

# Passenger Car Unit(PCU) Based Traffic Analysis of Tilkamanjhi Intersection, Bhagalpur, Bihar

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**Abstract:** *This study analyzes the effect of different Passenger Car Unit (PCU) estimation methods on roadway capacity under heterogeneous traffic conditions at the Tilkamanjhi Chowk signalized intersection. Traffic volume data collected from the Zeromile, Barari, Manali Chowk, and Kachari Chowk approaches showed that the highest traffic load was observed at the KH approach with 573.1 PCU/hr, followed by the ZM approach with 508.8 PCU/hr. PCU values were estimated using the Static PCU method, Dynamic PCU method, and Indo-HCM (2017) method. Greenshield's Linear Model was used to establish the Speed-Flow-Density relationship and estimate roadway capacity. The study found that dynamic PCU values provide a more realistic representation of heterogeneous traffic conditions and significantly influence roadway capacity estimation. The results may be useful for traffic signal optimization and urban traffic management.*

**Keywords:** Passenger Car Unit (PCU), Heterogeneous Traffic, Traffic Flow, Signalized Intersection

## I. INTRODUCTION

Traffic conditions in developing countries such as India are predominantly heterogeneous in nature, consisting of various categories of vehicles with distinct static and dynamic characteristics. Since all vehicle types operate within the same roadway space, the movement and performance of one category are considerably affected by the presence of others. Such interactions become more pronounced on intermediate and two-lane roads compared to multilane highways. In India, a major proportion of National Highways (NH) and State Highways (SH) comprise single-lane, intermediate-lane, or two-lane facilities; therefore, traffic heterogeneity and speed variation among vehicles considerably influence roadway capacity. To overcome the effect of such heterogeneity, different vehicle categories are transformed into a common representative unit termed as Passenger Car Unit (PCU).

Several approaches have been developed for the estimation of PCU values, and the selected method plays an important role in determining roadway capacity. The present study primarily focuses on analysing the effect of varying PCU values of the same vehicle category on the estimated roadway capacity. In addition, the study aims to evaluate PCU values for different vehicle categories using three established methodologies, develop the Speed-Flow-Density relationship through Greenshield's Linear Model for capacity estimation, and compare the obtained capacity values with those corresponding to the base condition.

Several studies have been carried out to determine the most appropriate Passenger Car Unit (PCU) values for different vehicle categories. Among these studies, the concept of dynamic PCU proposed by Chandra and Sinha in 2001[1] is considered one of the most significant contributions. Their approach incorporated the dynamic characteristics of vehicles while estimating PCU values. The methodology was based on the principle that the PCU value of a vehicle is directly proportional to the ratio of its clearing speed and inversely proportional to the ratio of space occupancy with respect to a standard design vehicle.

Following the introduction of the dynamic PCU concept, numerous studies were conducted in India as well as in other countries focusing on capacity estimation under heterogeneous traffic conditions. Researchers such as Dey et al. (2008)[2], Mehar et al. (2013)[3], and Mondal et al. (2017)[4] further explored the application of dynamic PCU in roadway capacity analysis. On the other hand, Saha et al. (2017)[5] applied the concept of static PCU for estimating the



capacity of two-lane roads under mixed traffic conditions. However, they emphasized that the adoption of dynamic PCU could minimize the limitations associated with existing capacity standards for heterogeneous traffic operations on two-lane roads.

Outside India, Al-Kaisy et al. (2005)[6] considered Queue Discharge Flow (QDF) capacity as the equivalency criterion for developing Passenger Car Equivalent (PCE) factors. Similarly, Zhang et al. (2006)[7] proposed vehicle moving space as a parameter for deriving PCE values under varying roadway and level-of-service conditions. In India, Basu et al. (2006)[8] utilized stream speed as the equivalency measure for modelling Passenger Car Equivalent values and employed a Neural Network (NN) approach to capture the nonlinear effects of traffic volume and composition on stream speed.

Further studies by Satyanarayana et al. (2012)[9] focused on the development of PCU factors and capacity norms for rural highway mid-block sections in Visakhapatnam. Subsequently, Dhamaniya and Chandra (2013)[10] introduced an innovative methodology for converting heterogeneous traffic volume from vehicles per hour into homogeneous PCU per hour using stream equivalency factors, thereby eliminating the need to estimate individual PCU values for each vehicle category. This methodology was later adopted by Nokandek et al. (2016)[11], who observed that PCU factors are highly sensitive to variations in traffic volume and traffic composition. Their findings also indicated that stream equivalency factors exhibit a linear relationship with the proportion of different vehicle categories in the traffic stream. The concept of stream equivalency factor was subsequently incorporated into the Indo-HCM Manual (2017) as a part of roadway capacity estimation procedures. In the present study, static PCU values, dynamic PCU values, and the PCU values recommended in the Indo-HCM (2017) are employed for roadway capacity estimation and comparative analysis.

## II. LITERATURE REVIEW

The rapid growth in urban population and the increasing number of vehicles have made traffic congestion a major issue in cities. Traffic congestion not only increases travel time and driver stress but also causes greater fuel consumption, higher transportation expenses, and increased carbon dioxide emissions. Traffic signal controllers are important for regulating vehicle movement; however, traditional traffic systems are generally nonlinear and complex in nature and mostly operate using fixed timing schedules instead of adapting to changing traffic conditions. This study presents an adaptive traffic control system based on image processing in MATLAB to modify the duration of green, amber, and red signals according to real-time traffic density and vehicle count. The system uses two Arduino Uno boards, where one board controls the green and amber lights while the other controls the red light, allowing continuous and automatic adjustment of traffic signals[12]

This study examines the traffic composition at a particular intersection using Passenger Car Unit (PCU) values and shows that passenger cars and trucks contribute significantly to traffic congestion. Although the number of buses is comparatively lower, their impact on congestion is considerable because of their higher PCU values. The overall traffic load at the intersection is estimated to be 160 PCU/min, indicating the importance of considering both vehicle volume and vehicle type for efficient traffic management, urban planning, and infrastructure development [13].

The continuous increase in the number of vehicles in urban areas has resulted in growing traffic congestion, lower travel speeds, and increased fuel consumption. This study proposes an adaptive traffic signal controller based on fuzzy logic for an isolated intersection, where the green signal duration is dynamically modified using real-time parameters such as queue length, arrival flow, and exit flow. The controller independently regulates the primary and secondary driveways according to the prevailing traffic volume. Simulation outcomes indicate that the proposed system provides better performance than conventional fixed-time traffic signals under different traffic conditions [14].

Traffic congestion and road accidents have become serious problems in highly populated urban areas, causing loss of time and increased economic costs. Conventional fixed-time traffic signal systems are often inefficient as they do not consider fluctuations in traffic volume, leading to uneven traffic movement at intersections. Intelligent transportation systems provide a more efficient solution by adjusting signal timings dynamically according to the number of vehicles present at each intersection. This study proposes an automated algorithm based on artificial intelligence and image



processing techniques for controlling traffic signal durations and evaluates its effectiveness by comparing the obtained results with manual traffic control methods. The implementation of the proposed algorithm can contribute to better traffic regulation and help minimize both travel time and vehicle waiting time on roads[15].

The increase in population and the rapid growth in the number of vehicles have resulted in severe traffic congestion, leading to unnecessary loss of time and fuel. Conventional fixed-time traffic signal systems are often ineffective in handling varying traffic conditions, whereas sensor-based systems can modify signal timings according to traffic volume. This study proposes the use of a digital camera to capture real-time road images for estimating traffic density and dynamically controlling traffic signals to achieve more efficient traffic movement[16].

Traffic congestion in urban areas, particularly in large cities, has increased due to the growing number of vehicles and the limitations of fixed-time traffic signal systems. This study utilizes live video feeds and image processing techniques to estimate traffic density in real time and dynamically modify signal timings accordingly. The proposed approach is intended to minimize congestion, reduce vehicle waiting time, lower fuel consumption, and decrease the occurrence of road accidents. In addition, the system can provide useful traffic data for future roadway planning and the possible synchronization of multiple traffic signals[17].

The increasing level of traffic congestion in urban areas has led to the development of intelligent traffic management systems, as conventional fixed-time traffic signals are often insufficient for handling varying traffic conditions. Various approaches based on sensors and video-based vehicle detection techniques have been proposed to optimize traffic signal timings and enhance overall traffic flow efficiency[18].

### III. METHODOLOGY

Several macroscopic models developed by different researchers are available for analysing the relationship among speed, flow, and density. In the present study, the relationship between speed, flow, and density is established using the conventional speed–density model, namely Greenshield’s Linear Model. According to this model, the speed–density relationship is linear in nature, where the maximum speed occurs under low traffic flow conditions and the speed becomes zero under jam conditions. The speed–volume relationship follows a parabolic trend, with the maximum traffic volume occurring at a density equal to half of the jam density. The relationship between flow and density is expressed as follows:

$$F = \frac{d}{v}$$

Where,

F = Traffic flow in PCU/hr

d = Density in PCU/km.

v = Space Mean Speed in km/hr

The generalized linear form of the relationship is given as follows:

$$V = a' - b'K$$

where,  $a'$  and  $b'$  are constants representing the free-flow speed and the ratio of free-flow speed to jam density, respectively.

Now, dynamic PCU values are estimated using the methodology proposed by Chandra and Sinha (2001). The fundamental concept of the proposed method states that the PCU value is directly proportional to the ratio of clearing speed and inversely proportional to the ratio of space occupancy with respect to the standard design vehicle, i.e., a passenger car.

$$PCU_i = \frac{\text{Speed ratio of car to } i\text{-th vehicle}}{\text{Space ratio of car to } i\text{-th vehicle}}$$

The dynamic PCU value for the  $i$ -th vehicle category is expressed as follows:

$$PCU_i = \left( \frac{V_c/V_i}{A_c/A_i} \right)$$



where,  $PCU_i$  = Passenger Car Unit of the  $i$ -th vehicle type,

$V_c$  = Mean speed of passenger car (kmph),

$V_i$  = Mean speed of the  $i$ -th vehicle type (kmph),

$A_c$  = Projected rectangular area of passenger car ( $m^2$ ), and

$A_i$  = Projected rectangular area of the  $i$ -th vehicle type on the roadway ( $m^2$ ).

The PCU values obtained using this method are utilized in the present study for the estimation of roadway capacity.

Vehicle Type	Range	Median
Car	1.00	1.00
Two-Wheeler	0.20-0.50	0.30
Auto Rikshaw	1.10-2.00	1.20
Bus	2.80-4.80	4.50

Table1: Range of PCU (Source-Indo-HCM)

The present study primarily focuses on examining the effect of PCU estimation on highway capacity. Therefore, the PCU values used for capacity estimation are determined using three different methods: (i) the Static PCU method as recommended in Indian Roads Congress IRC-64: 1990[19], (ii) the Dynamic PCU method proposed by S. Chandra (2004)[20], and (iii) the Indian Highway Capacity Manual method. The methodologies adopted for determining the PCU values are described below.

### III. TILKAMANJHI SIGNALIZED INTERSECTION

Before proceeding with the detailed analysis, it is necessary to describe the characteristics of the Tilkamanjhi Chowk signalized intersection. The intersection comprises two lanes in each direction and functions as an important connecting junction between Zeromile, Manali Chowk, Barari, and Kachari Chowk. Vehicles approaching from Zeromile can either continue straight towards Manali Chowk, take a right turn towards Barari, or turn left towards Kachari Chowk. In a similar manner, vehicles arriving from Barari may move straight towards Kachari Chowk, turn right towards Manali Chowk, or turn left towards Zeromile. Traffic coming from Manali Chowk may proceed straight towards Zeromile, turn right towards Barari, or take a left turn towards Kachari Chowk. Likewise, vehicles approaching from Kachari Chowk can continue straight towards Barari, turn right towards Zeromile, or turn left towards Manali Chowk. Consequently, the intersection experiences several conflicting traffic movements, making it an important location for traffic control and signal optimization.

The signal control system at the intersection operates with four distinct phases. In three of these phases, vehicles from different approaches are allowed to move simultaneously while consolidating within their respective lanes. When the green interval of a given phase terminates, the vehicles on those approaches are instructed to stop, and the subsequent phase is activated, permitting movement from the next approach. This sequence continues until all four phases are executed, beginning with the Zeromile approach and completing one full signal cycle.



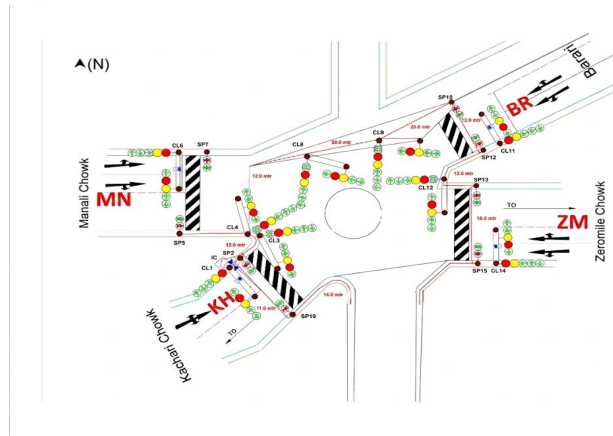


Figure 1: Tilkamanjhi Intersection

Here, the two-letter notation as shown in the Figure 1 illustrates for vehicle arrival rate variables, which are explained as follows

- ZM- Average vehicle arrival rate at Zero-Mile road.
- BR- Average vehicle arrival rate at Barari road.
- MN- Average vehicle arrival rate at the Manali Chowk road.
- KH- Average vehicle arrival rate at the Kachari Chowk road.

### III. ESTIMATION OF PCU AT TILKAMANJHI INTERSECTION

Traffic volume data at the Tilkamanjhi Chowk intersection were collected in terms of vehicles per hour (veh/hr) for different categories of vehicles such as cars, two-wheelers, auto-rickshaws, and buses. Since the traffic stream at the intersection is heterogeneous in nature, the observed vehicle counts were converted into equivalent Passenger Car Units (PCU/hr) to obtain a uniform measure of traffic flow. The conversion of vehicular traffic into PCU values helps in representing the effect of different vehicle categories on roadway performance by considering variations in vehicle size, speed, and road occupancy characteristics. The converted PCU values were further used for traffic flow analysis, roadway capacity estimation, and evaluation of traffic conditions at different approaches of the Tilkamanjhi signalized intersection.

PCU Value Tables

Vehicle Type	Vehicle (10:00–11:00 AM)	PCU
Car	189	189
Two-Wheeler	196	58.8
Auto Rickshaw	195	234
Bus	6	27
<b>Total</b>	586 veh/hr.	508.8 PCU/hr.

Table 2: PCU values for ZM phase

Vehicle Type	Vehicle (10:00–11:00 AM)	PCU
Car	48	48
Two-Wheeler	59	17.7



Auto Rickshaw	41	49.2
Bus	3	13.5
<b>Total</b>	151 veh/hr.	128.4 PCU/hr.

Table 3: PCU values for BR phase

Vehicle Type	Vehicle (10:00–11:00 AM)	PCU
Car	119	119
Two-Wheeler	120	36
Auto Rickshaw	135	162
Bus	5	22.5
<b>Total</b>	379 veh/hr.	339.5 PCU/hr.

Table 4: PCU values for MN phase

Vehicle Type	Vehicle (10:00–11:00 AM)	PCU
Car	259	259
Two-Wheeler	227	68.1
Auto Rickshaw	175	210
Bus	8	36
<b>Total</b>	669 veh/hr.	573.1 PCU/hr.

Table 5: PCU values for KH phase

#### IV. CONCLUSION

The present study examined the influence of different PCU estimation methods on roadway capacity under heterogeneous traffic conditions at the Tilkamanjhi signalized intersection in Bhagalpur. Traffic volume analysis revealed considerable variation among the four approaches of the intersection. The Kachari Chowk (KH) approach experienced the highest traffic load with 669 veh/hr equivalent to 573.1 PCU/hr, followed by the Zeromile (ZM) approach with 586 veh/hr and 508.8 PCU/hr. The Manali Chowk (MN) and Barari (BR) approaches recorded 339.5 PCU/hr and 128.4 PCU/hr respectively. These results indicate that the KH and ZM approaches are the most congested movements at the intersection.

The study demonstrated that roadway capacity estimation is significantly influenced by the selected PCU values. Dynamic PCU estimation based on the methodology proposed by Chandra and Sinha provided a more realistic representation of heterogeneous traffic because it considers both vehicle speed and space occupancy characteristics. Greenshield's Linear Model successfully established the Speed–Flow–Density relationship and showed that traffic flow decreases under increasing density conditions, eventually reaching jam conditions at maximum density.

The analysis further revealed that although buses constituted a smaller proportion of the traffic stream, their contribution to congestion was comparatively higher because of their larger PCU values. Similarly, auto-rickshaws and



two-wheelers formed a major portion of the heterogeneous traffic composition and substantially affected traffic flow characteristics. Overall, the study confirms that the use of dynamic PCU values can improve the accuracy of roadway capacity estimation and may assist traffic engineers and urban planners in designing efficient traffic signal timings, roadway facilities, and traffic management strategies for mixed traffic environments.

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