Estimating PCU of Unconventional Modes of Transport

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APPROVAL

The dissertation entitled "***Estimating PCU of Unconventional Modes of Transport***", by Md. Sowaad Chowdhury has been approved fulfilling the requirements for the Bachelor of Science Degree in Civil Engineering.

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DECLARATION

I hereby declare that the undergraduate research work reported in this thesis has been performed by me under the supervision of Assistant Professor **Dr. Moinul Hossain** and I have taken reasonable care to ensure that this work has not been submitted elsewhere for any purpose.

_____

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ABSTRACT

Passenger Car Unit (PCU) is one of the fundamental measures in traffic engineering representing the impact a vehicle has on a road. Several major calculations in traffic, such as, capacity analysis, density determination, signal timing, etc. require conversion of traffic data into PUC. In most cases, the PCU values of conventional vehicles, such as, various kinds of trucks, buses, motorcycles, etc. are already determined by the related agencies of government. However, in the context of developing countries, a substantial part of the traffic comprise of unconventional modes of transport (UCM). Being a developing city, Dhaka city also accommodates various UCM, such as, leguna, auto-rickshaw, easy bike, etc. This study calculates the PCU values of these modes using both Speed-Data analysis method and Headway analysis method. Moreover, by calculating the Standard Deviation from these methods, the discrepancy from average value calculated in different methods are also determined.

The average PCU for auto-rickshaw using speed-data analysis method is calculated as 0.828 and from headway analysis method it is calculated as 0.642. Also the average PCU of leguna is calculated as 1.31 (speed-data analysis method) and 1.49 (headway analysis method). The difference of results using two different methods is due to inappropriate headway compared to the road conditions.

This dissertation will cover the overall procedure in finding the PCU, considering that these modes of transport play a vital role in the transportation system. Along with this, important problems are also mentioned and the difference of results obtained from different methods is showed. The reasons for the difference in PCU values are described briefly. Due to governmental jurisdictions it was not possible to take data from every roads. However, this research has huge potential in contributing to future road analysis by different organizations.

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LIST OF ACRONYMS

BRT	Bus Rapid Transit
BRTA	Bangladesh Road Transport Authority
CNG	Compressed Natural Gas
DCC	Dhaka City Corporation
DMP	Dhaka Metropolitan Police
HCM	Highway Capacity Manual
IRC	Indian Road Congress
LOS	Level of Service
NMT	Non-Motorized Traffic
OT	Occupancy Time
PC	Potential Capacity
PCE	Passenger Car Equivalent
PCU	Passenger Car Unit
QCR	Queue Clearance Rate
RHD	Roads & Highway Department
SD	Standard Deviation
TRB	Transportation Research Board
UCM	Unconventional Modes of Transport

NOTATION & DEFINITION OF VARIABLES

Vc	Speed of standard passenger car
Vi	Speed of ith class of vehicle
Ac	Area of standard passenger car
Ai	Area of ith class of vehicle
Hi	Average headway for ith class of vehicle
Hc	Average headway for standard passenger car
Hm	Average headway for sample including all vehicle types
Hb	Average headway for sample passenger car only
Pc	Proportion of standard passenger car
Pt	Proportion of t class of vehicles (in case of vehicles with low LOS)
Xi	Respective PCU value
$\bar{X}$	Mean PCU value
N	No of sample

Chapter 1

Introduction

1.1. Introduction

Population is an unbearable burden for Bangladesh. Bangladesh happens to be one of the most densely populated countries in the world. In an area as small as 555981 square miles, Bangladesh has a population of over 166 million, as of September, 2018. Bangladesh ranks number 8 in the list of countries by population. Also the population density is 1293 per km^2. Every year more than two million people are being added to our population. The problem is now so out of control that it has reached the position of being called 'Explosion' (*United Nations estimate, 2018).*

Basically, the major cities here, are the eight divisions namely, Dhaka, Khulna, Mymensingh, Rajshahi, Sylhet, Chittagong, Barishal and Rangpur. Of these, Dhaka is by far the most populated and have a mixed traffic stream all around the city. Besides Dhaka, the other cities also have a mixed traffic but the diversity is very small, consisting of not more than 4-5 modes of vehicles.

Dhaka is a city of heterogeneous vehicles. Human puller to latest model automobile, mechanical to non-mechanical, slow to fast-moving, every one of these can be found in the streets of Dhaka. It is quite difficult to control all these vehicles on the same road as they have different speed capacity. Besides this, public transport system in Dhaka city is not adequate and properly-routed. Instead of big and spacious buses, presence of large number of mini-buses and private vehicles can only contribute to carry few passengers, but not to reduction of traffic congestion.

The city is experiencing massive traffic congestion with the continued economic growth and development. Currently, there are approximately 500,000 rickshaws, 964500 registered motor vehicles and another 400,000 unregistered motor vehicles operating on the roads of Dhaka (*RHD, 2013*).

In my research, I have worked on estimating the PCU of unconventional modes of transport, namely Auto-Rickshaw and Leguna. Although there are other UCMs in our country i.e. Rickshaw, two/three stroke wheeler; I'll be conducting the research on those two modes only.

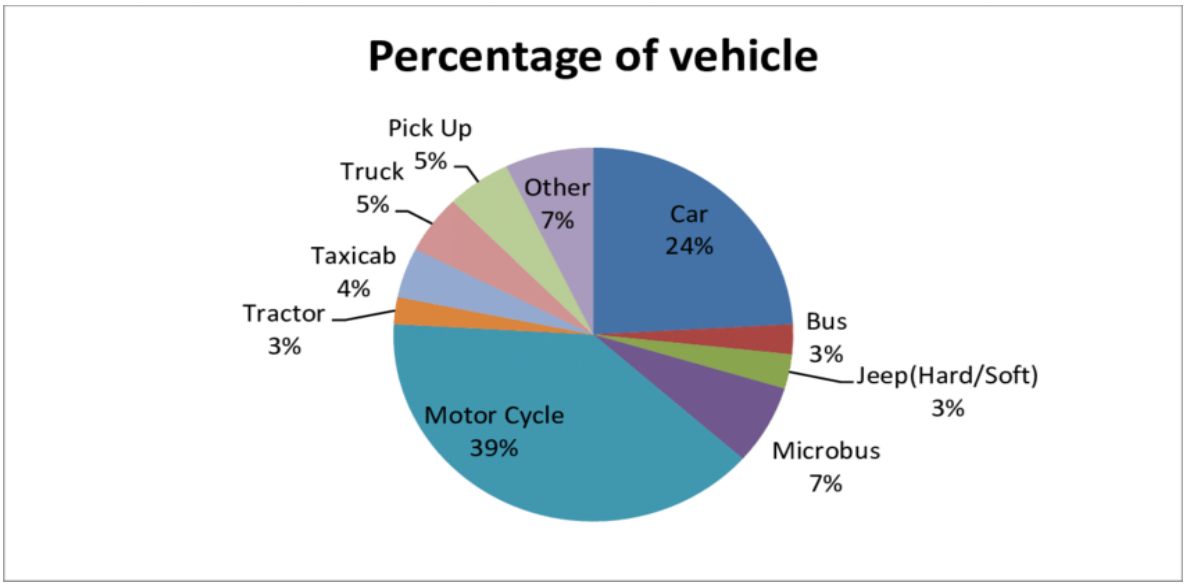

Fig 1.1: Composition of vehicles in Dhaka city *(source : Bangladesh Road Transport Authority BRTA, 2014)*

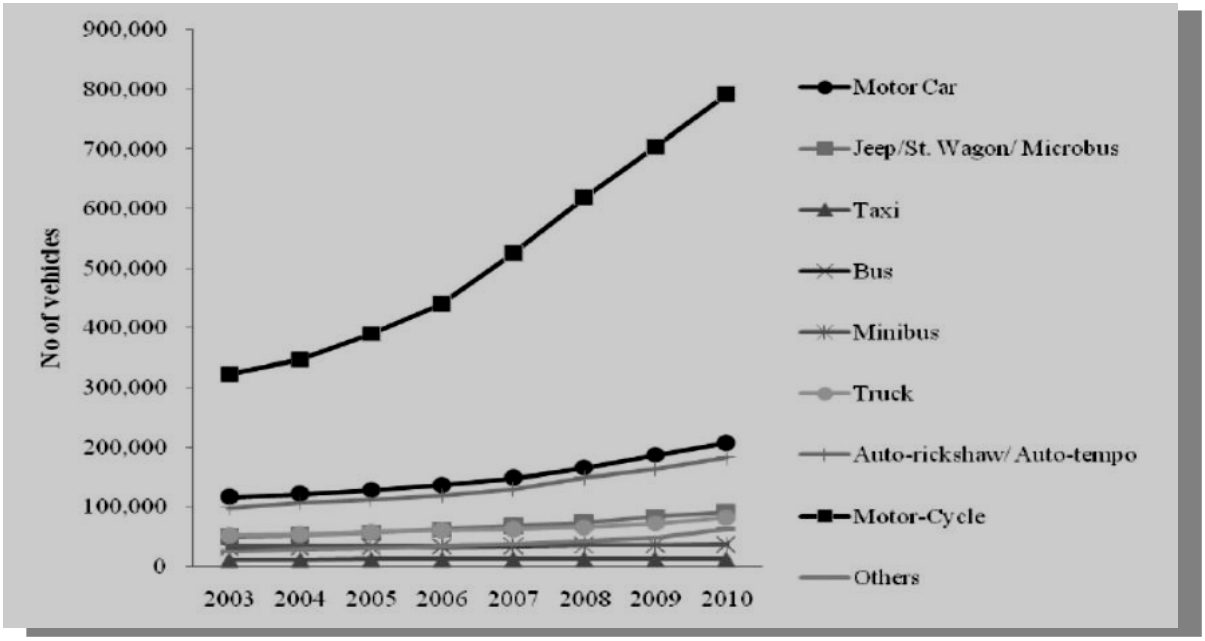

Fig 1.2: Gradual increase of vehicles, *Source: 1st International Conference on Civil Engineering for Sustainable Development (ICCESD-2012)*

1.2. Definition of PCU

Primarily, the traffic in our country is heterogeneous and consists of a wide variety of vehicles, each with difference in static and dynamic characteristics. To estimate volume of such heterogeneous traffic it is essential to convert the different types of vehicles into equivalent passenger cars and express the volume in terms of Passenger Car Unit (PCU) per hour. The equivalency unit is universally adopted for measurement of traffic volume and the value is obtained by taking the passenger car as the 'Standard Vehicle.' There are many studies available in literature to estimate the PCU of different categories of vehicles under heterogeneous traffic conditions in India and other countries.

The term PCU was first introduced in the *Highway Capacity Manual (1965)* and reported for grades of specific length and percent, proportion of trucks, and LOS (A-E). In the *Highway Capacity Manual (2000),* PCE is defined as 'the number of passenger cars displaced by a single heavy vehicle of a particular type under specified roadway, traffic, and control conditions.'

In general, A Passenger Car Equivalent is essentially the impact that a mode of transport has on traffic variables (such as headway, speed, density) compared to a single car.

Table 1.1: List of sample PCU for different types of vehicles

Vehicle type	Bus	CNG	Car	M. Cycle	H. Hauler	Rickshaw	Truck
PCU	2.5	0.5	1.0	0.3	0.5	0.8	2.0

Source: DITS 1994

1.3. Background

Estimating PCU is a very common method of analyzing the road conditions of any city. PCU value not only gives us the information about the vehicles but also for the necessary change in lane width, vehicle carrying capacity, estimating the volume of passengers on road, for betterment of existing roads and so many more. Also to be noted that PCU values have a great impact on signal design also *(Khanorkar and.Ghodmare, 2014).*

Studies show that estimation of PCU depends on certain variables depending on the type of transport and also on accessibility of using different methods.

The most common method for estimating PCU is by determining the speed and the dimension of different vehicle class *(Khanorkar and Ghodmare, 2014).*

Another method is also common is estimating PCU which is by computing the headway of different vehicles. The traffic composition is also an essential variable in this case *(Sarraj and Jadili, 2012).*

Moving on to more complex method is by determining the Occupancy Time, Queue Clearance Rate and Potential Capacity of vehicles *(Mohan and Chandra, 2016).*

Another uncommon method is by calculating the proportions of different vehicle categories which are basically of base flow proportions, mixed stream proportions. In this study, the speed of different vehicle class is also an essential factor. The introduction of avidemux software has perhaps broadened the estimation of speed data of vehicles also *(Kumar et al. 2018).*

Another study shows that the effect of lane width on PCU values and also on the capacity of a two lane road under mixed traffic conditions. PCUs are estimated at ten road sections for nine categories of vehicles. This found that PCU for a vehicle type increases linearly with the width of carriageway *(Chandra and Kumar, 2003).*

Some studies covered the dynamic PCU of different types of vehicles on urban roads. The effects of proportion of Non-Motorized Traffic (NMT) and heavy vehicles on PCU

of different categories of vehicles are studied and the effect of stream speed on PCU is presented in form of mathematical equations *(Paul and Sarkar, 2013).*

1.4. Problem Statement

The past studies shows that there is limited work on estimating PCU values especially for UCMs. In Bangladesh, very little study is carried out for the PCU estimation of these modes of transport. The researchers almost neglect the fact that these modes of transport play a vital role for the regular transportation works, mainly carrying people from place to places.

Para-transits share road capacity and geometry with conventional modes of transport, but there is no design guideline for this.

The legunas and the auto-rickshaws have no specific design criteria at all. For example, the legunas going in one particular route may be different from the ones going on a different routes. Same goes for auto-rickshaws; and perhaps they vary in shapes, size and even speed. There is no particular procedure to incorporate PCU of these vehicles. Besides, the difference in vehicle characteristics may impose different PCU values.

In Bangladesh, traffic stream consisting of a variety of vehicles with a wide range of static and dynamic characteristics, travel in a same stretch without any lane discipline. Therefore, to estimate the capacity of any road section having the heterogeneous traffic stream, it is needed to convert the different types of vehicles into an equivalent unit.

It is also to be noted that there is no specific procedure to calculate PCU these modes of transport, although they are far different from conventional modes of transport (i.e. bus, car, truck etc. which have specific design criteria).

The main problem conducting this research work is perhaps that the auto-rickshaw in specific is forbidden to function on the major streets of the city; permitted only on the local arterials for the transport of local people.

The leguna is also forbidden but still kept in some major streets which have high passenger volume. As a result I'll not be facing such problem like auto-rickshaw.

1.5. Purpose and Objectives

The first objective of this study is to identify the major UCMs inside and outside Dhaka city. In this case, the major vehicles that I found are Rickshaw, Auto-Rickshaw (locally called Tom-Tom), Leguna, two stroke and three stroke wheelers (locally called CNG and baby taxi), animal driven carts etc. This research considers only Leguna and Auto-rickshaw as they are more prominent and more used in the local and regional areas.

The main objective is to estimate the PCU values of the above mentioned modes of transport.

Fig 1.3: Leguna, as a mode of transport.

The UCMs play a vital role in our daily lives, yet we neglect the importance of them. Thus estimating PCU of these vehicles is necessary in obtaining better knowledge. Few studies have already been conducted on UCMs but PCU of vehicles changes time to time due to road conditions, population, weather etc.

Fig 1.4: Auto-Rickshaw, a UCM.

1.6. Study Area and Scope of Study

I have selected the Gazipur Chou-rasta as my location of the study. This location is chosen as it is the only place where both the concerning modes of transport run on a regular basis and also the passenger demand for both modes is very high in these areas.

Also this area has wide roads with very few roadside obstructions that may impede the speed of these vehicles.

Two different locations is chosen at the site. One is near Bashir Road and the other one at Teen Sarak. The data is collected for both routes at these two sites.

As the data is for both routes, a total of four sets of data is collected. These two sites has no ongoing roadside constructions or any other factors that may impede the speed of these vehicles. As such vehicles can run smoothly without facing any delay and as speed is a vital factor for this study, we can conclude that the speed measured is the free flow speed of these vehicles.

Also this area is full of heterogeneous vehicles, so the proportion of vehicles that I get is quite perfect.

So the scope of the study is well predefined. The study is done by using Action Camera which can be set at these sites easily using a tripod.

The speed is measured by using a Speed Gun and it is mentioned that the speed of vehicle is measured with proper care and only the free flow speed is considered. Any vehicle that stops at the nearest vicinity is rejected in the study.

1.7. Organization of Thesis

The thesis is organized into five chapters and each chapter consists of several sub-chapters. These chapters were divided based on the various activities that were done during this study. The sequence of the chapters is commensurate with the sequence in which the activities were performed.

Chapter 1: Introduction

This chapter contains the main idea of the thesis and gives a overview of what is actually conducted here. This section is divided into seven sub-section:

1.1 Introduction

1.2 Definition of PCU

1.3 Background

1.4 Problem Statement

1.5 Purpose and Objective

1.6 Study area and Scope of Study

Chapter 2: Literature Review

This chapter contains the major findings from reviewing previous literatures on the selected topic. The section is divided into three major sub-sections:

2.1 Introduction

2.2 Importance of PCU

2.3 Methods for Calculating PCU

2.3.1 Conventional Method

2.3.2 Headway Method

2.3.3 Other Methods

Chapter 3: Methodology

The methodology is the general research strategy that outlines the way in which research is to be undertaken and among other things, identifies the methods to be used in it. This is the most important part of the dissertation and comprises of five major sub-sections:

3.1 Introduction

3.2 Identification of Variables

3.3 Experimental Setup

3.4 Design of the Survey

3.5 Finding Standard Deviation

Chapter 4: Analysis and Results

This chapter deals with the overall calculation procedure to find out the PCU along with the necessary statistical analysis of these values. It is divided into four major sub-sections:

4.1 Introduction

4.2 Statistics of Data

4.3 Sample Data

4.4 Standard Deviation

Chapter 5: Conclusion

Contains the overall summary of the research. It is divided into four sub-sections:

5.1 Introduction

5.2 Findings

5.3 Limitations

5.4 Future Scope

Chapter 2

Literature Review

2.1. Introduction

Measuring PCU of different modes of transport is a very basic practice in transportation engineering. Many thesis is conducted worldwide for the estimation of PCU. Lots of new methods are introduced over time for calculating this. But all the methods are not suitable to use for different cases. These may be due to various reasons. However, this review will focus on four major variables and these are:

- Speed of Vehicle *(v)*
- Dimension of Vehicles *(A)*
- Proportion of Vehicles *(P)*
- Headway of Vehicles *(H)*

Some other variables are also found from the study and these are: Flow of vehicles, Occupancy time, Queue clearance rate, Passenger Carrying Capacity.

Although the literatures present these variables in a variety of contexts, this paper will primarily focus on the methods of their measurement and their implementation in finding the appropriate PCU values of the vehicles.

2.2. Importance of PCU

Estimating PCU is a common practice to consider the passenger car as the standard vehicle unit to convert the other vehicle classes and this unit is called passenger car unit or PCU.

The PCU may be considered as a measure of the relative space requirement of a vehicle class compared to that of a passenger car under a specified set of roadway, traffic, and other conditions.

The PCU value of a vehicle class may be considered as the ratio of capacity of a roadway where there are passenger cars only to the capacity of the same roadway when there are vehicles of that class only.

Factor effecting PCU values are categorized below:

- Vehicles characteristic
- Transverse and longitudinal gaps
- Traffic stream characteristic
- Roadway characteristic
- Regulation and control of traffic
- Environmental and climatic conditions

Basically, PCU stands for passenger car unit and it is a unit to measure the equivalent number of a motor vehicle/two wheeler or bullock cart etc, which use the road. This is a common unit for the purpose of design of the roads as it is needed to bring all vehicles to one unit so that a cumulative load may be calculated and considered on a particular road for its design.

As the traffic plays an important role in design of the highways and many types of vehicles (big and small) us the same road, it is essential to have a common unit so that the effect of all types of vehicles may be considered for the design traffic on the road.

PCU values can be further used for the analysis in improving road conditions, improved carriageway, estimating the volume of passengers on road, to know importance of a particular mode of transport, increase road side shoulder width, help to decide whether additional vehicles should be introduced on road to meet the public demand and many more.

As the traffic in our country is on an immense rise with respect to the increase in population, the PCU values of the vehicles tend to change in time. That is why this study will show the actual PCU values of the previously mentioned modes of transport.

2.3. Methods for Calculating PCU

Major methods in estimating PCU are narrowed down and the suitable methods (in this case, two methods) are chosen. The findings from the literature review are described below.

2.3.1. Conventional Method

Different performance measures have been used by researchers in estimating PCU factors. *Aerde and Yagar (1984)* commented that the major discrepancy among various PCU studies is the consideration of similar PCU factors for capacity, speed, platooning, and other types of analysis.

Krammes and Crowley (1986) stated that the basis of equivalence should be the parameter used to define the level of service of the facility.

Elefteriadou et al. (1997) stated that PCU values should be based on the same performance measure as the LOS designations for the respective facility types. Hence, the accuracy of estimated PCU will depend greatly on the right selection of performance measures

Khanorkar and.Ghodmare (2014) used the most common method of estimating PCU values, which is by using the speed data and dimension of vehicles.

In British practice it is usual to express capacity in the different types of vehicle offer different degree of interference to other traffic and it is necessary to bring all types to a common unit adopted is the passenger Car Unit (PCU). In the present study, to estimate the PCU values is that it is directly proportional to the ratio of clearing speed of vehicle, and inversely proportional to the space occupancy ratio of vehicle with respect to the standard Area of vehicle,i.e. a car. The PCU of a vehicle type is taken as given by *Chandra and Kumar (2003).*

$$PCU = \frac{Vc/Vi}{Ac/Ai}$$

2.3.2. Headway Method

Headway is a measurement of the distance or time between vehicles in a transit system. The minimum headway is the shortest such distance or time achievable by a system without a reduction in the speed of vehicles. The precise definition varies depending on the application, but it is most commonly measured as the distance from the tip of one vehicle to the tip of the next one behind it. It can be expressed as the distance between vehicles, or as time it will take for the trailing vehicle to cover that distance. A "shorter" headway signifies closer spacing between the vehicles. PCUs as reported in *TRB Circular 212* were developed based on the constant v/c method. An article published by *Linzer et al. (1979)* describes the constant v/c method, whereby PCUs are calibrated such that the mixed traffic flow will produce the same v/c ratio as a passenger car only flow.

Huber (1982) developed the above method by relating PCU to the flow of a passenger car only traffic stream and a mixed vehicle traffic stream. The effect of trucks is quantified by relating the traffic flows for an equal level of service (LOS). *Sumner et al. (1984)* expanded the relationship described by Huber to calculate the PCU of a single truck in a mixed traffic stream, which includes multiple truck types. This calculation requires an observed base flow, mixed flow, and flow with the subject vehicles.

Kockelman and Shabih (1999) found that light-duty trucks such as single large sport-utility vehicles in through traffic is equivalent to 1.41 passenger cars; and a van is equivalent to 1.34. They used the headway method to determine these PCE values at two signalized intersections in Austin, Texas. They also concluded that such long headways reduce intersection capacity and increase urban congestion.

Greenshields et al. (1947) estimated PCU value by the following equation. This method is known as basic headway method.

$$PCU = {}^{Hi}/_{Hc}$$

Miller (1968) developed PCU values at intersections based on the headway a heavy vehicle would require over a passenger car. His result for PCU value of a truck was 1.85.

Werner and Morrall (1976) suggested that the headway method is the best method to determine PCUs at low levels of service. The PCU is calculated as:

$$PCU = \frac{Hm/_{Hb} - Pc}{Pt}$$

Other methods were also used to calculate PCU values based on Queue Discharge Flow *(Al-Kaisy et al., 2002)* and traffic density (*Webster and Elefteriadou, 1999).*

2.3.3. Other Methods

Van Aerde and Yagar (1984) and *Elefteriadou et al. (1997)* used average speed as the performance measure in PCU estimation, while *Krammes and Crowley (1986)* and *Webster and Elefteriadou (1999)* made use of density.

A modified form of density, termed as area occupancy, was used by *Mallikarjuna and Rao (2006)* to arrive at PCU values. The concept of dynamic PCU was introduced by *Chandra and Kumar (2003)* which was based on relative speed and area of a vehicle type with respect to the standard car.

Al-Kaisy et al. (2002) used queue discharge flow capacity for PCU estimation for congested conditions on freeways.

Tanaboriboon and Aryal (1990) and *Sirisoponsilp et al. (2001)* used headway for PCU estimation on interrupted and uninterrupted facilities. But most of these studies were restricted to uninterrupted flow facilities operating in homogeneous traffic conditions.

Mohan and Chandra (2016) proposed three methods to estimate PCU at un-signalized intersections. The first one is by Occupancy time, second one is based on Queue clearance rate and the third one by using Potential capacity. They suggested empirical formulas to calculate PCU and introduced many terms such as Critical Gap, Follow-up time etc.

Huber (1982) proposed a methodology to estimate PCU values based on cars-only traffic and mixed traffic flow levels, for the same measure of performance. He introduced complex formulas in calculating PCU, but these formulas could represent a matrix solution from which getting different values were quite easy.

Kumar et al. (2018) introduced the latest mode of estimating PCU which consists of using the Avidemux software for getting the speed data accurately. It can measure time at an accuracy of 1/100 s. They also used flow and proportions of different vehicles for constructing a matrix equation for further explanations. The matrix solution was obtained using MATLAB software. The solution of the matrix gives the unique or optimized PCU values for different vehicle categories in the traffic stream. This unique PCU value is based on the observed base traffic (with all-cars traffic) and mixed traffic flows at the same performance level.

Chapter 3

Methodology

3.1. Introduction

In this section, discussion about the data collection procedure as well as the methodology for estimating PCU is described in brief. The key variables for the study is described first and then the required mathematical formulas are used. In conducting the research, some equipment are required, which are also described here, along with their usage.

The methodology is followed by identifying variables, experimental setup, collecting data and theoretical analysis of the collected data. So this portion of the research will give a clear idea about how the experiment is conducted along with the analysis method of the data.

Overall workflow diagram is shown in the following figure:

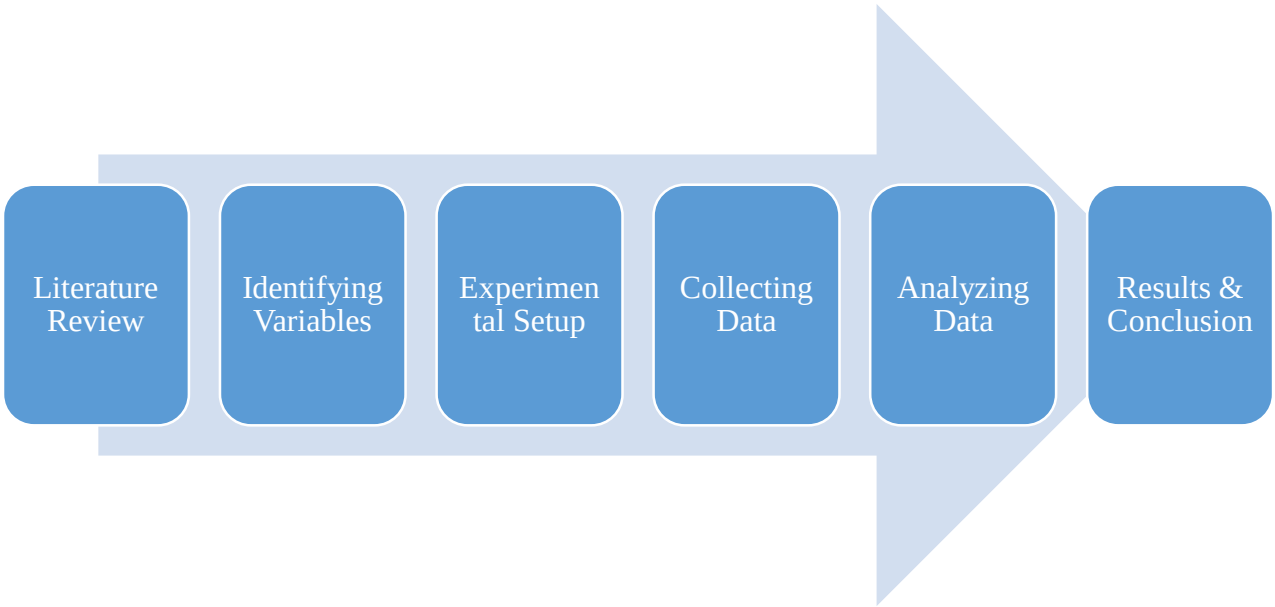

Fig 3.1: Work Flow Diagram.

3.2. Identification of Variables

A variable is a factor that can change in quality, quantity, or size, which you have to take into account in a situation. There are two types of variables in general. The first variable type is called the independent variable. This variable is the one that is manipulated or changed by the scientist. The second type of variable is the one that is observed or measured in the experiment, and it is known as the dependent variable. One can remember this because the observation or measure of the dependent variable will change as the independent variable is altered.

So the estimation of PCU is the dependent variable here and all the independent variables are described below:

3.2.1. Speed (v)

The present study has adopted the method proposed by *Chandra and Sikdar (2000)* to estimate the PCU values of vehicles. In a heterogeneous traffic stream, speed of the vehicles is mostly affected among the other traffic stream parameters. In their methodology speed is considered as the basic parameter for determination of PCU. Hence, their methodology has been adopted as proposed methodology. In this study Standard Car is considered as the standard design vehicle.

3.2.2. Dimension of Vehicle (A)

The physical size of different types of vehicles have been adopted from the study of *Chandra and Kumar (2003).* Although, they cited that using appropriate dimension for calculating PCU is essential but they only showed the dimension of conventional modes of transport i.e. passenger car, light commercial vehicle, heavy vehicle, bus, motor cycle and many more. However, the unconventional modes of transport which are found here is not available elsewhere in the world. So there is a definite shortage of information about their design criteria. Despite of this, the dimension of the leguna is found from *RHD Manual (2007)* and the dimension of the auto-rickshaw is manually measured using a measuring tape.

3.2.3. Time Headway (H)

Greenshields et al. (1947) started using the headway of vehicle for estimating PCU. *Miller (1968)* developed PCU values at intersections based on the headway, a heavy vehicle would require over a passenger car. *Werner and Morrall (1976)* suggested that the headway method is the best method to determine PCUs at low levels of service. Since the study is of UCMs which have very low LOS, the estimation of PCU using headway is more appropriate.

3.2.4. Proportion of Vehicles (P)

Traffic density was used to calculate PCU by *Webster and Elefteriadou (1999).* They used a complete different method using the density as a prime factor. However, in this research, the proportion is taken as an independent variable in order to calculate PCU using the Headway Analysis Method.

3.3. Experimental Setup

The necessary equipment needed for the research are not that much complicated. These are listed below:

- Speed Gun
- Action Camera
- Tripod

3.3.1. Speed Gun

A speed gun (also radar gun) is a device used to measure the speed of moving objects. It is generally used in law-enforcement to measure the speed of moving vehicles and is often used in professional spectator sport, for things such as the measurement of bowling speeds in cricket, speed of pitched baseballs, athletes and tennis serves. Speed guns use Doppler radar to perform speed measurements.

Fig 3.2: Speed Gun

3.3.2. Action Camera

An action camera or action-cam is a digital camera designed for recording action while being immersed in it. Action cameras are therefore typically compact and rugged, and waterproof at surface-level. Mostly record on a micro SD card, and have a Micro-USB connector.

Fig 3.3: Action Cam

3.3.3. Tripod

A tripod is a portable three-legged frame or stand, used as a platform for supporting the weight and maintaining the stability of some other object. A tripod provides stability against downward forces and horizontal forces and movements about horizontal axes.

Fig 3.3: Tripod.

3.4. Design of the Survey

Although there is many methods in calculating PCU values, this study uses two methods in calculating PCU values and differentiates among them in their values.

The first one will be based on measuring speed data, which is the most common method of calculating PCU. A speedgun is used in the experiment to measure the speed data of ongoing vehicles. Also standard dimension of vehicles is used in determining the PCU. A simple empirical formula is used in conducting this experiment. To estimate the PCU values that it is directly proportional to the ratio of clearing speed of vehicle, and inversely proportional to the space occupancy ratio of vehicle with respect to the area of a

standard vehicle (standard passenger car). The PCU of a vehicle type is taken as given by *Chandra and Kumar (2003)*;

$$PCU = \frac{Vc/Vi}{Ac/Ai}$$

The second method is based on calculating the average headway of vehicles. In this case I used the time headway rather than headway spacing. For collecting time headway data, I selected the suitable roads that fulfill the following criteria:

- High traffic volume,
- Good mix of different vehicle types,
- No parking allowed on the intersection approach,
- The presence of traffic signals or a traffic policeman to organize traffic flow.

Using a video recording action cam I collected the footage which was shot on a *Dry Weather Condition*. The videos were then processed and time stamps were added. After that time headway data was calculated under much supervision. To ensure the validity of results, a representative and a statistically accepted sample was chosen in which time headways of the following vehicles were rejected and excluded from the analysis:

- The first three vehicle discharging from the queue,
- Vehicles impeded by pedestrians,
- Platoons with turning vehicle.

Warner and Morall (1976) introduced the following equation in calculating the PCU value,

$$PCU = \frac{Hm/Hb - Pc}{Pt}$$

For both cases, it is ensured that data is collected during day time only, the data sets are collected on a 20 min interval in each location and the data sets are collected on weekdays between the interval 3:00PM-5:00PM.

3.5. Finding Standard Deviation

In statistics, the standard deviation is a measure that is used to quantify the amount of variation or dispersion of a set of data values. A low standard deviation indicates that the data points tend to be close to the mean of the set, while a high standard deviation indicates that the data points are spread out over a wider range of values.

Standard deviation is expressed by the following formula:

$$SD = \frac{\sum(Xi - \bar{X})}{n - 1}$$

The standard deviation is a commonly used statistic, but it doesn't often get the attention it deserves. Although the mean and median are out there in common sight in the everyday media, a person rarely sees them accompanied by any measure of how diverse that data set is. That is why a person is getting only part of the detailed scenario.

Without standard deviation, we can't get a handle on whether the data are close to the average or whether the data are spread out over a wide range. Without the standard deviation, one can't compare two data sets effectively.

That is why this study conducts the SD calculation table in order to find out the discrepancy among the PCU values.

Chapter 4

Analysis & Results

4.1. Introduction

This part of the study covers the mathematical analysis of the captured data along with proper identification of certain variables. A statistical model is also formed, in which the SD is determined. At first the units of certain variables are identified, followed by the input of different variables gathered from the field survey. As this research used two different methods in calculating PCU of two different modes of transport, a total four sets of PCU were obtained. Furthermore, with these values, the SD is identified and noted.

4.2. Statistics of Data

For my research, four sets of data are gathered at two different locations on both lanes, in between Gazipur Chou-Rasta and Shib-Bari roundabout. The collected data sets are of: Speed, Area occupancy of vehicles, Headway time and Proportion of vehicles.

Variables	Unit
Speed	$km/_h$
Area of vehicles	m^2
Headway	s
Proportion of Vehicles	-

Table 4.1: Units of Variables

Table 4.1 shows the units necessary for different variables. The speed in this case is measured in mile/hr format from using the speed gun. It is then converted into km/hr format by multiplying the data collected from speed gun with the value 1.61.

Vehicle Type	Length (m)	Width (m)	Area (m^2)
Standard Passenger Car	3.72	1.44	5.39
Leguna	3.44	1.28	4.40
Auto Rickshaw	2.48	0.96	2.38

Table 4.2: Dimension of vehicles.

It is mentioned that the dimensions mentioned here is gathered form the study of *Khanorkar and Ghodmare (2014)*. The data of leguna is taken from *RHD Manual (2007)* and the data of auto rickshaw is manually measured using measuring tape.

In addition to this, the average headway for base flow (standard passenger car) is estimated to be 32.93 secs. For which, a range of 30-35.5 secs is used for the calculation using headway method. The average headway for mixed flow is estimated to be 10.15 secs. So a range of 10-10.6 secs is taken for calculation.

4.3. Sample Data

Total four sets of PCU data is calculated using two different methods. The detailed data sets are shown in Appendix A1 and A2.

Vc	Vi(leguna) kph	Vi(auto) mph	Vi(auto) kph	Ac	Ai(auto)	Ai(leguna)	PCU(Leguna)	PCU(Auto)
40	25.8	11	17.71	5.39	2.38	4.4	1.26	0.99
40	25.8	13	20.93	5.39	2.38	4.4	1.26	0.84
40	19.3	20	32.2	5.39	2.38	4.4	1.69	0.54
40	24.1	10	16.1	5.39	2.38	4.4	1.35	1.09
40	27.4	16	25.76	5.39	2.38	4.4	1.19	0.68
40	22.5	12	19.32	5.39	2.38	4.4	1.45	0.91

Table 4.3: Sample PCU using speed data analysis.

Hm	Hb	Pc	Pi(leguna)	Pi(auto)	PCU(for leguna)	PCU(for auto)
10	30	18%	9%	21%	1.70	0.73
10	30.1	18%	9%	21%	1.69	0.72
10	30.3	18%	9%	21%	1.66	0.71
10	30.5	18%	9%	21%	1.64	0.70
10	30.7	18%	9%	21%	1.61	0.69
10.1	30.9	18%	9%	21%	1.63	0.70

Table 4.4: Sample PCU using Headway analysis.

4.4. Standard Deviation

The standard deviation from the extracted PCU values are calculated which shows the discrepancy from the mean value.

PCU(Leguna)	PCU(Auto)	Deviation about the mean (x-mean) Leguna	(x-mean)^2	Deviation about the mean (x-mean) Auto	(x-mean)^2
1.26	0.99	-0.04	0.002	0.169	0.028
1.26	0.84	-0.04	0.0022	0.016	0.0002
1.69	0.54	0.37	0.14	-0.27	0.078
1.35	1.09	0.04	0.001	0.26	0.072
1.19	0.68	-0.12	0.01	-0.14	0.0202

Sum	39.38	24.83	2.9976E-15	1.79	2.22045E-16	0.480
Count (n)	30	30	30	30	30	30
Average Mean	1.3127	0.8278				
Variance(s^2)				0.061		0.016
Standard Deviation				0.248		0.128

Table 4.5: Standard Deviation using speed data analysis.

Using the speed data analysis method, the average PCU for leguna is 1.31 with a standard deviation of 0.248. The average PCU for auto rickshaw is 0.8278 with a standard deviation of 0.128. The sum that is shown here is the summary of Appendix A1. The upper chart in this page demonstrates the sample values corresponding for getting the SD.

	PCU(for leguna)	PCU(for auto)	Deviation about the mean (x-mean) leguna	(x-mean)^2	Deviation about the mean (x-mean) auto	(x-mean)^2
	1.70	0.73	0.20	0.042	0.09	0.007
	1.69	0.72	0.19	0.037	0.08	0.006
	1.66	0.71	0.16	0.028	0.07	0.005
	1.64	0.70	0.14	0.02	0.06	0.003
	1.61	0.69	0.12	0.01	0.05	0.002
Sum	44.94	19.26	-2.66454E-15	0.36	-2.22045E-16	0.06
Count(n)	30	30	30	30	30	30
Average(mean)	1.49	0.642				
Variance(s^2)				0.012		0.002
Standard Deviation(s)				0.112		0.04

Table 4.6: Standard Deviation using headway analysis.

Using the headway analysis method, the average PCU for leguna is 1.49 with a standard deviation of 0.112. The average PCU for auto rickshaw is 0.642 with a standard deviation of 0.04. The sum that is shown here is the summary of Appendix A2. The upper chart in this page demonstrates the sample values corresponding for getting the SD.

Chapter 5

Conclusion

5.1. Introduction

The principal objective of this study is to measure the PCU of the major UCM inside or outside the city. In doing this, certain steps are followed which come as literature review, identifying variables, experimental setup, collecting & analyzing data. In this last part of the dissertation proper conclusion along with limitations and future scope of this study is mentioned. This study shows the enormous potential of using a micro-level traffic flow parameter, area occupancy, speed of vehicle and proportionality of vehicles as a persuasive basis of a measure of performance for estimating optimized PCU values for two different kinds of UCMs. The major outcome of this research work is the deriving of an optimized set of PCU value for these vehicle classes, applicable to any flow levels, on multilane urban roads as observed in the field, as established by *Chandra and Kumar (2003)* and *Werner and Morrall (1976).* Estimation of PCU is a very basic work in transportation engineering and from which many other important assumptions are made for ensuring better road conditions and safety. As two different methods are used here, we can also differentiate the values which have larger discrepancy from another.

5.2. Major Findings

1. Using speed data analysis, I have found the PCU of leguna as 1.31 and PCU of auto rickshaw as 0.827.
2. Using headway analysis, I have found the PCU of leguna as 1.4981 and PCU of auto rickshaw as 0.642.
3. PCU calculated from both these methods are close to each other.
4. Only the PCU from headway and speed-data, for auto rickshaw is slightly different. This is because headway analysis uses proportionality of vehicles and

due to the high proportion of auto rickshaw in the location site, the PCU of auto tend to be a little smaller than that we got from speed data analysis.

5. The standard deviation is also slightly different for both methods due to headway method using a certain small range of data-sets, where speed-data analysis method is based on a large scale of variables (speed differs in larger range).

5.3. Limitations

In conducting the research, certain limitations were encountered:

- Although leguna and auto rickshaw both have significant impact on people's daily lives, both these transports are prohibited to run inside the Dhaka city. DMP chief *Commissioner Asaduzzaman Mia* on 5th of September, 2018 said on a press conference "Lagunas are not supposed to be in the city. These vehicles will ply outside the city, on the feeder roads, where they have been given route permits." That is why I have to go outside the city in order to get my required data sets. The same goes for auto rickshaw as it is also prohibited to run in the city from very early stage.
- There are some places inside the city where these vehicles still run on the roads, but considering announcements by the DMP, I could not take the risk of taking the data inside the city.
- It is noted that the speed data and headway both may differ if the traffic composition and road conditions change. Since the traffic and road conditions inside Dhaka is different from the location site, the values would have been slightly different if the data was taken from inside the city.
- The speed gun is a very costly equipment and might not always be provided to random people as it is only used by law enforcements. However, the equipment was managed through the help of my supervisor.
- The location site had roadside ongoing construction projects for which I had to go through the whole area to find out the suitable locations.
- More or less, the legunas have a certain design criteria but for the auto rickshaws there was no specific design guideline for which I had to manually measure the

dimensions using measuring tape and the speed data was recorded for only those types of auto rickshaws.

- It was necessary to convert the speed measure from the speed gun into different units.

5.4. Future Scope

Although PCU is a basic factor in transportation, its importance is more often neglected. In our country very small research work is taken in order estimate the PCU of the vehicles. For the UCMs this problem is even more. As the PCU tends to change with certain factors and our country is going through vast changes, both for increased population and change in road conditions, the PCU of the vehicles are likely to change. That is why the PCU of different vehicle class needs to be estimated on a regular interval. From this citation, we can see the actual PCU values of two major UCMs in the current road conditions.

One of the important aspect of this study is to deliver these values for further road analysis by govt. or private organization. PCU is required for further analysis on road conditions. As Bangladesh is going through vast improvements in the transportation sector, it is required to find out all possible values which helps to construct better road conditions and ensure safety. To be more specific, the concerned authority can use these values to improve road capacity, change in lane width, increase of roadside shoulder, estimating the importance of certain mode of transport, additional vehicle implementation on roads and many more.

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Appendix A

Appendix A1

Vc	Vi(leguna) kph	Vi(auto) mph	Vi(auto) kph	Ac	Ai(auto)	Ai(leguna)	PCU(Leguna)	PCU(Auto)	Deviation about the mean (x-mean) Leguna	(x-mean) ^2	Deviation about the mean (x-mean) Auto	(x-mean) ^2
40	25.8	11	17.71	5.39	2.38	4.4	1.265622528	0.997308733	-0.047130053	0.0022212 4	0.16945801 7	0.028716019
40	25.8	13	20.93	5.39	2.38	4.4	1.265622528	0.843 87662	-0.047130053	0.0022212 4	0.01602590 4	0.000 25683
40	19.3	20	32.2	5.39	2.38	4.4	1.691868457	0.548 51980 3	0.379 11587 6	0.143 72885	-0.279 33091 3	0.078 02575 9
40	24.1	10	16.1	5.39	2.38	4.4	1.354898806	1.097 03960 6	0.042 146225	0.001 7763	0.269 18889	0.072 46265 9
40	27.4	16	25.76	5.39	2.38	4.4	1.191717563	0.685 64975 4	-0.121 035018	0.014 64948	-0.142 200962	0.020 221114
40	22.5	12	19.32	5.39	2.38	4.4	1.451247166	0.914 19967 2	0.138 494585	0.019 18075	0.086 348956	0.007 456142
41	40.25	13	20.93	5.39	2.38	4.4	0.831537584	0.864 97353 6	-0.481 214997	0.231 56787	0.037 122819	0.001 378104
41	26.4	11	17.71	5.39	2.38	4.4	1.267779839	1.022 24145 1	-0.044 972742	0.002 02255	0.194 390735	0.037 787758
41	25.8	12	19.32	5.39	2.38	4.4	1.297263091	0.937 05466 4	-0.015 489489	0.000 23992	0.109 203947	0.011 925502

41	35.4	14	22.54	5.39	2.38	4.4	0.945462931	0.80318971 2	-0.36728965	0.13490169	-0.02466100 5	0.00060816 5
41	27.4	13	20.93	5.39	2.38	4.4	1.221510502	0.86497353 6	-0.09124207 9	0.00832512	0.03712281 9	0.00137810 4
42	27.4	16	25.76	5.39	2.38	4.4	1.251303441	0.71993224 2	-0.06144914	0.003776	-0.10791847 5	0.01164639 7
42	22.5	17	27.37	5.39	2.38	4.4	1.523809524	0.67758328 6	0.21105694 3	0.04454503	-0.15026743	0.02258030 1
42	25.8	17	27.37	5.39	2.38	4.4	1.328903654	0.67758328 6	0.01615107 4	0.00026086	-0.15026743	0.02258030 1
42	30.6	15	24.15	5.39	2.38	4.4	1.120448179	0.76792772 4	-0.19230440 2	0.03698098	-0.05992299 2	0.00359076 5
42	27.4	11	17.71	5.39	2.38	4.4	1.251303441	1.04717417	-0.06144914	0.003776	0.21932345 3	0.04810277 7
43	24.1	15	24.15	5.39	2.38	4.4	1.456516216	0.78621171 8	0.14376363 6	0.02066798	-0.04163899 8	0.00173380 6
43	27.4	15	24.15	5.39	2.38	4.4	1.281096 38	0.78621171 8	-0.03165620 1	0.00100212	-0.04163899 8	0.00173380 6
43	32.2	14	22.54	5.39	2.38	4.4	1.090125491	0.84236969 8	-0.22262709	0.04956282	0.01451898 1	0.00021080 1
43	24.1	16	25.76	5.39	2.38	4.4	1.456516216	0.73707348 6	0.14376363 6	0.02066798	-0.09077723 1	0.00824050 6
44	19.3	14	22.54	5.39	2.38	4.4	1.861055303	0.86195969 1	0.54830272 2	0.30063588	0.03410897 4	0.00116342 2
44	30.6	14	22.54	5.39	2.38	4.4	1.173802854	0.86195969 1	-0.13894972 6	0.01930703	0.03410897 4	0.00116342 2

44	32.2	12	19.32	5.39	2.38	4.4	1.115477247	1.0056196339	-0.19727533	0.0389175	0.17776892	0.03160179
44	24.1	13	20.93	5.39	2.38	4.4	1.490388687	0.9282642822	0.17763610	0.0315545	0.10041356	0.01008288
44	19.3	15	24.15	5.39	2.38	4.4	1.861055303	0.8044957111	0.54830272	0.3006358	-0.02335500	0.00054545
45	33.8	15	24.15	5.39	2.38	4.4	1.086825263	0.8227797705	-0.22592731	0.0510431	-0.00507101	2.57152E-05
45	24.1	19	30.59	5.39	2.38	4.4	1.524261157	0.6495629255	0.21150857	0.0447358	-0.17828779	0.03178653
45	22.5	15	24.15	5.39	2.38	4.4	1.632653061	0.8227797705	0.31990048	0.1023363	-0.00507101	2.57152E-05
45	32.2	16	25.76	5.39	2.38	4.4	1.140829002	0.7713559733	-0.17192357	0.0295577	-0.05649474	0.00319165
45	38.6	18	28.98	5.39	2.38	4.4	0.951676007	0.6856497554	-0.36107657	0.1303762	-0.14220096	0.02022111

Sum	39.38257742	24.83552149	2.9976E-15	1.79117506	2.22045E-16	0.480443326
Count (n)	30	30	30	30	30	30
Average Mean	1.312752581	0.827850716				
Variancce(s^2)				0.06176466		0.016567011
Stancard Deviation				0.24852496		0.128712902

Appendix A2

Hm	Hb	Pc	Pi(leguna)	Pi(auto)	PCU(for leguna)	PCU(for auto)	Deviation about the mean (x-mean) leguna	(x-mean)^2	Deviation about the mean (x-mean) auto	(x-mean)^2
10	30	18%	9%	21%	1.703703704	0.73	0.205598712	0.042270830	0.09	0.007764030104356 94
10	30.1	18%	9%	21%	1.691399040	0.72	0.193294049	0.037362590	0.08	0.006862516416498 09
10	30.3	18%	9%	21%	1.667033370	0.71	0.168928379	0.028536800	0.07	0.005241452538287 44
10	30.5	18%	9%	21%	1.642987250	0.70	0.144882258	0.020990870	0.06	0.003855465692900 49
10	30.7	18%	9%	21%	1.619254434	0.69	0.121149442	0.014677190	0.05	0.002695809927261 35
10.1	30.9	18%	9%	21%	1.631787127	0.70	0.133682136	0.017870910	0.06	0.003282412666097 52
10.1	31.1	18%	9%	21%	1.608431583	0.69	0.110326591	0.012171960	0.05	0.002235665532074 72
10.1	31.3	18%	9%	21%	1.585374512	0.68	0.087269521	0.007615970	0.04	0.001398851492226 00
10.1	31.5	18%	9%	21%	1.562610229	0.67	0.064505238	0.004160930	0.03	0.000764251665547 25
10.2	31.7	18%	9%	21%	1.575184017	0.68	0.077079026	0.005941180	0.03	0.001091236442248 85
10.2	31.9	18%	9%	21%	1.552769070	0.67	0.054664079	0.002988160	0.02	0.000548845991302 57
10.2	32.1	18%	9%	21%	1.530633437	0.66	0.032528446	0.001058100	0.01	0.000194344860343 78
10.2	32.3	18%	9%	21%	1.508771930	0.65	0.010666939	0.000113780	0.00	0.000020899024685 11
10.3	32.5	18%	9%	21%	1.521367521	0.65	0.023262530	0.000541150	0.01	0.000099394036180 89
10.3	32.7	18%	9%	21%	1.499830105	0.64	0.001725114	2.976E-06	0.00	0.000000546615670 73
10.3	32.9	18%	9%	21%	1.478554542	0.63	-0.019550449	0.000382220	-0.01	0.000070203682712 19
10.3	33.1	18%	9%	21%	1.457536086	0.62	-0.040568905	0.001645840	-0.02	0.000302296422374 68
10.4	33.3	18%	9%	21%	1.470136803	0.63	-0.027968188	0.000782220	-0.01	0.000143672974335 07
10.4	33.5	18%	9%	21%	1.449419569	0.62	-0.048685422	0.002370270	-0.02	0.000435355779604 75
10.4	33.7	18%	9%	21%	1.428948236	0.61	-0.069156755	0.004782660	-0.03	0.000878447164624 06

10.5	33.9	18%	9%	21%	1.441494592	0.62	-0.056610399	0.00320474	-0.02	0.000588625219991500
10.5	34.1	18%	9%	21%	1.421309873	0.61	-0.076795118	0.00589749	-0.03	0.001083212485130420
10.5	34.3	18%	9%	21%	1.401360544	0.60	-0.096744447	0.00935949	-0.04	0.001719089637975700
10.5	34.5	18%	9%	21%	1.381642512	0.59	-0.116462479	0.01356351	-0.05	0.002491256764636860
10.5	34.7	18%	9%	21%	1.362151777	0.58	-0.135953214	0.01848328	-0.06	0.003394887506428530
10.6	34.9	18%	9%	21%	1.374721426	0.59	-0.123383565	0.0152235	-0.05	0.002796153813752200
10.6	35	18%	9%	21%	1.365079365	0.59	-0.133025626	0.01769582	-0.06	0.003250252141439140
10.6	35.1	18%	9%	21%	1.355492244	0.58	-0.142612747	0.02033384	-0.06	0.003735623675321120
10.6	35.3	18%	9%	21%	1.336480957	0.57	-0.161624034	0.02612233	-0.07	0.004797978700861010
10.6	35.5	18%	9%	21%	1.317683881	0.56	-0.180421111	0.03255178	-0.08	0.005978897815559540
Sum					44.943149743	19.261349893	-2.66454E-15	0.368706911	-2.22045E-16	0.067721677
Count(n)					30	30	30	30	30	30
Average(mean)					1.498104991	0.642044996				
Variance(s^2)								0.012714031		0.00233523
Standard Deviation(s)								0.112755651		0.04832422