intersections." Paper presented at the Traffic and Transportation Studies.