

Passenger Car Equivalent Estimation Methods of Trucks in Traffic Stream



Syed Omar Ballari

Abstract: *In Most Of Developing Countries, The Traffic Is Heterogeneous In Nature Consisting Of Wide Variety Of Vehicles Having Different Dynamic And Static Characteristics. Passenger Car Unit (PCU) / Passenger Car Equivalent (PCE) Values Show A Vital Job In Changing Over Heterogeneous Traffic Stream Into Comparable Homogeneous Traffic, Which Comprises Of Traveller Vehicles As It Were. PCE Values Are Vital In Rush Hour Gridlock Stream Investigations. This Paper Reviews The Previous Researches Carried Out About The Estimation Of Passenger Car Equivalents With Different Performance Measures At Mid-Block Sections And Summarizes PCE Variation With Percentage Of Trucks And Flow Rates In The Tabular Form.*

Keywords: *Heterogeneous, Passenger Car Equivalent, Mid-Block Sections.*

I. INTRODUCTION

Traffic streams in India for the most part heterogeneous comprising of wide variety of vehicles which varies in their physical and operating characteristics. Their movements are highly depending on the available road space. This heterogeneous traffic consists of motorized vehicles (like heavy vehicle such as truck, mini truck, bus etc.; medium vehicle such as car, etc.; lighter vehicle such as two-wheeler, auto rickshaw etc.) and non-motorized vehicles (like cycle, cart, rickshaw, pedestrian, etc.). Further, the vehicles in Indian rush-hour traffic streams do not pursue path discipline which makes prevailing rush-hour traffic stream behaviour even more complex.

A Traveller Car Equivalent is basically the effect that a method of transport has on traffic factors, (for example, progress, speed, thickness) contrasted with a solitary vehicle. Passenger cars Equivalents (PCE) are used to express different vehicles in the heterogeneous traffic stream to passenger cars in the homogeneous traffic stream.

These PCEs are considered to be most essential in the analysis of heterogeneous traffic. The first study on PCE was conducted in 1965 and PCE were introduced in Highway Capacity Manual (HCM) 1965 and characterized as "The quantity of traveller vehicles dislodged in the rush hour gridlock stream by a truck or a transport, under the predominant roadway and traffic conditions".

Manuscript received on January 02, 2020.

Revised Manuscript received on January 15, 2020.

Manuscript published on January 30, 2020.

* Correspondence Author

Syed Omar Ballari*, Professor, Department of Civil Engineering, Anurag Group of Institutions, Hyderabad, Telangana, India

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an [open access](http://creativecommons.org/licenses/by-nc-nd/4.0/) article under the CC-BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>)

This meaning of PCE was for relative homogeneous traffic conditions (just transport, vehicle and trucks) winning in created nations. It identified six parameters to estimates PCE values which are, headway, delay, platoon formation, speed, vehicle hours or density, and travel time. From that point forward a few people have dealt with evaluating PCE values for various vehicles under various traffic and roadway conditions [Huber (1982); Craus et al., (1980); Kimber et al., (1985); Kaisy et al.,

(2005); Kimber et al., (1985); Sumner et al., (1984); Webster et al., (1999); Elefteriadou et al., (1997); Demarchi and Setti (2003) ; Mallikarjuna et al., (2006);]. The majority of the works done here in past were planned for creating PCE values for substantial vehicles, for example, trucks. In a large portion of the cases PCE estimation is completed for one sort of vehicle. A few works were completed to gauge diverse PCE values for various sorts of trucks characterized dependent on weight to torque proportion. Sumner et al., (1984) proposed a model for the case in which traffic is made out of more than one class of overwhelming vehicle. Be that as it may, this strategy didn't think about the connection between various overwhelming vehicles (Demarchi and Setti 2003) and proposed a model in which total proportionality factor is determined for blended stream. Even the existing code available in India (IRC: 64-1990) suggested two arrangements of PCE thinking about compositional impact. It is perceived that the PCE of a vehicle type changes with extent of that vehicle type in the rush hour gridlock stream. These recommended PCE values are based on limited field observed data. The PCE embraced are for the most part static, independent of the blend or some other trait of traffic or sign. In any case, the PCE esteems are only here and there static, and fluctuate contingent upon a few components like traffic synthesis, static and dynamic qualities of vehicles just as geometry of the crossing point and the control framework.

II. PCES BASED ON SPEED

There are three different ways to estimate PCEs based on speed.

- i) To process PCE that outcomes in a similar normal working velocity for traveller vehicles as it were.
- ii) To figure PCE that outcomes in a similar normal working rate for the entire traffic.
- iii) To consider the overall paces decrease identified with every vehicle type.

Messer (1983) used first way to compute PCE for studying two-lane two-way rural highways. St. John et al., (1978), Huber (1982) utilized second approach to consider PCE.

Particularly, Huber examined three PCE measures: normal voyaging speed, absolute travel time, and normal voyaging speed for traveller vehicles as it were. Some recommending outcomes are accomplished. To begin with, it is demonstrated that PCE esteems will increment as level of substantial vehicles increments. This is sensible on the grounds that high level of substantial vehicles implies visit collaboration among overwhelming vehicles and traveller autos.

Second, it is indicated that PCE esteem diminishes as stream rate increments if normal voyaging speed is utilized as PCE measure, while it increments as stream rate increments if all out movement time is picked as PCE measure. Which one is right is disputable? It should be natural that higher stream rate should mean successive communication among substantial vehicles and traveller autos. Contingent upon this, higher PCE worth should exist for high stream rate. Or then again, in any event, it keeps consistent as stream rate increments. Nonetheless, there exists a contention about whether PCE will be kept steady over stream rate or not. Supporters of the point show two reasons. In the first place, this will conserve the field or model information required. Second, it infers that principal relationship doesn't change in structure between the vehicle just and blended streams. Since Huber (1982) just utilized the Greenshields model in his work, these ends ought to be just seen as natural and must be approved through a great deal of in-field information approval.

Hu and Johnson depicted how to utilize the 1965 HCM to discover PCEs dependent on speed in a report distributed in 1981. As indicated by this report, PCEs are utilized to change over a blended vehicle stream into a traveller vehicle just stream with the equivalent working rate. They utilized condition [1] created by Linzer et.al., (1979) to compute the PCE. Working velocities depended on the plan outlines acquired by examine performed by the MRI, as depicted in the area on the TRB Circular 212. Hu and Johnson didn't utilize explicit level changes, yet rather built up their PCEs dependent on broadened expressway portions.

$$E_T = \frac{[q_B - q_M(1 - P_T)]}{(q_M * P_T)} \quad (1)$$

Huber (1982) derived equation (1.1) given by Linzer et. al., (1979) in an alternate practical structure to relate PCE to the progression of a traveller autos just traffic stream and a blended vehicle traffic stream. The impact of trucks is measured by relating the traffic streams for an equivalent LOS. Huber (1982) utilized normal travel time as the proportion of LOS. Equivalent normal travel time on a one-mile fragment is equal to the reverse of the normal speed. The result of his presumption of equivalent speed is that PCEs decline as the traffic volume increments. A moderate moving truck will smaller affect the normal speed when the absolute volume is higher. Huber discovered this outcome questionable and presumed that equivalent all out movement time to be utilized as a proportion of LOS. Huber hypothesized that the complete travel time is the duplication of traffic volume and the normal travel time in hours per mile. By this portrayal, all out movement time is comparable to thickness since it depicts vehicle inhabitancy on the roadway in vehicles per mile. Huber's basic equation is formulated as equation (2).

Huber considered three PCE measures: normal speed of the whole traffic, whole travel time, and normal speed of the

traveller vehicles as it were. The following are the important conclusions:

- 1) PCEs increase as the percentage of heavy vehicles increases. This is observed when either avg. speed or the total travel time is taken as the LOS measure. This is sensible on the grounds that high level of overwhelming vehicles implies visit association among substantial vehicles and traveller vehicles.
- 2) PCE worth declines as stream rate increments if normal voyaging speed is utilized as PCE measure.
- 3) PCE value increments as stream rate increments if complete travel time (equivalent to density) is used as PCE portion.

It must be understood that higher the stream rate means more common interactions among substantial vehicles and traveller vehicles, which means as flow rate increases PCE should increase or, at least, PCE should be constant as flow rate increases. It is controversial that regardless of whether PCE will be steady over stream rate or not.

$$E_T = \frac{1}{P_T} \left[\frac{q_B}{q_M} - 1 \right] + 1 \quad (2)$$

Where

PT is the extent of trucks in the blended rush hour gridlock stream,

qB is the base stream rate (traveller vehicles just), and

qM is the blended stream rate.

Sumner et al., (1984) extended the relationship portrayed by Huber to ascertain the PCE of a solitary truck in a blended rush hour gridlock stream, which incorporates different truck types. This estimation requires a watched base stream, blended stream, and stream with the subject vehicles. The equivalent LOS or impedance measure would cut over every one of the three-stream bends. The relationship depicted by Sumner et al., is figured as

$$E_T = \frac{1}{\Delta P} \left[\frac{q_B}{q_S} - \frac{q_B}{q_M} \right] + 1 \quad (3)$$

where ΔP is the extent of subject vehicles that is added to the blended stream and subtracted from the traveller vehicle extent, qB is the base stream rate (traveller autos just), qM is the blended stream rate, and qS is the stream rate including the additional subject vehicles. Sumner et al utilized complete travel time as far as vehicle hours as the equivalent proportion of LOS. For this situation complete travel time was applied to urban blood vessel streets and estimated as far as vehicle hours, which isn't proportional to thickness.

Van Aerde and Yagar (1984) built up a philosophy to ascertain PCE dependent on relative pace decrease which is third way. This PCE was planned for use in normal speed examination of limit, which is one of a kind to two path thruways. Field perceptions and known speed-stream connections were utilized to align a numerous direct relapse model that gauges the percentile speed dependent on the free speed and speed decrease coefficients for every vehicle type. A direct speed-stream model was picked on the grounds that the speed-stream relationship inside the limits of functional working volumes was seen as about straight. The numerous direct relapse model is

$$\text{Percentile speed} = \text{free speed} + C1(\text{number of traveler autos}) + C2(\text{number of trucks}) + C3(\text{number of RVs}) + C4(\text{number of different vehicles}) + C5(\text{number of contradicting vehicles}) \quad (4)$$

where coefficients C1 to C5 are the general sizes of speed decreases for every vehicle type. In spite of the fact that this model was detailed for two path thruways with restricting traffic stream, it could be applied to multilane parkways by setting the coefficient C5 to zero. Utilizing the speed decrease coefficients, the PCE for a vehicle type n is determined as

$$E_n = \frac{C_n}{C_1} \quad (5)$$

Where Cn is the speed decrease coefficient for vehicle type n and C1 is the speed decrease coefficient for traveller vehicles.

For two-path interstates St. John (1984) and St. John and Kobett (1984) built up a nonlinear relationship for determining PCE utilizing mean speed as the proportion of equality. As an expansion to his examination on truck execution on updates, St. John (1986) proposed a non-straight truck factor. This non-linearity tended to the progressively little effect of trucks on the traffic stream as the extent of trucks expanded. He contemplated that as the extent of trucks expands companies may frame and the communication with vehicles might be diminished. Moreover, St. John attested that the impact of different truck types features the requirement for a non-straight truck factor. The truck factor depended on a speed stream relationship. He presented the idea of comparability bit, which represents the gradual impact of trucks in a rush hour gridlock stream and is utilized to ascertain PCEs. Speed has been utilized as the proportion of execution essentially for two-path and multilane thruways.

III. PCEs BASED ON HEADWAY RATIO METHOD

The progress proportion technique was spearheaded by Greenshields (1947). The idea driving utilizing the degrees of progress (time or space) is that progress is a proportion of room involved by a vehicle. Therefore average headways for the heavy vehicle class of interest and the passenger cars are computed and PCE is defined as

$$PCE_i = \frac{h_i}{h_c} \quad (6)$$

Where PCE_i = PCE of vehicle class I

h_i = normal progress of vehicle class I

h_c = normal progress of traveller vehicles

In Greenshields method the PCU estimations of various vehicles kinds were acquired by looking at headway of vehicle types with those of traveller vehicle. For more accurate results headways should be measured on a vehicle to vehicle basis of possible combinations for a large sample of each vehicle type.

Drawback of this method is that complications are involved in collecting data from a large number of possible combinations of vehicles.

For accurate results headways should be measured on a vehicle to vehicle basis of possible combinations for a large sample of each vehicle type. Because of complication involved in collecting data from a large number of possible combinations, a simpler calculation procedure has been developed, so long as there is no bias in doing so (Scraggs 1964). Assuming, in the traffic stream the proportion of heavy vehicles is low, the number of headways between heavy vehicles is small and headways are in any case almost dependent of the class of vehicle preceding and following it.

The formula for this is given below and is a simplification of that used by Scraggs (1964).

$$\text{Passenger care equivalent of vehicle type } h = \frac{h_{1-h}}{h_{1-1}} \quad (7)$$

Where,

h_{1-h} = mean headway between light vehicle and a following vehicle of type h

h₁₋₁ = mean headway between two consecutive light vehicles

In 1976, Werner and Morrall proposed that the progress technique is most appropriate to decide PCEs on level territory at low degrees of administration. Acknowledging one of the essential impacts of substantial vehicles in the rush hour gridlock stream is that they occupy more room; degrees of progress have been utilized for probably the most well-known techniques to ascertain PCEs. The PCE is calculated as

$$E_T = \left(\frac{H_M}{H_B} - P_C \right) / P_T \quad (8)$$

Where

H_M is the normal progress for an example including all vehicle types,

H_B is the normal progress for an example of traveller vehicles as it were,

P_C is the extent of autos, and

P_T is the extent of trucks.

Werner et al., utilized the progress strategy for low speed trucks and the regular speed technique for the 1965 HCM for higher speed trucks. One inquiry emerges as to utilization of the progress technique for low speed trucks when low speeds for the most part happen on redesigns instead of on level territory. The consequences of their examination by creators repeated PCEs in the 1965 HCM for higher speed trucks. PCEs were classified by percent grade, length of evaluation, and LOS gathered An and B, C, or D and E.

Huber (1982) proposed a model based on idea that a truck consumes more space than a single passenger vehicle, and which decreases the lane volume; finally estimate PCE standards for vehicle under free-streaming conditions. A proportion of impedance as an element of traffic stream is utilized to relate two traffic streams, one that has trucks blended in with traveller autos and the other that has traveller vehicle as it were. A deterministic model of traffic stream is utilized to appraise the impedance-stream relationship. The creator recommended that PCE esteems are identified with speed and length of the subject vehicles and to fluctuate with the extent of trucks in the rush hour gridlock stream Cunagin et al., (1982) in an article uncovered that the nearness of trucks in the rush hour gridlock stream of a turnpike brings about expanded normal degrees of progress. The biggest degrees of progress included trucks following trucks, and the types of progress expanded for bigger truck types. Seguin et al., (1982) figured the spatial progress strategy for ascertaining PCEs. This strategy characterizes the PCE as the proportion of the mean slacking progress of a subject vehicle partitioned by the mean slacking progress of the essential traveller vehicle and is defined as

$$E_T = \frac{H_{ij}}{H_B} \quad (9)$$

Where,

H_{ij} is the mean slacking progress of vehicle type i under conditions j and

H_B is the mean slacking progress of traveller vehicles.

The slacking progress is resolved from the back guard of the lead vehicle to the back guard of the accompanying vehicle and along these lines incorporates coming up next vehicle's length.

Central Road Research Institute (1982) proposed similar equation based on this concept for heterogeneous traffic streams, includes observed average headways under mixed traffic and only cars.

Krammes and Crowley (1986) utilized this strategy for fundamental turnpike areas then through considering space types of progress rather than time types of progress. Considering space progress used this method for considering density as the measure, because density is inverse of average space headway and similarly considering time headway implies considering the traffic flow. There are some approaches to computing the progresses also.

Single method is to consider lagging headway or in other words, the time or space from the rear of the leading vehicle to the rear of the subject vehicle. Therefore, it includes the length of the subject vehicle and the intervehicle gap. Another approach could be to consider the leading headway or the time or space gap between the front of the leading and following vehicles.

When the headway is used, the effect of the truck on only the vehicle that is immediately following it is being considered. But, the slower speeds of trucks delay all the vehicles that are travelling behind the truck. Along these lines, significant insufficiency of progress approach is that it doesn't consider the extra deferral caused to the whole traffic stream due to slower speeds of trucks in work zones.

Krammes et. al., (1986) compared the consistent volume to limit technique, equivalent thickness strategy, and spatial progress technique and reasoned that the spatial progress technique was generally fitting for level road portions. The creators call attention to that the spatial progress strategy not just records for the acknowledged impact of trucks because of estimate and lower execution, yet in addition the mental effect of trucks on drivers of different vehicles. This effect is as streamlined unsettling influences, sprinkle and splash, sign blockage, off tracking.

Spatial progress is viewed as a surrogate measure for thickness. The two of which mirror the opportunity of mobility in a rush hour gridlock stream. An adjustment to condition [2] set forth by Huber to figure PCE dependent on-stream rate permits the count of PCE dependent on progress. The condition utilizes the slacking progress since it is coming up next vehicle's view of mobility that influences the PCE. Conflicting to the discoveries of Cunagin et al., the slacking progress for trucks following trucks was seen as fundamentally not exactly the slacking progress for vehicles following trucks. In this way, as opposed to the suggested condition [10] by Seguin et al., suggests that PCE should be calculated

$$E_T = \frac{[(1-P_T)H_{TP} + pH_{TT}]}{H_P} \quad (10)$$

Where

P_T is the extent of trucks,

H_{TP} is the slacking progress of trucks following traveller autos in the blended vehicle stream,

H_{TT} is the slacking progress of trucks following trucks in the blended vehicle stream, and

H_P is the slacking progress of autos following either vehicle type in the blended vehicle stream.

An extra improvement over condition [9] prescribed by Seguin is that the extent of trucks is considered in condition [10]. Krammes et al., accepted that an expansion in the extent of trucks will bring about higher PCEs in light of the fact that the open door for cooperation among autos and trucks will increment and used above concept and taking basic and mixed flow headways instead of basic and mixed traffic volumes. The level of trucks in the rush hour gridlock stream and the effect of trucks on inter vehicular spacing are very important for PCE values. Later, this equation was used by Chandra (1997).

Molina (1987) proposed a changed progress way to deal with registering PCE at signalized crossing points. Not at all like the progress approaches talked about over, this methodology considers the expanded degrees of progress of the vehicles lined behind the truck at the signalized convergence. He discovered that the truck type essentially influenced the PCE esteems a littler, single unit truck had less effect on delay than five-pivot mix trucks. The situation of the truck essentially influenced the PCE of consolidated trucks. This can be expressed mathematically as follows

$$PCE = \frac{(h_t + \Delta H)}{h_c} \quad (11)$$

Where

PCE= PCE of the heavy vehicles

h_t = headway of heavy vehicle

h_c = immersion stream progress of traveller vehicle

ΔH = the all-out expanded progress of the line brought about by the truck

Molina's conclusions from the results are (i) Truck type influences the size of the PCE (ii) Position of the vehicle in the line didn't altogether influence the PCE esteem for the two-and three-pivot, single-unit trucks, (iii) Position of vehicle in line has an exceptionally articulated impact on the PCE estimation of enormous five-hub mix of trucks, (iv) The PCE estimations of 3.7 and 1.7 ought to be utilized for overwhelming and light vehicles, separately, (v) Position of trucks in queue and proportion of trucks are not considered in this study.

This method doesn't mirror the complete postponement experienced by vehicle in the queue when heavy vehicles are present in the queue.

IV. PCES BASED ON DENSITY

The use of the speed-flow-density relationship to calculate PCEs has been practiced since the late 1970's. Huber (1982) presented the idea of utilizing equivalent thickness to relate blended stream rate and base stream rate for count of PCE in condition (12). This equation processes the PCE by relating the progression of a traveller vehicle just traffic stream to that of a blended vehicle traffic stream. The impact of trucks is evaluated by relating the traffic streams for an equivalent LOS. Any proportionate LOS or impedance could be picked for the correspondence.

On the off chance that for instance, thickness was utilized to characterize the equivalent LOS criteria, the stream thickness relationship could be utilized to relate the traffic streams at an equivalent thickness esteem. The downside of Huber's calculation is that it expect the blended vehicle stream contains traveler autos and just one kind of truck.

Sumner et al., (1984) extended the relationship portrayed by Huber to ascertain the PCE of a solitary truck in a blended rush hour gridlock stream, by representing numerous truck types. This estimation requires a watched base stream, blended stream, and stream with the subject vehicles. The equivalent LOS or impedance measure would cut over every one of the three stream thickness bends. The relationship depicted by Sumner et al., is defined as in equation (13) which permits the computation of the PCE of a solitary truck in a blended vehicle stream including numerous truck types. As applied to roads, thickness is the most widely recognized equivalent proportion of LOS.

$$E_T = \frac{1}{P_T} \left[\frac{q_B}{q_M} - 1 \right] + 1 \quad (12)$$

Where E_T = the PCE value of the base vehicle (by definition)

P_T = the proportion of trucks (non- base vehicles) in the mixed flow,

q_B = the base vehicle stream

q_M = the blended vehicle stream

Downside of Huber's calculation is that it expect the blended vehicle stream contains traveler autos and just one sort of truck.

V. SUMNER METHOD

Sumner et al., (1984) extended the relationship depicted by Huber to ascertain the PCE of a solitary truck in a blended rush hour gridlock stream, by representing different truck types. This computation requires a watched base stream, blended stream, and stream with the subject vehicles. The equivalent LOS or impedance measure would cut over every one of the three stream thickness bends. The relationship portrayed by Sumner et al., is figured which permits the computation of the PCE of a solitary truck in a blended vehicle stream including various truck types.

$$E_S = \frac{1}{\Delta p} \left[\frac{q_B}{q_S} - \frac{q_B}{q_M} \right] + 1 \quad (13)$$

Thus knowing the three flows, equation (13) can be used to calculate the PCE value of any subject vehicle. Any proportional LOS or impedance could be picked for the correspondence. In the event that for instance, thickness was utilized to characterize the equivalent LOS criteria, the stream thickness relationship could be utilized to relate the traffic streams at an equivalent thickness esteem.

As applied to turnpikes, thickness is the most widely recognized equivalent proportion of LOS, and Webster and Elefteriadou (1999) utilized this technique to figure PCEs for trucks in 1999. Their methodology was to utilize re-enactment demonstrating to figure the stream stanzas

thickness connections. Once more, the specialists inspected the effect of winning traffic stream, extent of trucks, truck type (by length and weight to control proportion), length and percent level, and number of expressway paths in their assessment. The aftereffects of the examination by Webster et al., demonstrated that PCEs increment with expanding traffic stream on interstate sections and lessening with expanding extent of trucks and number of paths.

Demarchi et al., (2003) described the confinements of inferring PCEs for traffic streams with different truck types. In an arithmetical induction, they demonstrated that PCEs created for a solitary truck type in a blended rush hour gridlock stream containing numerous truck types utilizing condition (14) don't completely represent the cooperation between trucks. They contemplated that considered independently, "the PCE esteem for the subject vehicle is typically disparaged, in light of the fact that the minimal effect diminishes as the extent of subject vehicles in the stream increments." Conversely, the effect of trucks as of now in the blended vehicle stream is overestimated on the grounds that their genuine extent ought to be littler than it is preceding expansion of the subject vehicles.

Demarchi et al., recommended that a potential workaround to stay away from the mistakes related with computing the PCE for each truck independently is to figure a total PCE planned as

$$E_T = \frac{1}{\sum_i^n P_i} \left(\frac{q_B}{q_M} - 1 \right) + 1 \quad (14)$$

Where,

P_i is the extent of trucks of type I out of all trucks n in the blended rush hour gridlock stream,

q_B is the base stream rate (traveler vehicles just), and

q_M is the blended stream rate.

This condition is essentially condition (12) set forth by Huber and altered for different truck types in the blended rush hour gridlock stream. PCEs in the HCM 2000 are accounted for by percent grade, length of evaluation, and percent trucks. The PCEs display a reduction for expanding extent of trucks.

Estimating or assessing the thickness esteem is troublesome under heterogeneous traffic conditions, and simultaneously, thickness is autonomous of vehicle length and width of the vehicle. Because of these reasons utilizing the thickness esteem as a proportion of impedance in computing PCE values under blended traffic conditions may prompt mistaken outcomes. Mallikarjuna et al, used area occupancy (a modified measure of density) and proved that it is ready to speak to the blended traffic in a superior manner than mass and occupancy.

Variation of PCE values with respect to trucks and flow are given in the following tables 1 and 2 respectively.

S.No	Author	LOS as measure	Result with respect to trucks
1.	Linzer et. al., (1979)	V/c ratio	PCE decreases as proportion of trucks increases
2.	Huber(1982)	Speed	PCEs decrease with an increase in traffic volume. PCEs increase with an increase in proportion of trucks.

Passenger Car Equivalent Estimation Methods of Trucks in Traffic Stream

3.	Huber(1982)	Density(Total travel time)	PCEs increase with an increase in traffic volume. PCEs increase with an increase in proportion of trucks.
4.	Krammes & Crowley(1986)	Head way	PCE increases as proportion of trucks increases
5.	H. Botma (1988)	Macroscopic model	PCE increases as proportion of trucks increases
6.	Webster & Elefteriadou(1997)	Speed	For freeways , as flow rate increases, PCE remains almost unchanged PCE remains almost unchanged for increased proportion of trucks too. For arterials, PCEs decreases as proportion of trucks increases.
7.	Webster & Elefteriadou (1998)	Density	PCEs increase with an increase in traffic flow. PCEs decrease with an increase in proportion of heavy vehicles on freeway segments.
8.	HCM (2000)	Density	For specific upgrades, PCE decreases as proportion of trucks increases. For extended segments and level roads, PCEs remain constant.
9.	Mallikarjuna et.al.,(2006)	Area occupancy	PCEs decreases as proportion of trucks increases
10.	Debasis Basu et. al.,(2006)	Stream speed	PCEs increase with an increase in traffic volume. PCEs increase with an increase in proportion of heavy vehicles.
11.	Dazhi Sun et. al.,(2007)	Speed and proportion of trucks	At same speed, PCEs will fluctuate as percentage of trucks increases. The PCE will increase first and then decreases.
12.	Ali Hajbabaie (2010)	Roadway capacity	PCE decreases nonlinearly as percentage of trucks increases on both upgrade and level basic freeway sections
13.	Robert M. Brooks(2010)	V/c ratio	PCU estimation of vehicles increments with increments in rush hour gridlock volume for low volume levels and PCU esteem decline with increment in rush hour gridlock volume for higher volume conditions. PCUs increments with increment in width of street.
14.	Syed Omar et.al.,(2018)	Speed drop & Area occupancy	PCE values of larger sized vehicles increase with LOS but decrease for the smaller sized vehicles on rural highways. For the design of rural highways, PCE values corresponding to the zero percent speed drop should be used while calculating the design service volume. This is because on rural highways the drivers do not expect their speed to drop below the free-flow speed
15.	Syed Omar et.al.,(2018)	Speed drop & Area occupancy	Constant PCE values can be used for the different levels of service without much loss of accuracy in measuring the demand or the service volume The aggregate PCEs vary at the lower ranges of speed drop
16.	Syed Omar et.al.,(2019)	Speed drop & Area occupancy	Constant PCE values can be used for the different levels of service without much loss of accuracy in measuring the demand or the service volume The aggregate PCEs vary at the lower ranges of speed drop
17.	Syed Omar (2019)	Average Speed	The PCE value of HMV (Transport and Truck) increments directly with the expansion in rush hour gridlock volume, however for Two Wheeler and Motorized Three Wheeler it diminishes sprightly with increment in rush hour gridlock volume.

S.No	Author	LOS as measure	PCE variation
1.	St. John et. al.,(1978)	Speed	PCEs remain almost unchanged with flow rate variance
2.	Roess et al. (1984)	Weight to power ratio	PCE increases as flow rate increases
3.	Webster and Elefteriadou (1997)	Speed	For freeways, as flow rate increases, PCE remains almost unchanged PCE remains almost unchanged for increased proportion of trucks too.
4.	HCM (2000)	Density	For specific upgrades, PCE decreases as proportion of trucks increases. For extended segments and level roads, PCEs remain constant.
5.	Rahman et.al.,(2005)	Speed reduction of PCs	PCE of rickshaws increments with increment of stream rate and extent of rickshaws. The average speed passenger cars decrease with increase in proportion of rickshaws.
6.	Mallikarjuna et.al.,(2006)	Area occupancy	PCEs for buses and Tw decreases as their proportion increases.
7.	Dazhi Sun et. al.,(2007)	Speed and proportion of trucks	At same speed, PCEs will fluctuate as percentage of trucks increases. The PCE will increase first and then decreases.
8.	Arasan & Krishnamurthy(2008)	speed	PCE estimation of vehicles increments with increments in rush hour gridlock volume for low volume levels and PCE esteem decline with increment in rush hour gridlock volume for higher volume conditions

9.	Robert M. Brooks(2010)	V/c ratio	PCE estimation of vehicles increments with increments in rush hour gridlock volume for low volume levels and PCE esteem decline with increment in rush hour gridlock volume for higher volume conditions. PCEs increases with increase in width of road.
10.	Manraj Singh et al.,(2012)	Speed	PCE of a given vehicle category decreases with increase in volume capacity ratio, The PCE value of all categories of vehicles decreases when their proportion increases in the traffic stream
11.	Shriniwas S. Arkatkar et. al.,(2012)	Speed of traffic stream	For vehicles bigger than travellerS vehicles, at low volume levels, the PCE esteem diminishes with increment in rush hour gridlock volume and at high traffic volume levels, the PCE esteem increments with increment in rush hour gridlock volume and the other way around. PCE esteem increments fundamentally with increment in the size of review just as its length.
12.	Syed Omar et.al.,(2019)	Speed drop	Aggregate PCE values can be used to convert Heterogeneous traffic

VI. CONCLUSION

From literature review it can be concluded that heterogeneous traffic stream can be converted into an equivalent base stream either using individual PCEs or aggregate PCE. Several studies are available in literature which estimated the individual PCE values of multiple types of vehicles moving on rural highways. They have used simulation model, empirical data or combination of both. Most of the studies used individual PCEs and a reliable simulation model is essential for studying the effect of multiple variables on PCE. Very few studies have been conducted using the simulation as far as the developing countries are concerned. Majority of the studies in India have focused on obtaining the individual PCEs, but not using the simulation-based approaches. For estimating the individual PCEs using the simulation-based approaches, it is necessary to make several runs for each composition of the traffic stream. For studying the effect of varying compositions on the PCE, several simulation runs have to be made. For heterogeneous traffic mix, getting the individual PCE value for a specified proportion of vehicle type may not be that useful due to the following reason. PCE value of the subject vehicle will change with its proportion, depending on the proportion of the other vehicles present in the traffic stream. Hence, the concept of aggregate PCE can be used to convert the heterogeneous traffic stream into an equivalent base stream. For studying the influence of difference variables on aggregate PCE, it is also necessary to use a reliable simulation model and the simulation runs are to be made for all the traffic compositions.

REFERENCES

1. Arasan, V. T., and Arkatkar, S. S. (2008). *Assessing Passenger-Car Units for Vehicles of Heterogeneous Traffic Using Computer Simulation*. Paper presented at the Transportation Research Board 87th Annual Meeting.
2. Arasan, V. T., and Arkatkar, S. S. (2010). Microsimulation investigation of the impact of volume and street width on PCU of vehicles under heterogeneous traffic. *Diary of transportation designing*, 136(12), 1110-1119.
3. Chandra, S., and Sikdar, P. (2000). Factor influencing PCU in blended rush hour gridlock on urban streets. *Street Transport Res*, 9(3).
4. Cunagin, W. D., and Messer, C. J. (1982). Traveler vehicle reciprocals for country interstates.
5. Demarchi, S., and Setti, J. (2003). Impediments of traveler vehicle comparable determination for traffic streams with more than one truck type. *Transportation Research Record: Journal of the Transportation Research Board* (1852), 96-104.
6. Dhamaniya, An., and Chandra, S. (2016). Applied Approach for Estimating Dynamic Passenger Car Units on Urban Arterial Roads by Using Simultaneous Equations. *Transportation Research Record: Journal of the Transportation Research Board*, 2553, 108-116.
7. Dr. Syed Omar Ballari., (2019), "Estimation of Passenger Car Equivalents for Heterogeneous Traffic Stream", *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, April 2019, Vol.8 (6), Pages 1026-1031.
8. Fan, H. S. (1990). Traveler vehicle reciprocals for vehicles on Singapore roads. *Transportation Research Part A: General*, 24(5), 391-396.
9. Geistefeldt, J. (2009). Estimation of traveler vehicle reciprocals dependent on limit fluctuation. *Transportation Research Record: Journal of the Transportation Research Board* (2130), 1-6.
10. HCM. (1965). *Parkway Capacity Manual second version.*, Special Report 87. Transportation Research Board, Washington DC.
11. HCM. (1994). *Unique report 209: Highway Capacity Manual*, third ed. Transportation Research Board, Washington, DC.
12. HCM. (2000). *Parkway Capacity Manual fourth version*. Transportation Research Board, Washington DC.
13. HCM. (2010). *Parkway Capacity Manual fifth version*. Transportation Research Board, Washington DC.
14. Huber, M. J. (1982). Estimation of traveler vehicle reciprocals of trucks in rush hour gridlock stream (dialog and conclusion).
15. IHM. (1997). *Indonesian Highway Capacity Manual 2 Interurban Roads and Motorways*. Directorate General of Highways, Jakarta.
16. IRC 64. (1990). *Rules for Capacity of Roads in Rural Areas*. New Delhi: Indian Roads Congress.
17. Krammes, R. An., and Crowley, K. W. (1986). Traveler vehicle reciprocals for trucks on level road sections. *Transportation Research Record*, 1091.
18. Kumar, P., Arkatkar, S. S., Joshi, G. J., and Dhamaniya, A. (2017). *New Methodology for Estimating PCU on Multi Lane Urban Roads under Mixed Traffic Scenario Based on Area Occupancy*.
19. Mallikarjuna, C., and Rao, K. R. (2006). Demonstrating of Passenger Car Equivalency under Heterogeneous Traffic Conditions. Paper introduced at the Research into Practice: 22nd ARRB Conference.
20. Mehar, A. (2013). *Limit Analysis on Multilane Highways in Mixed Traffic Conditions*. (Ph.D), Indian Institute of Technology Roorkee.
21. Mehar, A., Chandra, S., and Velmurugan, S. (2013). Traveler vehicle units at various degrees of administration for limit examination of multilane interurban expressways in India. *Diary of transportation building*, 140(1), 81-88.
22. Okura, I., and Sthapit, N. (1995). Traveler vehicle counterparts of substantial vehicles for uncongested motorway traffic from naturally visible methodology. *Doboku Gakkai Ronbunshu*, 1995(512), 73-82.
23. Pal, D. (2016). *Examination and Modeling of Vehicular Movement in no-path trained Heterogeneous Traffic Stream*. (Ph.D), Indian Institute of Technology Guwahati.
24. Roess, R. P., and Messer, C. J. (1984). Traveler vehicle reciprocals for continuous stream: correction of roundabout 212 qualities.
25. Roess, R. P., and Prassas, E. S. (2014). *The thruway limit manual: An applied and research history*. Switzerland: Springer International Publishing.
26. Sumner, R., Hill, D., and Shapiro, S. (1984). Section traveler vehicle identical qualities for cost assignment on urban blood vessel streets. *Transportation Research Part A: General*, 18(5-6), 399-406.
27. Syed Omar and Ch. Mallikarjuna (2016), "Investigation of the Macroscopic Relations for No-Lane Based Heterogeneous Traffic Stream", *Procedia Engineering*, Vol.142, Pages 244–251. (Elsevier, ISSN: 1877-7058).
28. Syed Omar B., Pranab K., and Mallikarjuna, C., (2018), "Passenger Car Equivalents for the Heterogeneous Traffic on Divided Rural Highways based on Simulation Model". *Transportation in Developing Economies (TIDE)*, Vol 4 (14). (Springer, ISSN: 2199).
29. Syed Omar B., Pranab K., and Mallikarjuna, C., (2019), "Passenger Car Equivalent Estimation for Rural Highways: Methodological Review, 15th World Conference on Transport Research (WCTRS- 2019).
30. Syed Omar B., Pranab, K., and Mallikarjuna, C (2018), "Determination of the PCEs for multilane divided rural highways under heterogeneous traffic conditions". *TRB Paper No. 18-02596*, Transportation Research Board (TRB), 97th Annual meeting, Washington, DC, USA, January, 2018.
31. Washburn, S., and Kirschner, D. (2006). Rural freeway level of service based on traveler perception. *Transportation Research Record: Journal of the Transportation Research Board*(1988), 31-37.
32. Webster, N., and Elefteriadou, L. (1999). A simulation study of truck passenger car equivalents (PCE) on basic freeway sections. *Transportation Research Part B: Methodological*, 33(5), 323-336.