Fuzzy Model for Estimation of Passenger Car Unit

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Abstract: In most of the developing countries including India mixed traffic condition prevail on roads and highways. 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 is not constant but varies with traffic and roadway condition around. A number of factors have been identifies affecting PCU values. The current study aims at developing a fuzzy based model for the estimation of PCU values for bus. Fuzzy based model is of importance because of a number of independent affecting factors. Results of developed fuzzy MATLAB based model are compared with the quoted results and are found with high degree of correlation.

Key Words: Passenger Car Unit, fuzzy model

1 Introduction

Better infrastructure is a backbone to the economic growth of any country. India is a developing country, with second largest road network in the world after America. The total road length is over 3.4 million km. Even with this high volume of road length we have crowded and congested roads in poor condition off course not justifying the vehicular requirements of Indian traffic.

Traffic survey is carried out for important roads, at the time of design or at the time of up gradation. Based on this traffic survey and highway capacity level of service is assessed. To arrive at a common type of vehicle, concept of Passenger Car Unit (PCU) sometimes also known, as "Passenger Car Equivalent" (PCE) was first introduced in HCM-1965 to account for the effect of trucks and buses in the traffic stream [1]. The PCU definition in the most recent version of the Highway Capacity Manual (HCM) is ''the number of passenger cars that are displaced by a single heavy vehicle of a particular type under prevailing roadway, traffic, and control conditions'' [2]. Highway capacity, as defined by the HCM [3], is the maximum flow rate achievable at a specific location on a roadway under prevailing roadway, traffic, and control conditions. Traffic on Indian roads is of heterogeneous nature with a wide variation in the static and the dynamic characteristics. One class of vehicles cannot be considered equal to any other class. The only way of accounting for this non-uniformity in traffic stream is to convert all vehicles into a common unit and the most accepted unit for this purpose is PCU. In mixed traffic condition traffic volume/capacity is calculated by adding different vehicles after multiplying them by their respective PCU values. The HCM provides different sets of PCE values, to be used for different types of highway facilities; i.e. two-lane highways, multilane highways, and freeways.

Since the introduction of PCE concept in 1965, many researchers have tried to quantify the effect of heavy vehicles on traffic flow by developing HCM like PCE factors using different methodologies and equivalency criteria [4] – [11]. A few of these studies utilized field data but most of the studies used traffic simulation to derive the PCU values under a wide range of traffic and geometric conditions. From the available literature it is observed that PCU value for a vehicle vary with highway geometric and traffic characteristics around. A number of factors affecting PCU value include roadway width, type of shoulders, direction split, percentage of slow moving traffic and surface condition etc. [12]. None of the literature is available in which combined effects of all these affecting parameters are considered. An accurate and easy estimation of PCU factors for different vehicles are useful in determination of traffic volume/capacity and level of service (LOS), which can make the decision of future expansion of highways and roads (widening and improvement) more constructive. Therefore these factors affecting PCU values should be incorporated suitably for accurate estimation of traffic volume.

In this present study a fuzzy based model is developed considering some of known affecting factors as input and PCU value for bus as output. Results are compared with the quoted values and are found to be in consonant with each other.

2 Methods of Calculating PCU Value

Since the publication of HCM-1965, 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. 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 [10].

Out of various available methods, the one proposed by Chandra [10] is most suitable for mixed traffic condition prevailing in India [13]. According to Chandra 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 that is car [10].

PCU_i = (Speed ratio of the car to the i^{th} vehicle)/ (Space ratio of the car to the i^{th} vehicle)

$$PCU_i = \frac{Vc}{Vi} \Big/ \frac{Ac}{Ai}$$

Where

- PCU_i passenger car unit value of the i^{th} vehicle
- Vc/Vi speed ratio of the car to the i^{th} vehicle
- Ac/Ai space ratio of the car to the i^{th} vehicle

The variable of speed ratio in the equation is a function of roadway and traffic conditions. Any change in these conditions will affect the speed of vehicles, which is duly reflected by the changes in the speed ratio. The speed of any vehicle type will be true representation of overall interaction of vehicle type due to presence of other vehicles of its own category and of other type. The second variable of space ratio represents pavement occupancy and indicates maneuverability of a vehicle with respect to car is a constant for a particular class of vehicle.

3 Factors Affecting PCU Value

A number of studies have been performed by various researchers to identify the effect of different roadway and traffic condition of PCU values for different vehicles. Factors identified affecting PCU value includes pavement width, shoulder condition, percentage of direction split in two way traffic, percentage of slow moving traffic, grade and its length, surface characteristics etc. A critical review of these studies is presented in this section.

3.1 Effect of Pavement Width

Leong measured speeds and capacity at 31 sites (with varying lane and shoulder widths) on rural highways in New South Wales [14]. The data were analyzed using multiple regressions and it was found that speed increased with increasing shoulder width. Farouki and Nixon studied the effect of the carriageway width on speeds of cars in the special case of free-flow conditions in suburban roads in Belfast [15]. It was found that the mean-free speed of cars in a suburban area increases linearly with the carriageway width over a certain range of width from 5.2 to 11.3 m. Yagar and Aerde found that speed changes exponentially with the change in lane width [16]. For a practical range of lane width from 3.3 to 3.8 m, it was found that the operating speed at a given location decreases by approximately 5.7 km/h for each meter reduction in the width. Nakamura has suggested speed adjustment factors for lane width less than 3.25 m as [17]

$$YL = 0.24WL + 0.22$$

Where

YL speed adjustment factor for lane width WL.

Hossain and Iqbal studied the vehicular free speed characteristics on two-lane national highways in Bangladesh [18]. An analysis revealed that the free speeds of commonly available vehicles follow a normal distribution. A linear regression analysis was conducted to explore the relationship between free speed and the pavement and shoulder widths. It has been found that in a pavement width range of 5.8 to 7.5 m, the free speed of motorized vehicles increased in a range of 7.3 to 10.3 km/h for each meter of pavement widening for flat and straight sections. Increase in speed with width is more in cars as compared to that of trucks/buses resulting in higher PCU value for buses or trucks.

Chandra and Kumar observed the effect of lane width on PCU values and hence upon the capacity of a two-lane road under mixed traffic conditions [13]. Data were collected at different sections of two-lane roads with the carriageway width ranging from 5.5 to 8.8 m. These data were analyzed and adjustment factors for lane width were calculated. They concluded that the lane width of two lane highways varies from less than 3.0 to 4.0 m or even more. The narrow lanes do not provide an adequate margin of error for vehicles and, therefore, speeds of individual vehicles drop. The effect of lane width is more prominent under mixed traffic conditions when vehicles do not follow one another and tend to move abreast. It is found that the PCU for a vehicle type increases with increasing lane width. The effect of lane width on the PCU is apparently linear; the slope of linearity depends on type of vehicle.

The second-degree equation developed between the capacity and the total width of the carriageway was used to derive the adjustment factors for capacity on substandard lane width. These adjustment factors are lower than those given in the HCM (1994). This indicates that the negative effect of mixed traffic is more pronounced on narrow lanes. These results illustrate the importance of widening a lane in congested areas. The first 0.3 m of lane widening (widening lanes from 3.0 to 3.3 m, for example) corresponds to an increase in capacity of about 14% while 0.6 m of lane widening (from 3.0 to 3.6 m) results in a 24% increase in capacity.

Sachdeva also studied the effect of pavement width on PCU value for single lane, two lane and four lane roads [19]. In general he observed an increase in PCU value with increase in lane width of for all category of vehicles, for all other identified influencing factors (shoulder condition, directional split and percentage of slow moving traffic) remaining constant. This may be attributed to more freedom of movement experienced by the individual vehicle at wider road.

3.2 Effect of Shoulder Condition

Turner found that the conversion of a shoulder to an additional travel lane could be expected to increase the average speed of a two-lane highway by about 5% for volumes exceeding 150 vehicles/h [20]. For an average speed of 80 km/h, this corresponds to an increase of 4 km/h. Chandra and Kumar studied the effect of shoulder condition on the speed of different types of vehicles and their placement on the road during passing and overtaking maneuvers on single- and two-lane highways [21]. They found that the average speed of a vehicle on a two-lane highway decreases by 5 to 8.5% depending upon the class of vehicle, when shoulder condition changed from bad to worse. Sachdeva performed a study to observe the effect of shoulder on PCU values [19]. He classified the shoulders into four categories namely surfaced, good, average and poor shoulder. From the study it is observed that PCU value of a vehicle on a road increases with increase in quality of shoulder. For example PCU of a bus is 5.40 if shoulder is excellent and 5.26 if it is poor all other factors remaining constant. This may be explained on the basis of speed differential. A better shoulder provides an additional usable width to a vehicle whereas inferior shoulder may even restrict the use of the available carriageway of the road. Thus a better shoulder can effectively increase the width of the carriageway and, therefore, results in higher PCU value for different vehicles due to more speed differential between car and a truck/bus. The qualitative categorization of shoulder is surfaced, good, average and poor which are assigned 5, 10, 15 and 20 numerical values respectively.

3.3 Effect of Surface Characteristics

The irregularity in the road surface is universally known as surface unevenness, or road roughness. The road roughness affects the dynamics of a moving vehicle, increases the wear on the vehicle parts and, hence, has an appreciable impact on vehicle operating cost (VOC), safety, comfort, and speed of travel. Roughness can have an adverse effect on the surface drainage, causing water to accumulate on the surface with a consequent adverse impact on both the performance of the pavement and on vehicular safety. The cost of operating the vehicles and transporting the goods rises as road roughness increases. A small improvement in roughness can yield high economic returns. The pavement condition that substantially affects the operating speeds can have substantial economic implications in terms of extra user time, discomfort, cost, and low capacity. Karan et al. established the relationship between speed and roughness for rural highways [22]. The riding comfort index (RCI) was chosen as an indicator of roughness. Watanatada et al. also studied the relation between road roughness and vehicle speeds [23]. Another study in Canada found that free-flow vehicle speeds are even influenced at a slightly lower level of roughness of the order of 5 to 6 m/km IRI. Kadiyali and Vishwanathan developed several relationships on the economic evaluation of highway projects for Indian conditions, which included the relationship between vehicle speed and road roughness, measured with a high-speed profilometer [24]. Chandra has identify the effect of road roughness on the free speed of a vehicle and thereby capacity of a two-lane road [25]. He collected the roughness and free-flow speed (FFS) data for various two-lane highways. These data were analyzed to establish the relationships between the roughness and the free speed of different vehicle types. It was observed that the FFS was influenced by roughness but only at relatively high speeds. The speed–volume data collected at eight other sections were analyzed to determine the effect of roughness on the capacity of a two-lane road.

The studies have shown that the FFS of vehicle decreases with the roughness of the road surface. The effect of roughness is more apparent on the speed of passenger cars than of heavy vehicles resulting in decrease in PCU value with increase in unevenness index. The speed–volume relationships drawn at different sections of two-lane rural roads indicate that the capacity decreases with an increase in the road roughness. The capacity of a two-lane road with a good surface condition (UI = 2500 mm/km) is estimated to be 3,140 PCU/h, which is close to the value given in the HCM (2000). Highway capacity decreases by 300 PCU/h with an increase in unevenness index by 1000 mm/km.

3.4 Effect of Directional Split

Yager and Aerde have shown the operational characteristics of two-lane rural highways to be a function of directional volume [16]. Speeds were generally insensitive to volume for a large practical range of volume, and percentile speed tends to converge as main line directional volume is increased.

HCM (1994) states that the capacity of a two-lane road under ideal condition is 2800 passenger car units per hour (PCU/h) at an even split in each direction. It reduces to 2000 PCU/h when all traffic is in one direction only. The capacity has now been revised to 3200 PCU/h in the 2000 edition of HCM. It is assumed that the capacity is nearly independent of the directional distribution of traffic on the facility. Chandra and Sinha concluded in a study conducted on two-lane roads in India that capacity reduces as the split moves away from 50 / 50 [26]. The capacity of a two-lane road at even split in two directions is estimated as 2920 PCU/h, which is less than the value specified in HCM (2000).

Sachdeva also studied the effect of direction split on PCU value on two lane, intermediate lane and single lane roads and observed that PCU value for a vehicle decreases as the directional split of traffic deviates from 50/50 [19]. As the traffic increases the overtaking requirements also increases but the overtaking opportunities depend upon the traffic from the opposite direction. If the traffic is not balanced in two directions then the overtaking opportunities will sharply reduce and vehicles will be forced to travel at low speed. This will result in overall low speed of traffic stream with less speed differential with car and hence low PCU value for a vehicle.

3.5 Effect of Slow Moving Traffic

Slow moving vehicles being part of developing countries traffic stream only, its effect has not been studies that thoroghly. A few studies are available in literature in which the effect of slow-moving vehicles is evaluated. It is found that capacity decreases as the proportion of slow-moving vehicles in the traffic stream increases. Botma developed a macroscopic model to study the effect of a slow-moving vehicle on traffic operation [27]. Sachdeva also studied the effect of slow moving vehicle in traffic stream with large variation from less then 10% to 50% and concluded that PCU value for bus and truck increases with increase in percentage of slow moving vehicle [19].

4 Proposed fuzzy model

There are four inputs to the fuzzy model, namely Pavement Width, Shoulder Condition, Directional Split and Slow Moving Traffic. Fig 1 shows the Fuzzy Model.

This model considers four inputs and provides a crisp value of passenger car unit (PCU) for bus using the Rule Base.

All inputs can be classified into fuzzy sets viz. Low and High. The output PCU is also classified as Low and high. In order to fuzzify the inputs, the following membership functions are chosen namely Low and High. They are shown in Fig. 2. Similarly the output variable i.e. passenger car unit has three membership functions as shown in Fig 2. Rule view and rule editor of the output Passenger Car Unit are shown in Fig 4 and Fig 5 respectively.

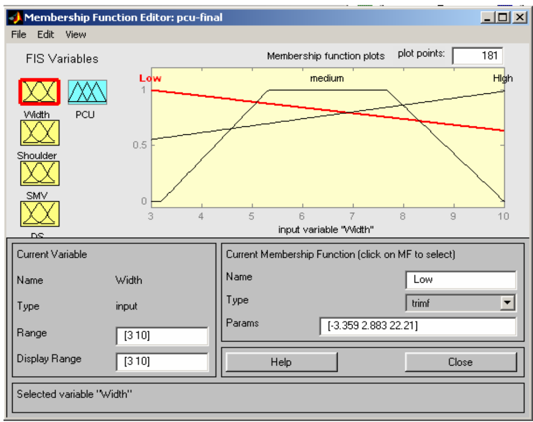

Figure 2 Fuzzification of Width of pavement

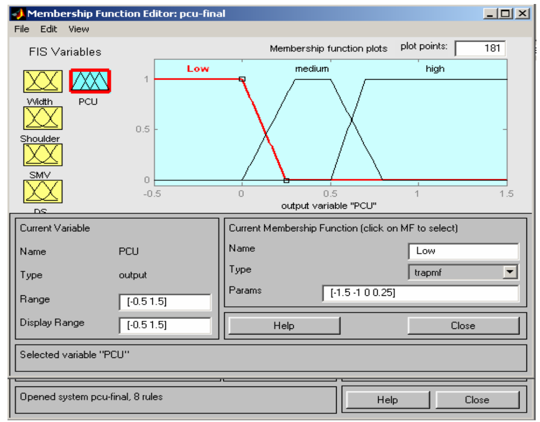

Figure 3 Fuzzification of output Passenger Car Unit

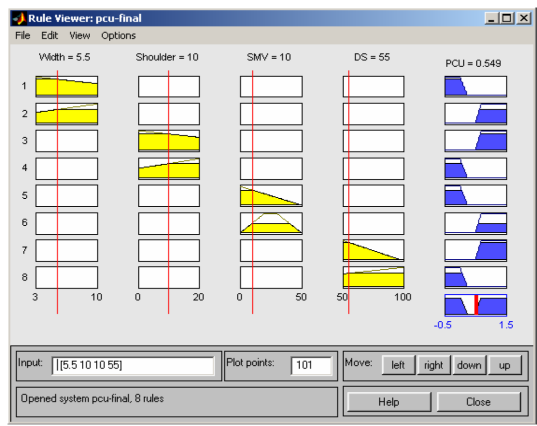

Figure 4 Rule View of Output Passenger Car Unit

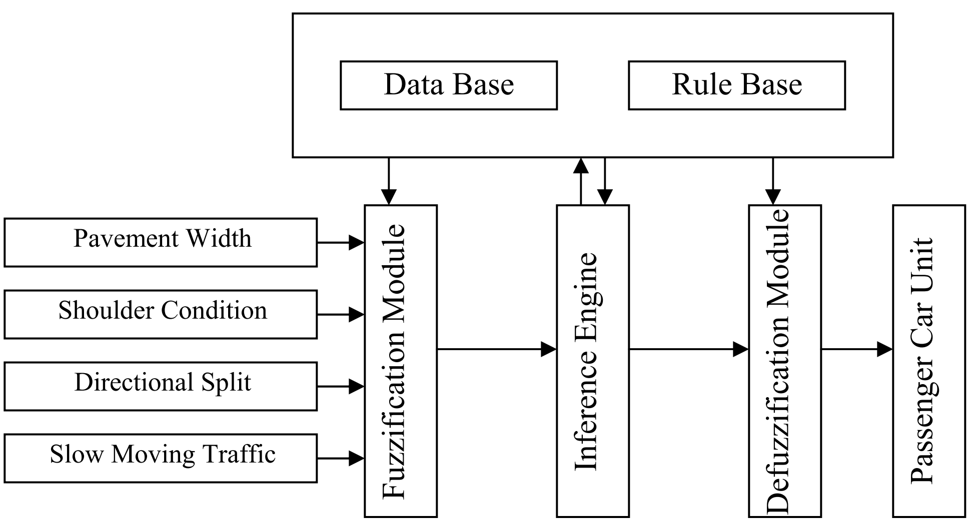

Figure 1: Fuzzy model for PCU Estimation

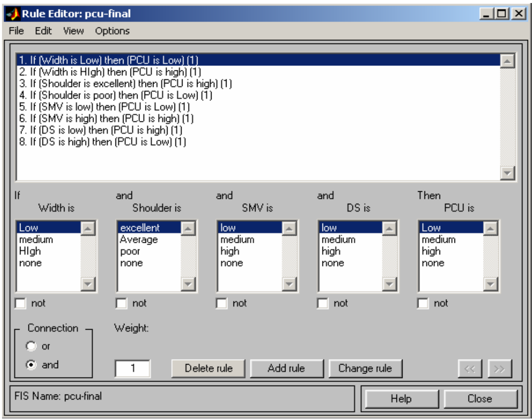

Figure 5 Rule Editor of Output Passenger Car Unit

5 Materials and Methods

i. All the inputs and outputs were fuzzified as shown in Fig. 2 and Fig 3.

ii. All possible combination of inputs was considered which leads to 8 sets. The PCU in all 8 cases of combinations is classified as low and high. These lead to formation of 8 rules for the fuzzy model and some of them are shown below:

1. If (Pavement Width is low) then Passenger car Unit is low.
2. If (Pavement Width is high) then Passenger car Unit is high.

. . . . . .

4. If (Shoulder condition is very excellent) then Passenger car Unit is high.

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8. If (percentage of slow moving traffic is high) then Passenger car Unit is also high.

iii. All twelve rules are inserted and a rule base is created. Depending on a particular set of inputs, a rule will be fired.

iv. Mamdani style of inference is used.

v. Using the rule viewer, output i.e Passenger Car Unit for bus is observed for a particular set of inputs using the MATLAB Fuzzy toolbox.

vi. The output is compared with the quoted results.

6 Results

Results of the developed model are compared with the quoted passenger car unit value for bus by different researchers under varying affecting parameters, shown in Table 1.

Degree of correlation between the modeled and observed results are also calculated and it is observed that a high degree of correlation exit between the modeled and quoted results.

7 Conclusions

In heterogeneous traffic condition to bring down different categories of vehicle a common unit Passenger Car Unit is used world wide. The accurate estimation of PCU in itself is a complex task as there are different independent parameters affecting PCU value of a vehicle. A number of methods are available for the estimation of PCU value for different vehicles such as Walker's Method, Headway Methods, Multiple linear Regression Methods, Simulation Technique and Density method etc. In the present study a MATLAB based fuzzy model is developed using four well identified affecting factors (width of pavement, type/quality of shoulder, directional split and traffic composition/ percentage of slow moving traffic) for estimation of PCU value of standard vehicle Bus. The results so obtained are compared with the quoted results in the literature and high degree of correlation is observed. This will open a new direction for the traffic engineers for accurate easy estimation of PCU value and hence traffic volume, capacity and level of service in any situation giving due weightiness to different affecting parameters.

Table 1 Correlation between the Quoted and Modeled PCU value for standard vehicle Bus

	Pavement Width	Shoulder Condition	Direction split	Percentage of slow moving traffic	Quoted: Passenger Car unit	Modeled: Passenger Car unit	Level of correlation
1	9.0	10	55	10	5.35	0.589	Sachdeva, 2004
2	7.5	10	55	10	5.22	0.58	
3	7.0	10	55	10	5.17	0.574	
4	6.7	10	55	10	5.1	0.569	
5	6.6	10	55	10	5.07	0.567	
6	5.5	10	55	10	4.87	0.549	
							0.998
1	5.5	5	50	20	5.17	0.581	Chandra and Kumar, 2004
2	6.0	5	50	20	5.25	0.589	
3	6.4	5	50	20	5.31	0.596	
4	6.6	5	50	20	5.37	0.599	
5	6.7	5	50	20	5.4	0.601	
6	6.9	5	50	20	5.45	0.604	
7	7.0	5	50	20	5.46	0.606	
8	7.4	5	50	20	5.51	0.612	
9	8.0	5	50	20	5.56	0.623	
10	8.8	5	50	20	5.64	0.638	
							0.969
1	7.0	10	55	4.4	5.23	0.545	Sachdeva, 2004
2	7.0	10	55	6.2	5.17	0.556	
3	7.0	10	55	9.2	5.14	0.574	
4	7.0	10	55	12.3	5.28	0.574	
5	7.0	10	55	16.3	5.22	0.574	
6	7.0	10	55	20.3	5.32	0.606	
7	7.0	10	55	24.2	5.37	0.606	
							0.724
1	7.0	5	55	10	5.31	0.581	Sachdeva, 2004
2	7.0	10	55	10	5.17	0.574	
3	7.0	15	55	10	5.1	0.55	
4	7.0	20	55	10	5.03	0.515	
							0.898
1	7.0	10	51	10	5.23	0.6	Sachdeva, 2004
2	7.0	10	55	10	5.17	0.574	
3	7.0	10	57	10	5.14	0.56	
4	7.0	10	59	10	5.12	0.553	
5	7.0	10	62	10	5.1	0.553	
6	7.0	10	65	10	5.08	0.553	
7	7.0	10	72	10	5.03	0.546	
8	7.0	10	90	10	4.91	0.509	
							0.967

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