ISSN 2229-5518

Estimation of free flow speeds and passenger car equivalent factors for multilane highways

Lecturer Dr. Ahlam k. Razzaq Al-zerjawi

Abstract- Free-flow speed is a parameter that is being used extensively for capacity and level-of- service analysis of various types of highway facilities. This study collects and analyzes free-flow speed data at the midpoints of forty-two multilane rural and suburban highway segments throughout Al-Najaf government. The objectives of this study are to develop models for estimating average free-low speed and for identifying the distribution of individual free-flow speeds. The most important variables that govern free-flow speed are vehicle type, space mean speed, and functional classification of highway . The resulting models facilitate the estimation of free flow speeds of rural and suburban highways.

The Highway Capacity Manual (HCM- 2000) uses density method to derive its passenger-car equivalent factors (PCE) for heavy vehicles. These PCEs appear as " ET " in HCM tables where the ET is 1.5 for all urban highways and rural highways in level terrain . The density method assumes homogeneous traffic. Strict lane discipline characterizes homogeneous traffic. By using the density method, we can derive more accurate passenger car unit factors for Iraqi conditions. The passenger car unit factor (PCU) for trucks and buses is 2.0 in level terrain.

Key Words: Space mean speed, free-flow speed, model ,PCU ,multilane highways , and Rural and suburban highways.

———————————— ◆ ————————————

1-Introduction

Free-flow speed is the speed of a vehicle when the vehicle movement is not interfered by other vehicles or interrupted by control devices. The mean value of the free-flow speeds of individual vehicles can be determined either as a space mean or as a time mean. Time-mean speed is the arithmetic mean of individual speeds; space-mean speed is the harmonic mean. Mean free-flow speed has a wide range of applications. For example, space-mean free-flow speed is the basis of many planning models that are used to estimate average travel speeds and capacities (Dowling, R., et al. 1997). And the estimated travel speeds, in turn, are being used for estimating fuel consumptions and vehicles emissions (Dowling, R., et al. 1997; Teply, S., et al., 1995). The U.S. Highway Capacity Manual (Transportation Research Board 2000) also uses space-mean speed extensively to analyze the capacities and levels of service of open highways and urban and suburban arterials highways. On the other hand, all microscopic traffic simulation models have to use time-mean free-flow speed and its related distribution of individual free-flow speeds as inputs for estimating travel time, delays, and fuel consumptions. Many researchers have investigated the problem of estimating free-flow speed (Dowling, R., et al., 1997; Agent, K. R., et al. 1998; Dixson, K. K., et al. 1999; Kyte, M., et al. 2000).

Driver speed is a function of several factors apart from the posted speed limits, e.g., alignment, lane and shoulder width, design speed, land use, surrounding land use, traffic volumes, percentage of trucks in the traffic stream, weather, time of day, enforcement (Wilmot, C.G. and Khanal, M. ,1999), visibility, vehicle operating characteristics, and driver factors such as risk taking behavior. Hence, it is difficult to identify the effect of a single factor on speeds. To find out the effect of changes in speed limit on average speeds, most researchers have relied on a comparison of average speeds before the change in speed limit with average speeds after the change in speed limit.

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 (HRB,1965). 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'' (TRB,2000). Highway capacity, as defined by the HCM (TRB,2000), is the maximum flow rate achievable at a specific location on a roadway under prevailing roadway, traffic, and control conditions.

ISSN 2229-5518

2. Data Collection

Many factors can affect the free-flow speed of a highway segment. They include but are not limited to the spacing between signalized intersections, lane width, shoulder width, lateral clearance, median type, grade, curvature, vehicle types, speed limit, land use and drivers' behaviors. This study concerns only the free-flow speeds on straight and level segments that have median barriers. Forty two such segments were chosen for the study with the aid of Al-Najaf and Kufa municipalities . Each segment lies between two signalized intersections.
Free-flow speeds of vehicles were measured with moving car observer technique along each segment under fair weather conditions. Vehicles were classified into passenger car , single unit trucks , and buses.

Field surveys on vehicle classification counts and speed were complete for a total of 21 survey locations in the Najaf city . The lane width, shoulder width, and driver population are important parameters in selecting highway location samples. The main purposes of these surveys are to estimate free-flow speeds, to update vehicle classification traffic counts and to investigate volume-delay relationships for the study area.

Data was collected in 15 minutes time periods for a of 4 hours (7:30-11:30) in winter months (December and November) on Monday , Tuesday and Wednesday in 2009. The surveys were conducted with observer moving car method at the survey spot. The counters can instantly record space mean speed , traffic density and classification data.

The following major factors influence the vehicle travel speed:
Geometrics of the road
Posted speed
Interference by traffic
Interference by heavy vehicles
Impact from traffic signal
Weather conditions
Special incidents
Highway location (rural and urban)
Functional classification

There are three primary federal highway functional classifications: arterial, collector, and local roads. All streets and highways are grouped into one of these classes, depending on the character of the traffic (i.e., local or long distance) and the degree of land access that they allow. These classifications are described in Table 1.

Table 1 : Description of functional classification systems

Functional System	Services Provided
Arterial	Provides the highest level of service at the greatest speed for the longest uninterrupted distance, with some degree of access control.
Collector	Provides a less highly developed level of service at a lower speed for shorter distances by collecting traffic from local roads and connecting them with arterials.
Local	Provides a less highly developed level of service at a lower speed for shorter

Typically, travelers will use a combination of arterial, collector, and local roads for their trips. Each type of road has a specific purpose or function. Some provide land access to serve each end of the trip. Others provide travel mobility at varying levels, which is needed en route. The Functional Classification system can be further broken down into "rural' and "urban" classifications, and there are sub-classifications within these groupings as well. (See Figure 1) For more detailed information, please see Highway Functional Classification:
Concepts, Criteria and Procedures (AASHTO Policy,2004).

Table 2 presents vehicle space mean speeds measured at various survey locations for different multilane highway classifications

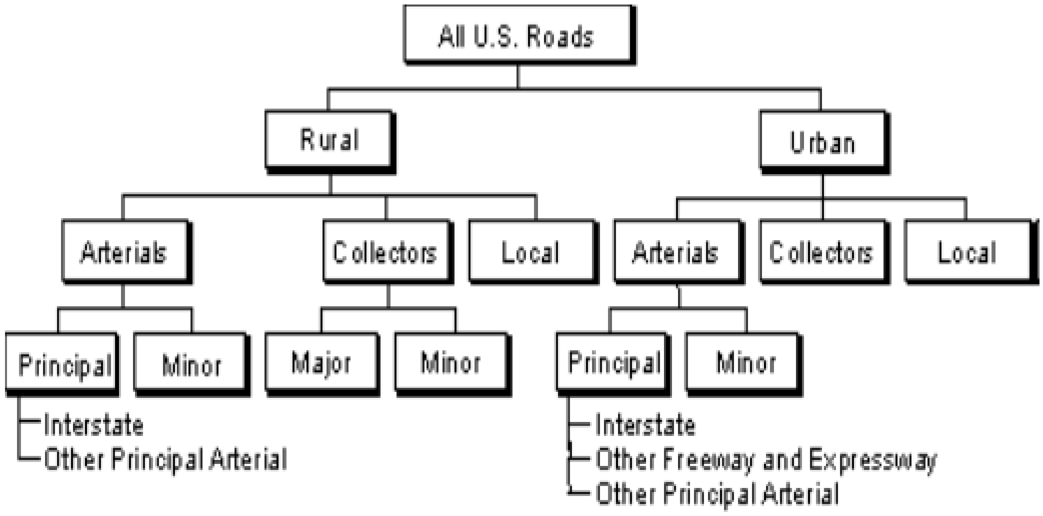

Figure 1. Functional classification of highways

.

Table 2 : Vehicle space Mean speeds from survey locations

Survey Location	Highway name	Function Class	No. of lanes in one direction	Space mean speed (Kmph)	
				Direction 1	Direction 2
1	Najaf-Kerbala	Rural Principal Arterial	2	102.4	106
2	Najaf-Diwaynia	Rural Principal Arterial	3	113.8	109.4
3	Kufa-Hilla	Rural Principal Arterial	2	107.6	109.1
4	Najaf-silo to Kufal intersection	Rural Minor Arterial	2	90.3	94.4
5	Al-Hurria –Kufa	Rural Minor Arterial	2	81.4	85.8
6	Najaf-Abu Sukhayr	Rural Minor Arterial	3	91.6	93.5
7	Najaf-Kufal	Rural Major Collector	2	79.2	75.8
8	Ring road (Al-houly)	Rural Minor Collector	2	71.3	72.4
9	Najaf-Kufa (Segment 1) Kufa Bridge to Al-Sherstanee square	Urban Principal Arterial	2	52.3	61.5
10	Najaf-Kufa (Segment2) Muslim Abn Aqeel to Alahly hosiptal	Urban Principal Arterial	2	57.7	67.4
11	Najaf-Kufa (Segment 3) Alahly hosiptal to Thoreet alShreen sqaure	Urban Principal Arterial	3	60.3	69.5
12	Alateba – Algarage shemal	Urban Principal Arterial	3	74.6	70.1
13	Algarage shemaly – Najaf silo	Urban Principal Arterial	3	82.9	83.7
14	Al-ansar-Airport	Urban Minor Arterial	3	68.3	72.5
15	Al-Shoureth	Urban Minor Arterial	2	71.3	71.0
16	Al- Aadalh - Al- Jamah	Urban Minor Arterial	2	64.7	70.8
17	Al-Ghdeer -Alshoohra	Urban Minor Arterial	2	73.6	71.6
18	Al-Ghdeer	Urban Collector	3	50.3	55.8
19	Al Skan	Urban Collector	2	65.7	68.9
20	Alsalam and Al- Jamah	Urban Collector	3	62.6	67.8
21	Alateba and Ghari	Urban Collector	2	70.7	64.5

In its definition, free-flow speed is the speed that occurs when density and flow are zero .Thus, factors determining free-flow speed only include geometrics of the road and posted speed without any interference by traffic, signals, weather or accidents. 21

locations were selected based on their survey location, area type, traffic volume at the time of survey and space mean speed compared to the posted speed. In selecting those locations for analysis, the following criteria to determine the free-flow conditions were used based on the(HCM 2000): multi-lane highways: mean speed of passenger cars under low to moderate flow conditions (up to 1,400 pcphpl) . Table 3 indicates free flow speed and speed differential measured at survey locations.

Table 3 : Free flow speed and speed differential from survey locations

Survey Location	Space mean speed (Kmph)		Free flow speed (Kmph)		Speed differential (Kmph)	
	Direction 1	Direction 2	Direction 1	Direction 2	Direction 1	Direction 2
1	102.4	106	112.1	111.9	9.7	5.9
2	113.8	109.4	120.7	119.5	6.9	10.1
3	107.6	109.1	112	119.5	4.4	10.4
4	90.3	94.4	100.6	103.3	10.3	8.9
5	81.4	85.8	88.8	95.3	7.4	9.5
6	91.6	93.5	100	103.7	8.4	10.2
7	79.2	75.8	86.3	88.1	7.1	12.3
8	71.3	72.4	78.7	80.4	7.4	8
9	52.3	61.5	67.7	70.8	15.4	9.3
10	57.7	67.4	67.3	76.3	9.6	8.9
11	60.3	69.5	68.7	77.2	8.4	7.7
12	74.6	70.1	83	80.4	8.4	10.3
13	82.9	83.7	89.1	91.6	6.2	7.9
14	68.3	72.5	77.5	82.9	9.2	10.4
15	71.3	71.0	80.4	80.6	9.1	9.6
16	64.7	70.8	73.2	79.7	8.5	8.9
17	73.6	71.6	78.9	81.8	5.3	10.2
18	50.3	55.8	58.7	66.3	8.4	10.5
19	65.7	68.9	75	80.6	9.3	11.7
20	62.6	67.8	71.8	78.1	9.2	10.3
21	70.7	64.5	79.1	75	8.4	10.5

By using traffic data , the model can be written as follows:

FFS=0.96 SMS +11.8 R2=0.995 … (1)

According to study results the base free flow speed can be estimated unless measured flow speeds are available as follows: base free flow speeds are 75 km/h and 105 km/h for urban and rural highways respectively .where the free-flow speed is 5 to 15 mph faster than the space mean speed for both rural and urban highways.
Dowling et al. (1997) examined speed data from 10 speed measurement stations on four rural highways in three states. They developed the following relationship between free-flow speed and speed limit: For posted speed limits exceeding 50mph, the free-Flow Speed = 0.88*Posted Speed Limit + 14 , and for posted speed limits less than or equal to 50mph , the free-Flow Speed = 0.79*Posted Speed Limit + 12.

The guidance provided in the HCM (TRB,2000) and by the aforementioned researchers indicates that speed limit is likely correlated with free-flow speed. With the exception of the guidance provided in Chapter 10 of the HCM, there is a trend where the free-flow speed is 5 to 7 mph faster than the speed limit.

3. Passenger Car Equivalent Factors

Many methods exist for determining passenger-car equivalents (PCEs), passenger-car units (PCUs) or the homogenization coefficient: the semi-empirical method, Walker's method, headway method, multiple linear regression method, and the simulation method (CRRI, 1982 ; Kadiyali and Viswanathan 1992). In the homogenization coefficient method, comparing theoretical maximum capacities when different vehicle types exclusively use the road produces PCUs. The method compares the 'all passenger-car' and 'all other than passenger car type'capacity of traffic lanes. Walker's method (Cunagin and Messer 1982) bases PCUs on overtakings that the traffic type would perform per kilometer length of highway if each vehicle continued at its normal speed. The ratio of overtakings when traffic has one slow-moving vehicle per hour to overtakings when traffic has passenger cars of equal volume calculates passenger-car units. The concept that a heavy vehicle occupies more space than a passenger car and reduces capacity forms the basis of the headway method. Analysis of time headways of a single stream of vehicles in a platoon during congested conditions can determine capacity-based PCUs. However, calculating PCUs based on the ratio of headways does not produce straightforward results; several approaches for determining headways exist. Plots of spacing versus headway can generate PCUs. Similarly, a plot of speed versus headways of individual vehicles by entering curves at constant speeds can calculate PCUs (McShane and Roess 1990).

Bang et. al.(1998) have estimated PCUs for road links and township roads in China using the regression method. Regression analyses produced speed-based PCUs using 5-minute, average speed and flow data from sites with sufficient flows to show a significant speed reduction at increasing flow. The relative effect of different vehicle types in a mixed traffic flow on the speed of light vehicles serves as a criterion for equivalence. The analysis of the ratio between the regression coefficient for a specific vehicle type and that for light vehicles produced final PCU values.

Bang et. al. (1995) developed a simulation method for determining PCUs using the VTI simulation model. The simulation method produces PCU values through successive simulations studying the impact on light vehicle speed at the introduction of other vehicle types in the traffic stream.

Webster and Elefteriadou (1999) estimated passenger-car equivalents for heavy vehicles using simulation based on traffic density. The study investigated the effect of several characteristics related to freeway design, vehicle performance, and the traffic stream on passenger-car equivalents for heavy vehicles. Traffic density proves a good indicator of the driver's freedom to maneuver, an accurate measure of proximity to other vehicles, and consistent with the measures of effectiveness for freeways and multi-lane highways used in the Highway Capacity Manual (HCM, 2000). New PCU values in HCM 2000 stem from Webster's and Elefteriadou's work. PCU values derived from the density method use underlying homogeneous traffic concepts such as strict lane discipline, car following logic, and a vehicle fleet whose elements do not vary much in physical dimensions. Homogeneous traffic represents a very narrow case of heterogeneous traffic. Indian highways carry non-homogeneous traffic, which often includes non-motorized traffic entities. Loose lane discipline prevails; lane driving and car following is not the norm. Methods based on homogeneous traffic concepts have limited applicability for this non-homogeneous traffic.

One can equivocate the density of trucks to the density of passenger cars under homogeneous conditions to find the PCUs for trucks.

$$\text{PCU} = \frac{K_{car}}{K_{truck}} \qquad \dots (2)$$

Where kcar is the density of cars in pure homogeneous traffic (cars/km) , ktruck is the density of trucks in pure homogeneous traffic (trucks/km) and PCUtruck is the passenger-car unit for trucks given homogeneous traffic behavior. Field measurements were carried out to determine the density values of cars and trucks.

The average spacing or density of trucks changes depending on the grade and length of the grade according to the U.S. Highway Capacity Manual (TRB,2000). For uniform upgrades, PCUtruck may go as high as 15.0. On uniform downgrades, PCUtruck can go as high as 7.5. However, all Al-Najaf study sites lay on level terrain; the effect of grade and grade length is negligible. Table 4 indicates the passenger car units for trucks and buses.

Table 4: Passenger car unit for trucks and buses

Survey Location	Density of passenger cars kcar (cars/ km)	Density of trucks ktruck (trucks/km)	Passenger car unit for trucks and buses (PCUtruck)

ISSN 2229-5518

	Direction 1	Direction 2	Direction 1	Direction 2	Direction 1	Direction 2
1	29.3	31.3	16.4	17.5	1.78	1.79
2	26.4	30.4	15.1	16.1	1.75	1.89
3	27.9	30.2	17.5	19.9	1.59	1.52
4	33.5	34.9	15.6	13.3	2.15	2.62
5	36.8	38.5	20.4	22.1	1.80	1.74
6	32.9	35.3	18.3	19.4	1.80	1.82
7	37.8	43.5	25	21.5	1.51	2.02
8	42.0	45.6	15.3	24.9	2.75	1.83
9	57.3	53.6	29.8	26.5	1.92	2.02
10	51.9	48.9	28.8	27.2	1.80	1.80
11	49.7	47.5	27.6	25.5	1.80	1.86
12	40.2	47.1	22.3	14.3	1.80	3.29
13	36.2	39.4	19.1	23.5	1.90	1.68
14	43.9	45.5	24.5	23.5	1.79	1.94
15	42.0	46.4	20.3	21.9	2.07	2.12
16	46.4	46.6	25.7	22.1	1.81	2.11
17	40.7	46.1	20.6	22.3	1.98	2.07
18	59.6	59.1	14.1	29.27	4.23	2.02
19	45.6	47.8	21.3	23.69	2.14	2.02
20	47.9	48.6	27.6	30.1	1.74	1.61
21	42.4	51.2	24.1	20.3	1.76	2.52

As it is reported in table above , the average value of passenger car unit factor (PCU) for trucks and buses is 2.0 .

4. Conclusions and Recommendations

The main conclusions can be drawn as follows:

The developed model (FFS=0.96 SMS +11.8 , $R2=0.995$) can be used to estimate free flow speed based on space mean speed measured at certain segment of multilane.

According to study results the base free flow speed can be estimated unless measured flow speeds are available as follows : base free flow speeds are 75 km/h and 105 km/h for urban and rural highways respectively . Also, the paper results indicate that free-flow speed is 5 to 15 mph faster than the space mean speed for both rural and urban highways.

Based on the study results , the passenger car unit factor (PCU) for trucks and buses is 2.0.

The recommendations can be listed below:

There are need to study the effect of grade on the free flow speed and passenger car unit factors.

A study of estimation of passenger car unit factors for heterogeneous traffic.

5. References

AASHTO , 2004," A Policy on geometric design of highways and streets", American Association of State Highway and Transportation Officials , Washington D.C.

Agent, K. R., Pigman, J. G. and Weber, J. M. ,1998, "Evaluation of Speed Limits in Kentucky", Transportation Research Record No. 1640, Transportation Research Board, Washington, D.C., pp.57-64.

Bang K. L., Ronggui Z., and Huichen X., 1998, "Traffic performance and passenger car equivalents for road links and township roads in PRC" , Proceedings Third International Symposium on Highway Capacity, (Copenhagen: Danisu Road Directorate) 257–273.

Bang K. L., Carlsson A.,and Palgunadi, 1995, "Development of speed-flow relationships for indonesian rural roads using empirical data and simulation", Transportation Research Record 1484 (Washington, DC: National Academy Press)

CRRI , 1982, " Road user cost study in India" , Final Report (New Delhi: Central Read Research Institute).

Cunagin W D, and Messer C J 1982, "Passenger car equivalents for rural highways", Report FHWA/RD-82/132 (Washington, DC: FHWA, US Department of Transportation).
Dixson , K. K., Wu, C-H, Sarasua, W. and Daniel, J. ,1999, " Posted and Free-Flow Speeds for Rural Multilane Highways in Georgia", ASCE Journal of Transportation Engineering,Vol.125, No.6.
Dowling, R., Kittelson, W., Zegeer, J. and Skabardonis, A. ,1997, " Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications", NCHRP Report 387,Transportation Research Board.
Highway Research Board ,1965, "Highway Capacity Manual" , National Research Council. Department of Traffic and Operations, Special Report 87, Committee on Highway Capacity, Washington, DC.
Kadiyali L. R., Vishwanathan E. ,1992, " Study for updating road user cost data", Journal of Indian Roads Congress 54(3): 645–731.
Kyte M., Khatib, Z., Shannon, P. and Kitchener, F. ,2000, "Effect of Environmental Factors on Free-Flow Speed", Transportation Research Circular E-C018: 4th International Symposium on Highway Capacity
McShane W. R., Roess R. P. ,1990, "Traffic engineering" , Prentice-Hall, Englewood Cliffs, NJ Road Accidents in Delhi 2004 Accident Research Cell, Delhi Traffic Police (New Delhi, India).
Nicholas j Garber and Lester A Hoel ,Traffic and Highway Engineering , Cengage, Learning, 2009.
Teply, S., Allingham, D. I., Richardson, D. B. and Stephenson, B. W. ,1995, "Canadian Capacity Guide for Signalized Intersections", Institute of Transportation Engineers, District 7.
Transportation Research Board,2000, "Highway Capacity Manual 2000", National Research Council, Washington, D.C.
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): 315–385.
Wilmot, C.G. and Khanal, M. ,1999, "Effect of speed limits on speed and safety: a review", Transport Reviews, Vol. 19(4), pp. 315-329.