DEVELOPMENT OF PASSENGER CAR UNIT FACTORS FOR FOUR LANE ROADS UNDER SRI LANKAN CONTEXT

W A M A B Weerasinghe
(138322F)

Degree of Master of Engineering

Department of Civil Engineering

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Dissertation submitted in partial fulfillment of the requirements for the degree Master of Engineering in Highway and Traffic Engineering

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DECLARATION OF THE CANDIDATE AND SUPERVISOR

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ABSTRACT

Passenger Car Unit (PCU) or Passenger Car Equivalent (PCE) is a metric used in Transportation Engineering, to assess traffic-flow rate on a road or an intersection. A Passenger Car Equivalent is essentially the impact that a certain mode of transport has on traffic variables compared to a single passenger car.

Roads in Sri Lanka carry heterogeneous traffic, where road space is shared among many traffic modes with different physical dimensions and prevailing loose lane discipline. PCU factors used in Sri Lanka at present are somewhat older and do not reflect static and dynamic characteristics of modern vehicles, road conditions or driver behavior.

Data collection was done on various four lane road segments. Location for the study is identified based on uniformity of road characteristics in terms of pavement width, shoulder type, etc. There should be no visual obstructions to traffic because of bus stops, road side developments, etc. No intersection or side roads along the road stretch so that there are no changes in the traffic volume over the entire stretch. No signalized intersection for 3km road length.

Traffic volume data was collected using video camera to record vehicles in both directions during peak hours. These video footages were observed and the traffic volumes, speeds and 85% value of road width used by traffic volume were calculated.

Then using modified density method proposed by Tiwari, Fazio, and Pavitravas (2000), the PCU factors were derived.

$$PCU_{Xi} = \frac{(k_{car} / W_{85car})}{(q_{Xi} / u_{Xi}) / W_{85Xi}}$$

The results obtained, showed that there is a variation from homogenous conditions to heterogeneous conditions. These results can be used for traffic volume analysis, capacity calculations, road network planning and design purposes, etc. in Srilankan four lanes roads. Further research can be carried out to evaluate PCU factor for 6 lane roads, different highways and intersections.

Key words: PCU—PCE—Road capacity

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LIST OF ABBRIVIATIONS

Abbreviation	Description
TRB	Transportation Research Board
PCU	Passenger Car Unit
HCM	Highway Capacity Manual
PCE	Passenger Car Equivalent
TRRL	Transport and Road Research Laboratory
USA	United States of America
MCL	2 wheel Motor cycle
TWL	Motorized Three wheel
CAR	Passenger Car
VAN	Van, Jeep
LBU	Large bus unit
HV	Single unit truck

CHAPTER 1

1 INTRODUCTION

1.1 Background

Demand for roadway capacity is always at a hike. To cater for this ever increasing traffic demand new roads are added to the network and improvements to existing roads are carried out. The Highway Capacity Manual special report 209 of Transportation Research Board (TRB), USA defines six levels of service ranging from A to F to distinguish operational performance of highways (Transportation Research Board [TRB], 2000)

In order to assist the traffic planners and designers with estimating road capacity and forecasting future traffic volumes, it is important to model the traffic flow. When modeling the traffic flow, Passenger Car Unit (PCU) factors represent the impact of the wide variety of vehicles present in the traffic flow.

Passenger Car Unit (PCU) or Passenger Car Equivalent (PCE) is a metric used in Transportation Engineering, to assess traffic-flow rate on a highway. 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.

Highway capacity is measured in PCE/hour daily (Highway Capacity Manual, 2000). A common method used in the US to measure PCU is the “density method”. However, the PCU values derived from the density method are based on underlying homogeneous traffic concepts and lane disciplined conditions.

On the other hand, roads in Sri Lanka carry heterogeneous traffic, where road space is comprised of many traffic modes with different physical dimensions and maneuverability. Drivers practice loose lane discipline and car following is not the norm. The vehicle speeded vary from 10km/h to 80km/h due to differences in vehicle characteristics and driver perspective. Vehicles would follow a path which may seem advantageous rather than the marked lanes. This complicates computing

of PCU using multiple heuristic techniques. Transportation engineers convert a mixed traffic stream into a hypothetical passenger-car stream for analysis and planning purposes.

A number of studies have been taken up all over the world to determine PCU values for different types of vehicles in varying roadway and traffic conditions. Out of various available methods, Modified Density method by Tiwari, Pavithravas and Fazio (2000) and the one proposed by Chandra (1995) are most suitable for mixed traffic condition.

1.2 Problem Statement

At present, PCU factors used in Sri Lanka are relatively older. 21 years back the road surface condition was not as improved as today and the regular maintenance was not carried out as now. The vehicle dimensions and characteristics were different from today's vehicles. Modern vehicles are on roads and those vehicles are sometime entirely different than the time when the PCU factors were determined. Driver behavior was quite different from present behaviors as nowadays the drivers tend to take advantage of loose lane discipline conditions than in past. Therefore now is time to determine the new PCU factors for existing vehicle types. Otherwise the actual capacity of a road will not be captured in the analysis.

PCU factor for different vehicles vary with the number of lanes, intersections and road category. Most of the urban roads in Srilanka are 4lane roads. Thus it is important to find PCU for 4 lane roads.

1.3 Objectives

The specific objective of this study is, To Determine PCU factors for all types of vehicles for four-lane Road section with road terrain type.

1.4 Research Approach

In order to fulfill the objectives of this research the following approach will be followed:

- Review existing literatures in the area of highway capacity analysis and PCU factor calculation

- Data will be collected using videotaping, from four lane road sections by way of vehicle speeds, vehicle dimensions and road dimension measures.

- The collected data will be analyzed using Modified Density method and Chandra (1995)'s method to arrive at PCU values.

CHAPTER 2

2 LITERATURE SURVEY

In developing countries including Sri Lanka, mixed traffic condition prevails on roads and highways. It is important to understand that Heterogeneous traffic and Homogenous traffic requires different tools for planning and identify the factors which deviates a Heterogeneous traffic stream from a Homogenous traffic stream.

There is a wide variation in the static and the dynamic characteristics of different types of traffic. The only way of accounting for this non-uniformity for any traffic analysis in traffic stream is to convert all vehicles into a common unit and the most accepted unit for this purpose is passenger car unit (PCU). PCU value for a vehicle varies with traffic and roadway condition around (Aggarwal, 2008).

The heterogeneous traffic existing on urban roads of developing countries like India is characterised by the presence of vehicles of wide ranging static and dynamic characteristics. The unrestricted movement of these vehicles on road space makes the lane concept and expression of flow values, based on standard lane width, invalid. Also, when different types of vehicles share the same road space without any physical segregation, the extent of vehicular interactions varies widely with variation in traffic mix. (Arasan and Koshy,2004)

One prominent characteristic of Srilankan traffic when compared with a more Homogenous traffic stream is the presence of higher percentage of Motorcycles.

Motorcycles have a much smaller size and do not necessary follow the same lane discipline as automobiles. The lane width is determined based on the size of passenger cars; therefore, motorcycles can travel side by side in a lane (Branston, 1997) or follow a vehicle obliquely (Robertson, 2002). Motorcycle behavior influences the passenger cars further (Wong, Lee & Chen, 2016).

2.1 Factors affecting PCU Values

Passenger Car Unit (PCU) value has been defined by the TRRL as "On any particular section of road under prevailing traffic conditions, the addition of one vehicle of a particular type per hour will reduce the average speed of the remaining vehicles by the same amount as the additional of say, x cars of average size per hour. One vehicle of this type is equivalent to x PCU. In the case of a bottleneck, particularly in an intersection, if a particular type of vehicle under saturated conditions requires x times as much time at the intersection as is required by an average car, then that type is equivalent to x PCU" (Transport and Road Research Laboratory [TRRL], 1973).

If the addition of one vehicle of a particular class in the traffic stream produces the same effect as that produced by the addition of one passenger car, then that vehicle class is considered equivalent to a passenger car. Measure of relative space requirement of a vehicle class compared to that by a passenger car under a specified set of roadway, traffic and other conditions (Anand, Shekar, & Mohamed, 1999).

Capacity refers to the rate of flow during a specified period; and any change in the prevailing conditions results in a change in the capacity of the facility. Also, capacity is assumed to be stochastic in nature because of differences in individual driver behaviour and changing roadway and weather conditions (Minderhoud, et al. 1997).

PCU values depend on the following factors:

i. Vehicle Characteristics: Physical and mechanical, such as length, width, power, accelerations, deceleration and braking characteristics of the vehicles.

ii. Stream Characteristics:
   a) Mean stream speed
   b) Transverse gap or lateral clearance distribution of vehicles at different speeds of flow
   c) Longitudinal gap distribution of vehicles at different speeds of flow
   d) Speed characteristics of the stream such as speed distribution, dispersion and speed differences between different adjoining vehicles in longitudinal and transverse directions

e) Stream composition, i.e., percentage composition of different classes of vehicles Traffic volume to capacity ratio
f) Pedestrian volume
g) Flow conditions

iii. Roadway characteristics
   a) Horizontal alignment
   b) Location: rural, urban, and semi-urban
   c) Stretch: mid-block, signalized intersection, police controlled intersection, uncontrolled intersections, rotary
   d) Skid resistance of pavement surface
   e) Traffic flow regulations such as one-way, two-way, divided and undivided roads
   f) Number of lanes and pavement width
   g) Sight distance
   h) Pavement surface, unevenness' type and structural condition

iv. Environmental characteristics
   a) Surroundings and local factors
   b) Obstructions
   c) Roadway location - embankment, cut, underpass, overpass, tunnel
   d) Terrain conditions: plain, rolling, hilly, mountainous

v. Climatic conditions
   a) Fog, mist
   b) Rainy, dry

(Anand, Shekar, & Mohamed, 1999)

vi. Control conditions
   a) Posted speed limit
   b) Segregation of slow and fast moving vehicles

c) Free access, control of access

d) Traffic signals, stop signs, yield signs.

e) Restriction of curb parking

(HCM, 2000)

There are different approaches to estimate the capacity of a road. Fig. 2-1 shows the various methods, which are based on direct empirical and indirect empirical approaches (Minderhoud et al. 1997)

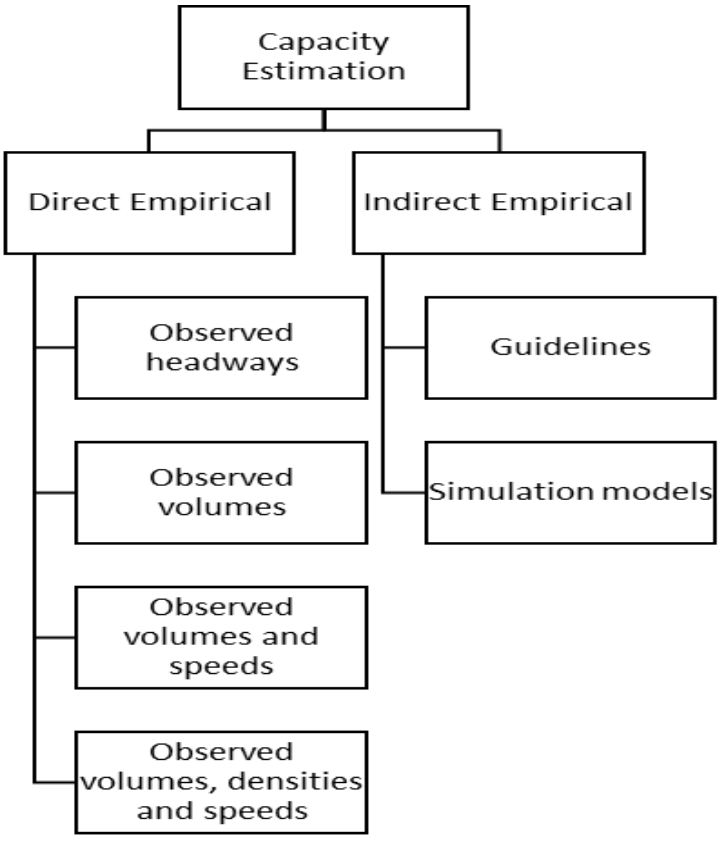

Figure 2-1:Approaches to estimating the road capacity (Minderhoud et al. 1997)

The approach proposed by Chandra (1995) states, PCU value for different vehicles under mixed traffic situation is directly proportional to the speed ratio and inversely proportional to the space occupancy ratio with respect to the standard design vehicle, which is car.

$$PCU_i = \frac{\text{(Speed ratio of the car to the ith vehicle)}}{\text{(Space ratio of the car to the ith vehicle)}}$$

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

Where;

PCUi passenger car unit value of the ith vehicle

Vc/ Vi speed ratio of the car to the ith vehicle

Ac/ Ai space ratio of the car to the ith vehicle

(Chandra, Kumar, and Sikdar, 1995)

There are few methods to calculate PCU factors but these do not necessarily reflect road conditions and road user behavior of Sri lanka.

1. Method based on relative delay (Walker's method) - biased towards gradient of a road.
2. Multiple linear regression model - based on speed reduction coefficient and does not take in to account the space taken by different vehicles.
3. Method based on headway - best suited to determine PCUs on level terrain at low levels of service
4. Density method - for pure homogenous conditions, does not include motorized three-wheelers, motorized two-wheelers, and non-motorized traffic.

(Retrieved on 06 December 2010 from http://www.ias.ac.in/sadhana/Pdf2007Aug/309.PDF)

Highway capacity manual uses Density Method to calculate PCU factors. PCU values derived from the density method are based on underlying homogeneous traffic concepts such as strict lane discipline, car following and a vehicle fleet that does not vary greatly in width.

Vehicle	**PCU**
CAR	1.00
Motor Cycle	n/a
3 – wheeler	n/a
Large Bus	1.60-5.00
HV	2.00-8.00

Table 2-1:PCU Factors derived in HCM (HCM, 2000)

However, Srilankan highways carry heterogeneous traffic, where road space is shared among many traffic modes with different physical dimensions. Loose lane discipline prevails; car following is not the norm. Therefore methods based on homogeneous traffic concepts have limited applicability for heterogeneous traffic.

Out of the various methods, Chandra's Method & Modified Density method are two methods that can be applied to heterogeneous traffic, which is characterized by loose lane discipline. All the other methods are primarily based on homogeneous traffic conditions mainly prevailing in developed countries.

CHAPTER 3

3 METHODOLOGY

3.1 Data collection

Data collection will be planned in two stages.

- Collection of preliminary data
- Collection of field data

3.1.1 Collection of preliminary data

Selection of survey location: Location for the study is identified based on following criteria;

- Uniformity of road characteristics in terms of pavement width, shoulder type, etc.
- No visual obstructions to traffic because of bus stop, road side developments, etc
- No intersection or side roads in the road stretch so that there is no change in the traffic volume over the entire stretch.
- No signalized intersection for 3.00 km road length.

Fixing stretch length: Minimum road length of any road section should be 400 meters.

Collection of vehicular dimensions: Different types of vehicles which are identified in the Srilankan vehicle categorization were identified. For all the vehicle types, physical dimensions such as breadth and length of the vehicles were collected.

3.1.2 Collection of field data

Traffic volume study: Traffic volume survey was carried out on all selected locations for certain duration by videotaping the traffic flow in both directions.

Speed study: Videotaping method was used to record the movements of every vehicle in both directions. Then the recording was observed to calculate the speed of each vehicle.

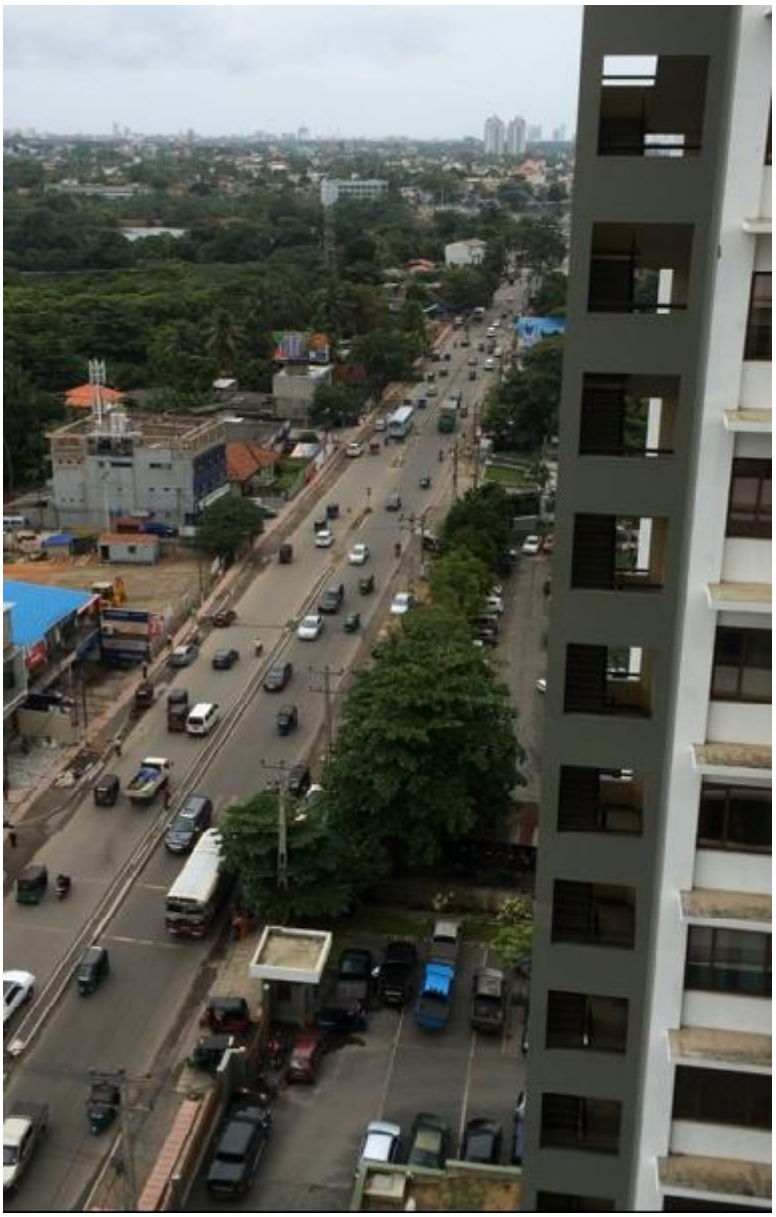

Figure 3-1 Video footage

3.2 Methods of Calculating PCU Value

Due to the vast application and importance of PCU factors, a number of studies have been taken up all over the world to determine PCU values for different vehicle types in varying roadway and traffic conditions.

Key methods on estimation of PCU values include Walker's method, Headway method, multiple

linear regression method, Simulation method, Density method (used by HCM 2000) and the method proposed by Chandra (1995).

Both Modified Density method and the method proposed by Chandra (1995), takes into account the heterogeneous nature and loose lane disciplined nature of the traffic stream. Hence they are considered in calculations during this study.

Chandra's method is to determine the PCU based on the Speed to Space ratio;

$$PCU_i = \frac{\text{(Speed ratio of the car to the ith vehicle)}}{\text{(Space ratio of the car to the ith vehicle)}}$$

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

Where,

PCUi passenger car unit value of the ith vehicle

Vc/ Vi speed ratio of the car to the ith vehicle

Ac/ Ai space ratio of the car to the ith vehicle

Modified density method proposed by Tiwari (Tiwari, Fazio, & Pavitravas, 2000);

$$PCU_{Xi} = \frac{(k_{car} / W_{85car})}{(q_{xi} / u_{xi}) / W_{85xi}}$$

W_{85car} = 85th percentile car distribution width

k_{car}= Density of cars (entities/km)

q_{xi}= flow of traffic entity group Xi in heterogeneous traffic (entities/hour)

u_{xi}= space mean speed of traffic entity group Xi (km/hr)

PCU factors for the observed road sections were calculated using both methods.

3.3 Sample Calculation

3.3.1 Measure the space covered by each type of vehicles

The vehicle categorization used by Srilankan guidelines as at present are as follows;

- MCL : 2 wheel Motor cycle
- TWL : Motorized Three wheel
- CAR : Passenger Car
- VAN : Van, Jeep
- LBU : Large bus unit
- HV : Single unit truck

Average breadth and width of the various vehicle types which falls within the above categories were taken.

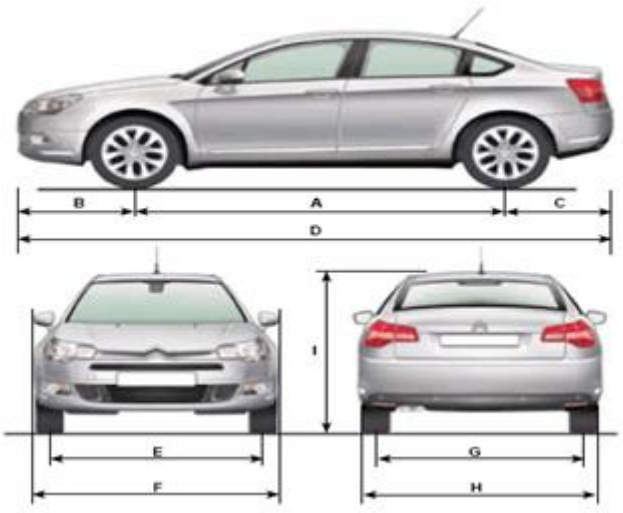

Figure 3-2:Vehicle Dimensions

3.3.2 Speed surveys on locations which are described under objectives.

Traffic volume data was collected using video camera to record vehicles in both directions during peak hours. Road length between two significant characteristics of the road section is measured on the ground. Then these video footages were observed and using a stop watch the time taken for a vehicle to travel between the pre noted two points are measured. The traffic volumes and speeds were calculated using these data.

85% value of road width used by traffic volume for Modified Density method:

The width of road utilized by a vehicle is measured as the distance from middle center between two vehicles to the carriageway edge.

The 85% value of the width distribution is taken as W85%.

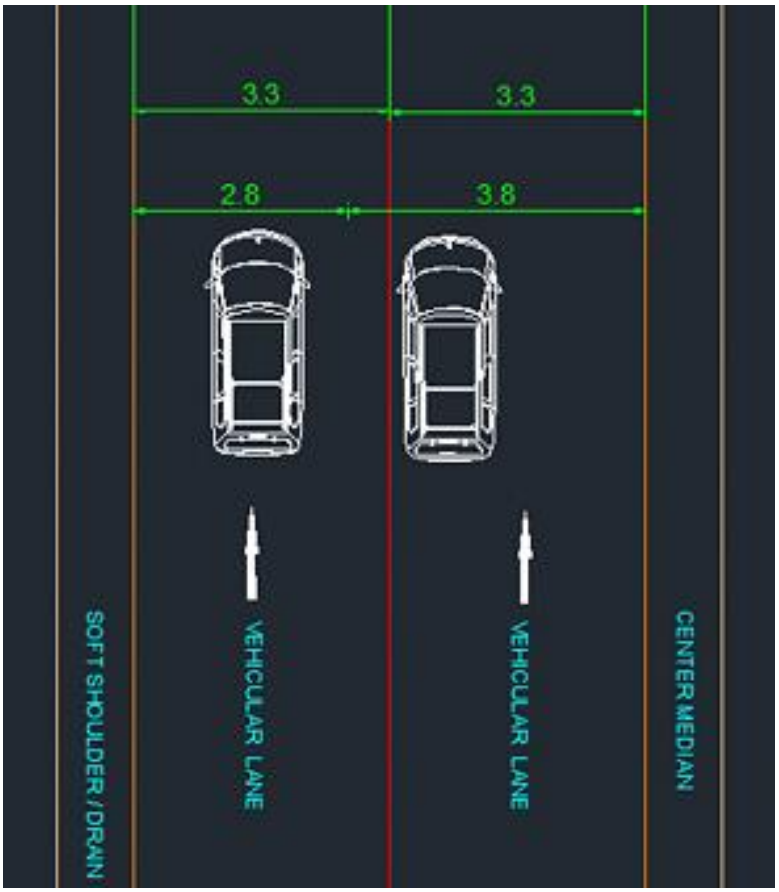

Figure 3-3:W85% measurement

3.3.3 Measuring road dimensions.

The road dimensions of every road section which are observed for traffic volume were measured for the road characteristics such as carriageway, hard shoulder, center median, etc.

3.3.4 Incorporate the above data with the selected model.

Since the traffic condition is heterogeneous, these collected data is analysed using Chandra's method and Modified Density method.

3.3.5 Development of suitable PCU estimation.

Sample calculation using data observed for Vehicle type "VAN"

1. 85th percentile Road width used by traffic entity group VAN (W85%) = 5.60m
2. Average speed of VAN = 51.50 km/h
3. Density forecast for car = k_{car}/km is obtained from the graph below.
   i.e. 61.00 cars/km

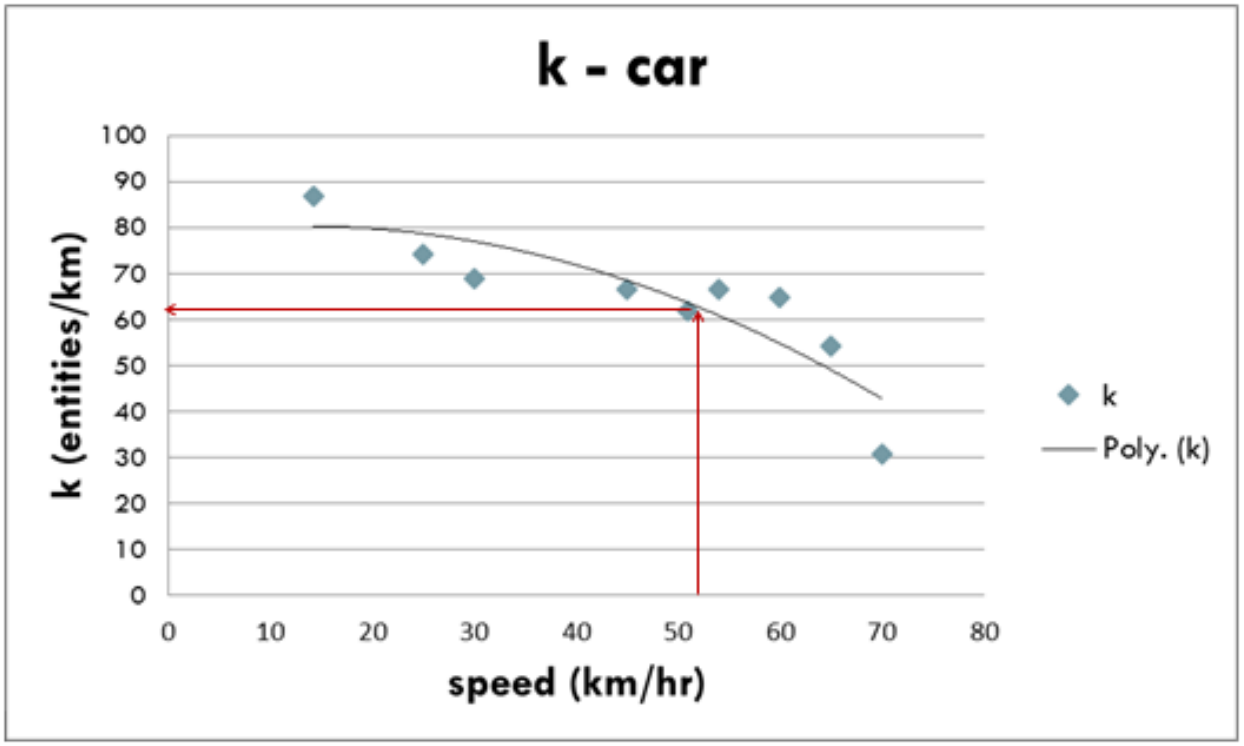

Figure 3-4:k value for standard car

5. Density adjustment to unit width k_{xi} / $W85_{xi}$
   = 61.00/5.60 = 10.87 (VAN/km/m)
6. Density adjustment to unit width for standard vehicle : car = 14.73 entities/km/m

$$PCU_{VAN} = \frac{(k_{car} / W_{85car})}{(k_{VAN} / W_{85VAN})} = \frac{14.73}{10.87} = 1.45$$

CHAPTER 4

4 RESULTS AND DISCUSSION

4.1 Results

4.1.1 PCU Calculation – Modified Density Method

	MCL	TWL	CAR	VAN	LBU	HV
W85%	5.78	5.35	5.50	5.60	6.70	6.60
Standard lane width - W_L	3.50	3.50	3.50	3.50	3.50	3.50
Average speed (km/h)	38.50	31.10	52.50	51.50	35.20	29.00
Density forecast for car (cars/km)	71.00	76.00	64.00	61.00	74.00	75.00
$K_{xi}/W_{85\%}$ (entities/km/m)	16.61	14.39	14.73	10.87	4.92	6.41
PCU	0.89	1.02	1.00	1.45	2.99	2.30

Table 4-1:PCU calculation according to Modified Density Method

4.1.2 PCU Calculation – Chandra's Method

For the Flat terrain condition.

Vehicle	Speed (kmph)	Veh.Projected Area (m^2)	PCU
CAR	52.50	8.11	1.00
VAN	51.50	11.05	1.39
Motor Cycle	38.50	1.48	0.30
3 - wheeler	31.10	3.41	0.74
Large Bus	35.20	26.61	4.89
HV	29.00	18.90	4.21

Table 4-2:PCU Calculation – Chandra's Method

4.2 Discussion

4.2.1 Srilankan Studies

Proffessor Amal S. Kumarage has used Regression Analysis to derive following PCU values for 4 lane roads in Sri Lanka.

	MCL	TWL	CAR	VAN	LBU	HV
Study results for 4 lane roads	0.60	0.90	1.00	1.00	1.70	1.50

Table 4-3:PCU Standards for Sri Lanka highway design (Kumarage, PCU Standards for Sri Lanka highway design,1996)

These values were derived in 1996 when the road environment and driver behavior were much different from today. With the recent developments in the infrastructure in the country, road environment has changed drastically. For planning and estimation purposes, it is better to derive new PCU factors which reflect current road environment.

4.2.2 PCU factor comparison

	MCL	TWL	CAR	VAN	LBU	HV
Study results using MDM	0.89	1.02	1.00	1.45	2.99	2.30
Calculated using Chandra's Method	0.30	0.74	1.00	1.39	4.89	4.21
Tiwari's MDM – literature (India)	1.40	11.70	1.00	1.00	2.40	2.40
RDA – literature (Used at present)	0.50	0.80	1.00	-	1.80	2.80
Srilankan studies	0.50	0.75	1.00	1.10	2.40	2.00

Table 4-4:PCU factor comparison

Study results calculated using Modified Density Method vary with Chandra's Method results mainly due to the use of W85% value in Modified Density Method instead of Vehicle area in Chandra's method.

PCU values derived using the Modified Density Method in India differs to study results which is carried out in Sri Lanka, due to differences in Environmental conditions and Driver behavior.

Both RDA-literature and Srilankan study results were derived in 1996 when the road surface condition was not as improved as today and the regular maintenance was not carried out as now. The vehicle dimensions and characteristics were different from today's vehicles as well. Such that, these values marginally vary with study results.

In order to validate the study results, the capacity values were calculated using the PCU values found in the study and compared against the capacity values found in literature.

According to the study results;

- Capacity of a four lane road using PCUs of Modified Density method is 2486 pcu/h/lane.
- Capacity of a four lane road using PCUs of Chandra's method is 2948 pcu/h/lane.

Observations in Chaandra's research on Indian roads has a capacity of 2818pcu/h/lane. Sachdeva has found capacity of intermediate-lane roads as 2000 pcu/h/lane. Sharma et al. reported a capacity value of 2200 pc/h/lane for four-lane and six-lane highways with earthen shoulders. Meher et al. has calibrated the VISSIM software to replicate mixed traffic flow behavior as observed on Indian highways and has found capacities of four-lane, six-lane and eight-lane highways as 2475, 2233 and 2180 pcu/h/lane respectively.

Theses capacities found in literature varies between 2000 – 2818 pcu/h/lane. Capacity value calculated using Modified Density method falls within this range but the capacity calculated using Chandra's method is out of the range. So that the PCU values calculated with Modified Density method can be voted as more applicable for modelling Srilankan four-lane roads.

CHAPTER 5

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Since the PCU factors used at present are out dated and do not reflect present road conditions and driver behavior, it is important to derive new up to date PCU factors.

There are many methods used around the world to derive PCU factors and these methods are applicable under different environmental conditions.

For Srilanka where the traffic is more of heterogeneous type, suitable methods to derive PCU s are "Chandra's method" and "Modified density method".

This research was carried out for 18 sections of 4 lane road sections in urban areas. The data recorded via video taping was later analysed to derive PCU factors using Chandra's method and Modified Density method.

$W_{85\%}$ values lies between 5.50m – 6.70m due to MCL and TWL running parallel to CARs, VANs, etc. for MCL $W_{85\%}$ is 5.78m reflecting the lane occupancy by one MCL covering the capacity of the road section that could cater for larger vehicles.

Above results show slight variations when compared to different methods and literature. These study calculations and results should be further clarified against other methods. Further to these methods there are more computer based methods used at present. Eg: Microsimulation, Multiple linear regression, "fuzzy model by Praveen Aggarwal". These methods have improved consistency in estimating PCU.

It was observed that vehicle occupy more area on wider roads due to the ease of movement. Even though widening of the carriageway is beneficial for the vehicles, it causes problems in the movement of pedestrians due to lengthy cross walks.

Motorized two-wheelers have PCU values less than one since they occupy less space due to smaller size. In the observed traffic streams the % composition of MCL was high thus the PCU value is low. It was observed that the PCU value decreases with increased percentage of composition of a slow moving vehicle type in the traffic stream.

Large PCU s of slow moving vehicles show the high capacity consumed by them. Speed plays a major role in determining PCU values. Including a service lane would improve the capacity by attracting these slow moving vehicles.

5.2 Limitations of Modified Density method

Modified Density method is a complex procedure due to the variables involved in calculating the final PCU value. The W85% value is difficult to measure because it keeps changing from frame to frame. Each and every frame should be analysed to arrive at an average value.

Also this is time consuming when compared to other available methods because there is a rigorous data collection and analysis procedure to obtain the required values.

Modified Density method is highly sensitive to the density forecast of the car. Since this is a parabolic graph, the change in k (entities/km) value with increase in speed is high. Minor change in average speed would drastically alter the k value and hence the PCU value.
This method does not take in to account the effect of oncoming traffic. Such that, only one way roads and divided highways can be modeled using Modified Density method.

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