transportation, roadway width, PCU values, highway capacity manual

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INFLUENCE OF ROADWAY WIDTH AND VOLUME TO CAPACITY RATIO ON PCU VALUES

Summary. The objectives of this paper are to determine the influence of volume to capacity ratio on Passenger Car Unit (PCU) values, speeds of the vehicles and volume of vehicles in PCUs. The limitation of Highway Capacity Manual's PCU values is explained. Statistical analysis determined that there is a significant difference in volume of cars only between homogeneous and heterogeneous traffic conditions for various road widths. Hence the PCU values of heterogeneous traffic are recommended for the design of traffic systems over homogeneous traffic conditions. The results of the present study shows that for heavy vehicles, SUVs and motorcycles, the PCU values as a function of volume to capacity ratio vary from 0.8 to 2.8, 1.0 to 2.3 and 0.2 to 0.65 respectively. The v/c ratio has a large influence on PCU values as found in this study. Under similar traffic conditions of this study, that exist elsewhere in the country, the values obtained in this study are recommended for use in the analysis and design of traffic engineering facilities.

WPŁYW SZEROKOŚCI DROGI I STOPNIA WYKORZYSTANIA PRZEPUSTOWOŚCI NA WARTOŚCI WSPÓŁCZYNNIKÓW PRZELICZENIOWYCH MIĘDZY POJAZDAMI RZECZYWISTYMI A POJAZDAMI UMOWNYMI

Streszczenie. Celem artykułu jest określenie wpływu stosunku natężenia ruchu do przepustowości drogi na współczynniki umożliwiające przeliczanie pojazdów rzeczywistych na pojazdy umowne (PCU), prędkość pojazdów i natężenie ruchu wyrażane w pojazdach umownych (PCU). Przedstawione są ograniczenia przy obliczaniu przepustowości wyrażanej w pojazdach umownych. Analizy statystyczne wykazują, że istnieją znaczne różnice między natężeniem samochodów w ruchu homogenicznym i heterogenicznym (ruchu jednorodnym i niejednorodnym), dla różnej szerokości dróg. W związku z tym do kształtowania układów komunikacyjnych rekomendowany jest opis warunków ruchu przy założeniu heterogenicznego potoku ruchu. Rezultaty aktualnych badań pokazują, że dla pojazdów ciężkich, samochodów osobowo-terenowych (SUV) i motocykli wartość współczynników przeliczeniowych jako funkcja stopnia wykorzystania przepustowości waha się odpowiednio od 0,8-2,8; 1,0-2,3 oraz 0,2-0,65. Stopień wykorzystania przepustowości ma więc znaczący wpływ na liczbę pojazdów umownych, co przedstawiono w wynikach przeprowadzonych badań. Otrzymane w tych badaniach wartości powinny być zalecane do używania w analizach i projektach związanych z inżynierią ruchu.

1. INTRODUCTION

The relationships between speed, volume and density are needed for the planning, design, operation and optimization of highways. Expressing traffic volume as number of vehicles passing a given section of road per unit time will be inappropriate when several types of vehicles with widely varying static and dynamic characteristics are comprised in the traffic (TRRL, 1965; PIARC, 1991). Passenger Car Unit is widely acknowledged as the measurement unit for traffic volume. This is an indicator of the interaction between the vehicles. It is obtained by considering the passenger car as the base vehicle. PCU value of any vehicle is the number of cars replaced by introducing the vehicle into the traffic stream, creating the same level of impedance in the traffic stream. The objectives of this study are to determine:

1. speed-volume relationships
2. Influence of volume to capacity ratio on PCU values
3. The relationship between volume to capacity ratio and the speed of vehicles.
4. The effect of volume to capacity ratio on volume of vehicles in PCUs.

TRANSYT simulation (TRANSYT 13, 2008) derives PCU values based on delays caused by different vehicles (Keller and James, 1984). Huber (1982), Krammes and Crowley (1986) recommended that PCUs may be calculated based on the impedance caused to the traffic. Highway Capacity Manual (2000) suggested PCU factors for heavy vehicles are applicable under free-flow conditions only (Al-Kaisy et al., 2005).

2. METHOD

Effect of roadway width on PCU values

By taking the impedance caused by a vehicle as the basis, PCU values were determined. The PCU values of the vehicle type (for example SUVs) can be calculated by trial and error method, as the ratio between number of cars removed from the homogeneous traffic stream and number of subject vehicle type added (SUVs) for maintaining the same speed of the stream. The effect roadway width has on PCU values of different categories of vehicles was studied. Estimation of the PCU values of different types of vehicles was done. This was achieved by the simulation of the traffic flow on different road widths. To study the effect of roadway width on heterogeneous traffic flow, 3 different lanes were considered. They were 2 lane, 3 lane and 4 lane roads in each direction. For 2 lane roads, the study was done on Mid-county Expressway between Conshohocken and Plymouth Meeting exits (Location 1). For 3 lane roads, the study was done on PA Route 1 on Roosevelt Blvd at 7^{th} St (Location 2). For 4 lane roads, the study was done on I-76 at Girard Ave (Location 3). The number of vehicles studied at the locations 1, 2 and 3 were 1203, 1156 and 1289 respectively. All these locations were chosen due to their proximity to Philadelphia. Each lane was of 3.66 meter width. The traffic composition at each location is given in Table 1.

A graphical relationship between the average speed and traffic volume was developed as shown in Figs. 1 and 2 for homogeneous and heterogeneous traffic respectively. In the homogeneous traffic, there were only cars. Both sections had a length of 915 meters. Time taken by each vehicle to traverse this stretch was observed and the speed was calculated. PCU values of vehicles in a large volume of traffic were taken into account. The roadway width affects the capacity of the road section. Hence the PCU values have to be compared on the basis of a traffic flow criterion. The v/c ratio (volume to capacity ratio) was selected for this. For the purpose of comparison, the PCU values of various categories of vehicles were found at selected volume-to-capacity ratios. The resulting data were plotted as shown in Figs. 3-5. Values of v/c ratio and speed of vehicles were plotted for the different lane width of the roads. These graphs are shown in Figs. 6-9.

Table 1

Distribution of Traffic Data

Vehicle Type	Location 1 2 – lanes (%)	Location 2 3 – lanes (%)	Location 3 4 – lanes (%)
Cars	74	77	70
Heavy Vehicles	14	15	18
SUVs	4	3	2
Motorcycles	8	5	10

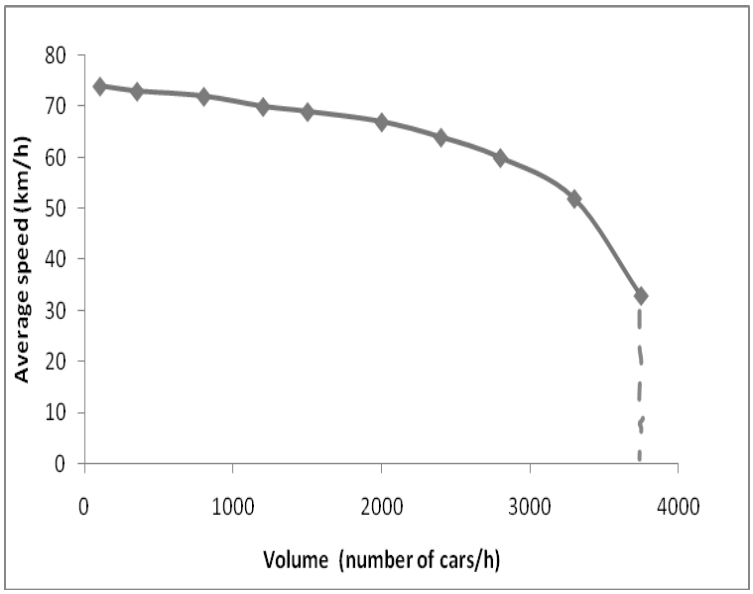

Fig. 1. Relationship between speed and flow under homogeneous traffic on a 2-lane road
Rys. 1. Relacja pomiędzy prędkością a natężeniem ruchu pojazdów na drodze o dwóch pasach ruchu w warunkach ruchu homogenicznego (jednorodnego)

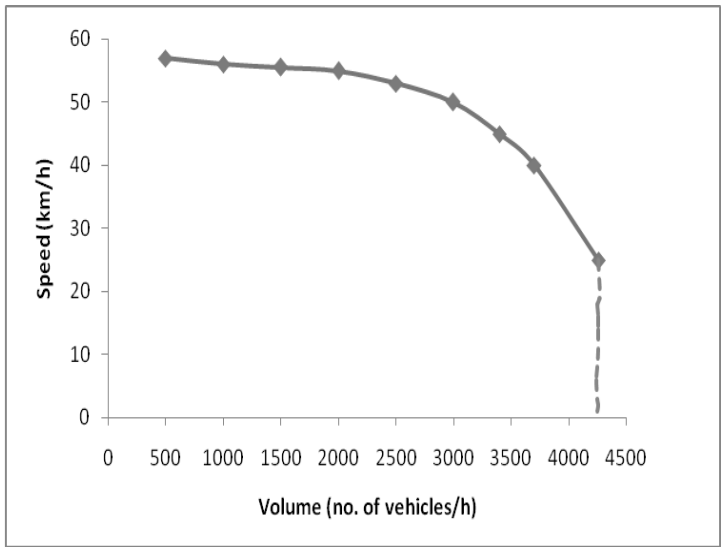

Fig. 2. Relationship between speed and flow under heterogeneous traffic on a 2-lane road
Rys. 2. Relacja pomiędzy prędkością a natężeniem ruchu pojazdów na drodze o dwóch pasach ruchu w warunkach ruchu heterogenicznego (niejednorodnego)

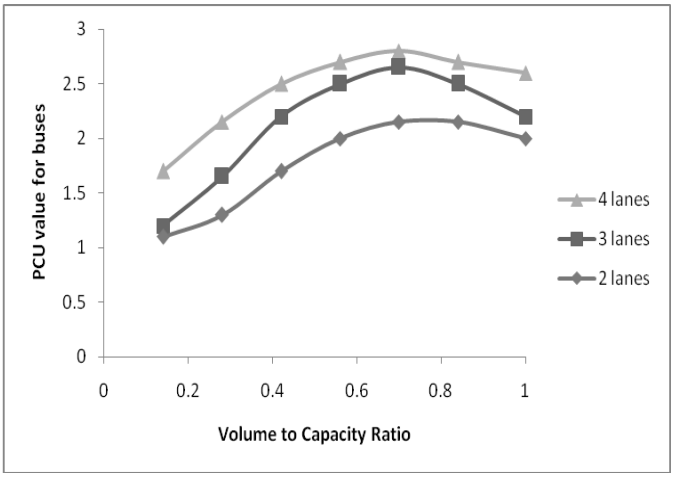

Fig. 3. Effect of V/C ratio on the PCU values of buses for various lane widths
Rys. 3. Wpływ stopnia wykorzystania przepustowości drogi na wartość współczynnika przeliczeniowego autobusów na pojazdy umowne, dla dróg o różnej szerokości

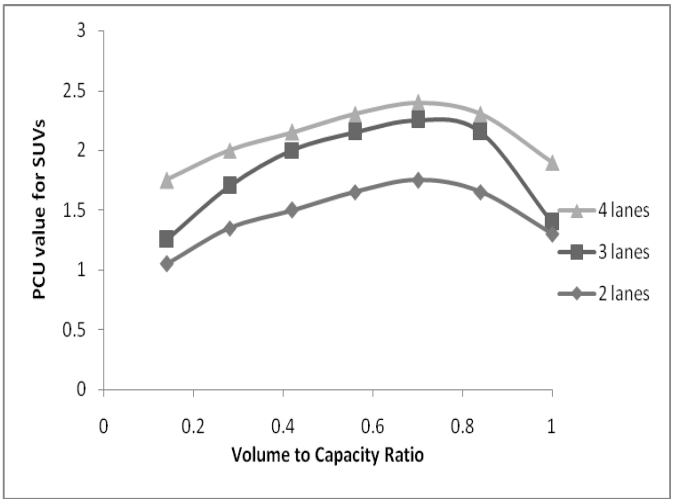

Fig. 4. Effect of V/C ratio on the PCU values of SUVs for various lane widths
Rys. 4. Wpływ stopnia wykorzystania przepustowości drogi na wartość współczynnika przeliczeniowego pojazdów osobowo-terenowych na pojazdy umowne, dla dróg o różnej szerokości

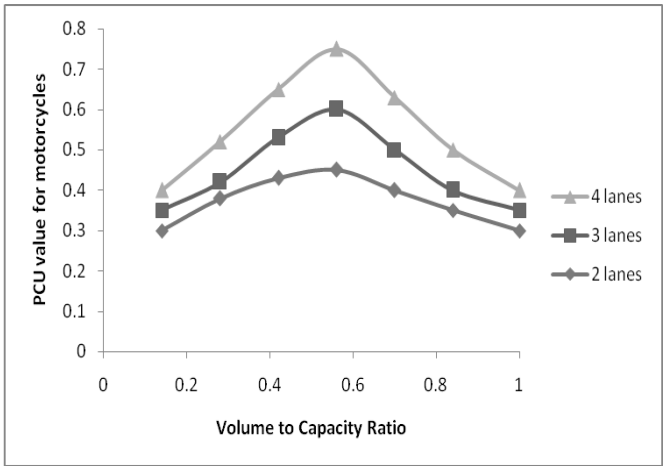

Fig. 5. Effect of V/C ratio on the PCU values of motorcycles for various lane widths
Rys. 5. Wpływ stopnia wykorzystania przepustowości drogi na wartość współczynnika przeliczeniowego motocykli na pojazdy umowne, dla dróg o różnej szerokości

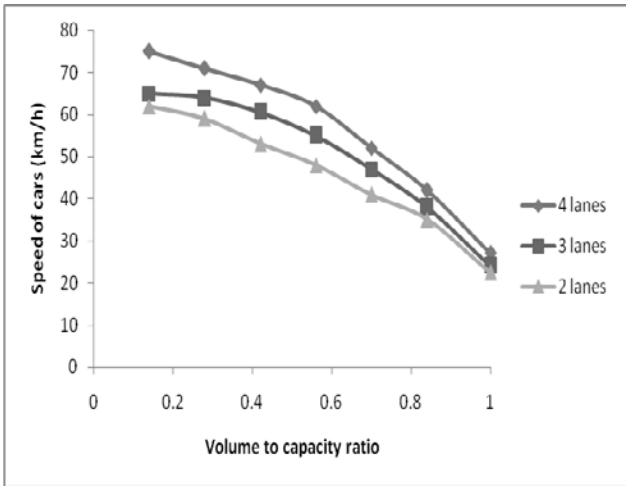

Fig. 6. Effect of v/c ratio on the speed of cars for different lane widths
Rys. 6. Wpływ stopnia wykorzystania przepustowości drogi na prędkość samochodów, dla dróg o różnej szerokości

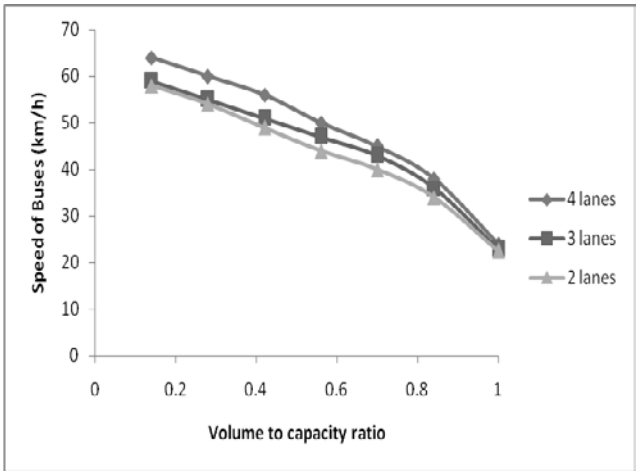

Fig. 7. Effect of v/c ratio on the speed of buses for different lane widths
Rys. 7. Wpływ stopnia wykorzystania przepustowości drogi na prędkość autobusów, dla dróg o różnej szerokości

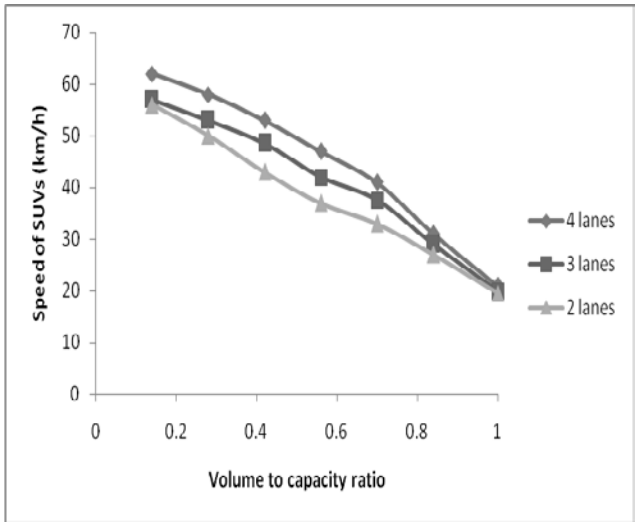

Fig. 8. Effect of v/c ratio on the speed of SUVs for different lane widths
Rys. 8. Wpływ stopnia wykorzystania przepustowości drogi na prędkość pojazdów osobowo-terenowych, dla dróg o różnej szerokości

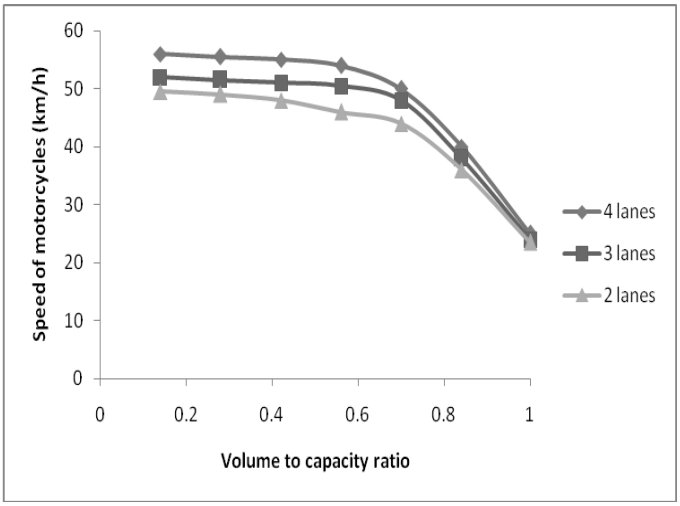

Fig. 9. Effect of v/c ratio on the speed of motorcycles for different lane widths
Rys. 9. Wpływ stopnia wykorzystania przepustowości drogi na prędkość motocykli, dla dróg o różnej szerokości

Determination of relationship between volume to capacity ratio and PCU volume

The relationship was determined using the following steps.
Step 1: From Fig. 1, a road capacity of 3740 was obtained for homogeneous traffic flow on a two lane road.
Step 2: From Fig. 2, a road capacity of 4270 was obtained for heterogeneous traffic flow on a two lane road.
Step 3: The PCU values for various vehicle types at various volume to capacity ratios were obtained from Figs. 3-5.
Step 4: The PCU equivalents of each type of vehicle was obtained by multiplying the number of vehicles with the corresponding PCU values.
Step 5: The influence of volume to capacity ratio on volume in PCU is developed and shown in Fig. 10 for both homogeneous and heterogeneous traffic. Similar results were found by Arasan and Krishnamurthy (2008).

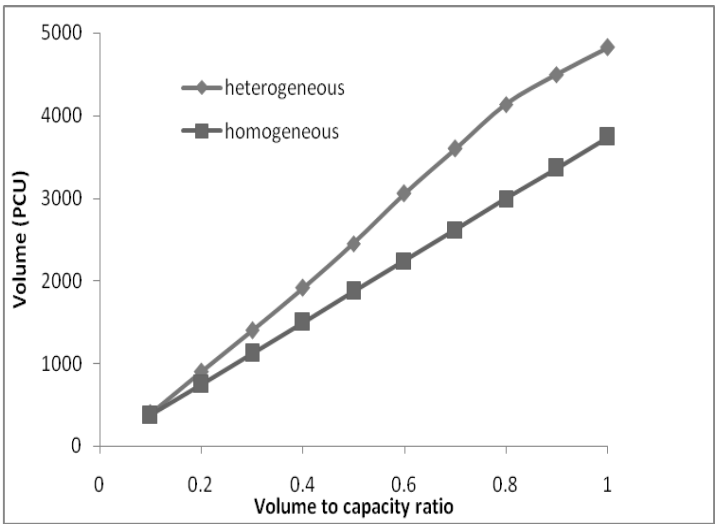

Fig. 10. Effect of volume to capacity ratio on volumes in PCU under different traffic conditions on a 2-lane road
Rys. 10. Wpływ stopnia wykorzystania przepustowości drogi na wartość współczynnika przeliczeniowego (PCU) pod wpływem różnych warunków ruchu, na drogach o dwóch pasach ruchu

Results and Discussion

For a given volume to capacity ratio, the speed of the vehicle type increases with increase in the width of the road space. This is because the maneuvering process becomes relatively easier on wider roads facilitating faster movement of vehicles. Table 2 shows that at any volume to capacity ratio, the percentage increase in speed of cars is larger than the percentage increase in speed of all other types of vehicles. Cars have the largest acceleration capabilities (Long, 2000; Fancher, 1983) among all the vehicles studied. This enables them to gain more speed compared to other vehicles (Bretherton Jr., 2003). Therefore the increase in speed difference between cars and other types of vehicles with increase in width of road space has resulted in increased PCU values. At lower volume levels, the PCU value increases with increase in traffic volume. This is due to longer space headway between the vehicles. The PCU value decreases with increase in traffic volume at higher volume levels. Cars can overtake the subject vehicle without significant reduction in speed due to the availability of larger headways. As the traffic volume increases, the headways decrease, causing larger magnitude of impedance. At volumes near capacity level, cars and subject vehicles have reduced speed differences because of smaller speed of the vehicles. This causes lesser PCU values for the subject vehicles. As seen in Figs. 3-5, the PCU value of a vehicle increases with increase in roadway width. Marginal increases in magnitude of PCU were noticed between 2 lane and 3 lane roads. Similar results were seen between 3 lane and 4 lane roads. It can be noticed from Figs. 6-9 that the speed of a vehicle increases with increase in road width. Increase in width of the roads gives allowance to higher maneuverability for all types of vehicles. While observing the variation of PCU, the change in the performance of the cars when the road width increases, also has to be taken into account.

Table 2

Speeds on 2 and 3 lane roads

Vehicle type	Volume to Capacity Ratio	Percentage Increase in Speed between 2 and 3 lane roads	Percentage Increase in Speed between 3 and 4 lane roads
Cars	0.2	6.0	8.0
	0.4	14.0	10.6
	0.6	14.6	12.4
	0.8	12.5	10.5
Buses and trucks	0.2	1.4	6.5
	0.4	4.0	9.7
	0.6	7.0	6.2
	0.8	6.1	5.5
SUVs	0.2	4.3	6.7
	0.4	12.0	9.3
	0.6	13.5	10.0
	0.8	8.5	7.0
Motorcycles	0.2	3.6	6.0
	0.4	6.2	7.8
	0.6	9.6	6.5
	0.8	6.0	5.2

The percentage increase in speeds of vehicles with increase in road width was calculated. This was done to compare the increase in speed of cars to the increase in speed of other vehicles. The percent increase in speed between 2 and 3 lane roads and between 3 and 4 lane roads as a function of volume to capacity ratio for various types of vehicles is shown in Table 2. These values are calculated from Figs. 6-9. As seen from Table 2, the percent increase in speed of cars was more than that of any type of vehicle for any given v/c ratio or lane width. Factors that facilitate the increase in speed include

higher acceleration, increased road width, better mechanical capabilities etc. For a given road width increase in speed is attributed to the higher acceleration capabilities of the vehicles.

Statistical analysis was conducted to establish the level of significance on the effect of volume to capacity ratio on volume in PCU under different traffic conditions for the three lane widths. For 2 lane roads, the critical value of t statistic for 5% significance level for 10 degrees of freedom obtained from standard t distribution is 2.23. The corresponding calculated t value is 4.88. Therefore, it is concluded that there is significant difference in the volume of cars only in PCU between homogeneous and heterogeneous traffic conditions. Similarly, for 3 lanes and 4 lanes, the calculated t values are larger than those of critical values. This indicates that there is significant difference in volume of cars only in PCU between homogenous and heterogeneous traffic conditions for 2, 3 and 4 lane roads as shown in Table 3.

Table 3

Summary of Statistical Analysis of PCU Values between Homogeneous and Heterogeneous Traffic Conditions at 5% Significance Level

No. of Lanes	$t_{calculated}$	$t_{critical}$	Conclusion
2	4.88	2.23	Significantly Different
3	6.3	2.16	Significantly Different
4	5.89	2.11	Significantly Different

The PCU values of heterogeneous traffic, obtained in this study, may be used for the analysis of traffic conditions in other parts of the country under similar circumstances.

Comparison of PCU values between this study and those of Highway Capacity Manual

Highway Capacity Manual gives PCU values for trucks, buses and recreational vehicles for 4 lanes and 6 lanes as a function of grade only. The manual does not give the PCU values as a function of volume to capacity ratio. Moreover the manual does not provide the PCU values for SUVs and motorcycles. Under level grade, the PCU values are 1.7, 1.5 and 1.6 for trucks, buses and recreational vehicles respectively. The results of the present study (Figs. 3-5) show that for heavy vehicles, SUVs and motorcycles, the PCU values as a function of v/c ratio vary from 0.8 to 2.8, 1.0 to 2.3 and 0.2 to 0.65 respectively. Since v/c ratio has a large influence on PCU values as found in this study, these values need to be used in the analysis of traffic engineering studies to reflect the real-life conditions.

CONCLUSIONS

1. Change in traffic volume affects the PCU values significantly. The PCU value of vehicles increases with increase in traffic at lower volume. The PCU value of vehicles decreases with increase in traffic at higher volume conditions.
2. The value of PCU increases with increase in width of road.
3. The PCU values for heterogeneous traffic differs significantly from those of homogeneous traffic. Hence, for the traffic conditions considered, there is enough proof to treat the PCU as a dynamic quantity rather than a constant.
4. The results of the present study show that for heavy vehicles, SUVs and motorcycles, the PCU values as a function of volume to capacity ratio vary from 0.8 to 2.8, 1.0 to 2.3 and 0.2 to 0.65 respectively. The v/c ratio has a large influence on PCU values as found in this study. Under similar traffic conditions of this study, that exist elsewhere in the country, the values shown in Fig. 3-5 are recommended for use in the analysis and design of traffic engineering facilities.

Acknowledgment

Keerthi Takkalapelli, a graduate student, organized the experiments. His work is duly acknowledged.

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Received 12.11.2009; accepted in revised form 26.06.2010