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EFFECT OF HIGHWAY DESIGN ELEMENTS ON THE CAPACITY OF 2-LANE ROADS

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FOREWORD

The paper prepared by Malik Mohammad Saeed Khan in the National Transport Research Centre attempts to bring in focus the latest procedures of estimating the effect of highway design elements on the capacity of 2-lane highways, which constitute bulk of highway mileage in the country. The paper highlights the factors which influence capacity of such roads and would help as a guide to our Highway and Traffic Engineers in determining the capacity of 2-lane highway, optimising traffic flow and evaluating the ability of the roads to carry future traffic volume and to develop a sound basis for the design of the 2-lane facilities.

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Majority of the Arterial Highways in Pakistan are 2-lane facilities whilst, the other roads are also being widened to 2-lanes from single lane operations, as and where warranted by the increase in the traffic intensity. Very few 4-lanes roads exist in the country and it is expected that 2-lane roads would constitute the highest class of rural highways in the foreseeable future.

2. The two basic characteristics which differentiate traffic operations on a two lane facility from multilane operations are firstly that the distribution of traffic by direction normally has little effect on capacity of a two lane highway and secondly, overtaking and passing manoeuvres must be made in the lane normally occupied by the opposing traffic. On a two lane highway, the maintenance of a desired speed involves passing manoeuvres and therefore, the volume of traffic plus the highway geometrics which establish available passing sight distances have a more significant effect on traffic operation on two lane roads than on multi-lane facilities.

3. On two lane highways in conditions where the traffic volumes are light and geometrics of the road are good thereby ensuring the availability of continuous sight distances, the vehicles can operate at the desired speed with little effect of the opposing traffic. With the increase in traffic volumes, however, in order to maintain the desired speed, the need to pass slower traffic increases and the speed of traffic is then affected by the availability of opportunities to pass in the face of opposing traffic. In rolling and mountainous terrain restricted sight distance and slow moving trucks further effect the opportunities to pass and freedom to manoeuvre thereby seriously affecting the volume of traffic that can be accommodated on the two lane road.

4. Highway Capacity has become recognised as an essential principle of highway planning and design. For the analysis of capacity and geometric design of highways, two publications are most extensively used. These are " A Policy on the Geometric Design of Rural Highways " published by the American Association of State Highway Officials (AASHO Policy) and the " Highway Capacity Manual " published by the U.S. Highway Research Board. Although the concepts and terminology in the two publications differ, the basic values obtained are approximately the same.

5. The original edition of the " Highway Capacity Manual " defined three levels of roadway capacity—basic capacity, possible capacity, and practical capacity. It was considered of prime importance that traffic volumes be accurately related to local operating conditions so that particular agencies could decide on the practical capacities for facilities within their jurisdiction. The manual recognized that practical capacity would depend on the basis of a subjective evaluation of the quality of service provided.

6. The 1965 Highway Capacity Manual has elected to define a single parameter for each facility and defines " capacity " as " the maximum number of vehicles which has a reasonable expectation of passing over a given section of a lane or roadway during a given period under prevailing roadway and traffic conditions ". This definition is synonymous with the " possible capacity ", utilized in the AASHO Policy. The practical capacity concept has been replaced by several specific ' Service Volumes ' which are related to a group of desireable operating conditions referred to as ' level of service '. The term ' level of service ' is used to denote conditions below capacity.

7. It is of extreme importance that the terms " volume " and " Capacity " should be properly conceived. Volume indicates an actual observed number of vehicles using a facility, whilst capacity represents the theoretical ability of the facility to carry traffic under prevailing set of conditions. Volume should also be differentiated from ' density '. Density is the number of vehicle per unit length of the facility.

8. As traffic volumes approach capacity, operating speed of the traffic reduces. At capacity, all traffic must operate at the speed of the slowest vehicles in the stream and there is traffic congestion. There is little or no opportunity to manoeuvre and traffic flow is unstable. Consequently if for any reason, traffic flow is disrupted, vehicles will stack up rapidly. Even if the cause of congestion lasts for a few seconds, additional vehicles will continue to stop for a considerable time after the cause of the restriction has been removed. A queue of successively stopping vehicles will form and this queue will progress along the traffic lane in a direction opposite to that in which the vehicles are moving. In some cases, these " shock waves " have been observed several miles from the scene of the original restriction, although traffic was operating in a normal manner between the queue and the point of origin. Vehicles keep peeling off from the queue whilst fresh vehicles keep adding to the queue and the shock wave travels progressively backwards. At volumes below the capacity, there is some freedom to manoeuvre and drivers to some extent can drive faster than the slowest moving vehicle. At low traffic volumes however there is complete freedom to manoeuvre

Factors Affecting Capacity

20. The Theoretical Service volumes recommended by the Highway Capacity Manual and the AASHO Policy are both based upon ideal roadway and operating conditions. The assumption for ideal conditions are:

(1) There is uninterrupted flow on the facility and there is no side interference from vehicles or pedestrians.

(2) There are only passenger cars in the stream.

(3) The roadway width is 24 feet with adequate shoulders and there are no lateral obstructions within six feet of the edge of the pavement on either side.

(4) The Horizontal and vertical alignment are satisfactory for design speeds of 70 miles per hour or average running speeds of 50 miles per hour with unrestricted passing sight distances.

21. Any deviation from the above condition requires application of correction factors to the theoretical service volumes. The critical elements which must be considered are :

(1) Lane width and lateral clearance.

(2) Truck, bus and animal drawn traffic, in relation to road grades.

(3) Alignment reflected by average highway speed.

(4) Passing sight distance.

Highway Capacity Manual Procedure

22. The maximum traffic volumes for each level of service under ideal conditions are reflected in table I, together with correction factors for average highway speed for passing sight distance. It may be noted that since Level of Service A depicts free flow conditions with operating speeds of 60 miles per hour or greater, there are no correction factors given. Any modification would result in a lower level of service. In all cases, the factors presented for each combination of available sight distance and speed are applied to a standard design capacity service volume of 2,000 vehicles per hour to determine the service volume for actual conditions.

23. Correction factors for other elements requiring consideration are derived from separate tables. Values for various percentages of trucks and character of terrain are given in table 3 and 4. These are generalized adjustment factors for use in the analysis of extended lengths of highways which may include a number of different grades of varying lengths.

24. For the analysis of an individual sub-section of a two-lane highway having a specific grade and length of grade, the passenger car equivalent for each truck may be estimated as shown in table 5. The passenger car equivalent and the actual percentage of trucks may then be used to calculate the correction factor for the sub-section on the basis of values in tables 6 and 7.

25. Adjustment factors for lane widths of less than 12 feet and for restricted lateral clearances are presented in table 8. Values for Level of Service B, the level most commonly used for rural highways, and Level of Service E, representing capacity, may be obtained directly from table 8. Values for other levels of service may be obtained by interpolation.

26. The procedure for analysis of two-lane highways as given in the Capacity Manual is expressed in the following basic equation :—

SV-2,000 (v/c) TW, where SV is the service volume in vehicles per hour (total for both directions) ;

v/c is the ratio of volume to capacity found in Table 1 ;

T is the truck adjustment factor found in Tables 4 and 5 ;

W is the adjustment factor for lane width and lateral clearance found in Table 8.

27. This equation is applicable only to those portions of the highway where conditions permit uninterrupted flow. The procedure does not apply to sections of roadway influenced by ramps, weaving or inter-sections.

28. Capacity problems involve three major variables-volume, level of service, and number of lanes. Anyone of the three major variables may be calculated if the other two are given, selected or assumed. Within each of the three variables, there are sub-variables. For example, with a given percentage of trucks, the effect of Trucks, may be modified by changing the per cent of grade or length of grade. For a given volume of traffic, the effect of lateral restrictions may be changed by changing the clear distance from the edge of pavement.

AASHO Procedure

29. While design problems can be analyzed by using the Highway Capacity Manual procedure illustrated above, the AASHO Procedures were developed specifically for design purposes. They are somewhat less complicated and offer a more direct technique for general use.

30. The application of the AASHO Procedures to the analysis of two-lane rural highways involves use of table 9. The design capacity is read directly from the table for given average running speeds, type of terrain, passing sight distance, lane width, percentage of trucks and design speed.

31. When there are restrictive lateral clearances or narrow shoulders, the results from the above tables must be multiplied by the adjustment factors presented in table 10.

32. These correction factors are identical to those in the Capacity Manual. The values given in table 9 above may be utilized for two-lane rural highways in level and rolling terrain. They are equivalent to values for level of Service B in the Highway Capacity Manual. For highways in mountanious terrain, the AASHO Policy recommends a design capacity closer to Level of Service C : a separate table is used for analysis. The AASHO Policy further simplifies the problems for the highway designer by relating the peak hour volume, to the average daily traffic and calculating the values shown in Table 11. Both the design capacity and the possible capacity of a two-lane roadway under varying conditions can be read directly from this table.

33. Road alignment and grade are two of the most significant factors affecting the design capacity of two-lane roads, and are the major determinants of design speed and sight distance. For purposes of capacity analysis it is assumed that passing opportunities may occur only where the passing sight distance (PSD) is greater than 1,500 feet.

34. Availability of passing sight distance is expressed as a percentage of the length of roadway in which the passing sight distance is 1,500 feet or more. It is important to remember that the last 1,500 feet should not be included in th length of roadway over which passing sight distance is measured, since adequat length is no longer available.

35. Ordinarily, the passing sight distance along a highway will vary cont nuously. Where the passing sight distance remains exactly 1500 feet (and greater) along an extended length of roadway (for example, across the inside of long horizontal curve in a cut section), the percentage of available passing sig distance is effectively less than 100 percent since some drivers will not take vantage of opportunities to pass under these conditions. It is assumed that o when the passing sight distance reaches approximately 2,000 feet will all dri take advantage of passing opportunities.

45. Where the need is to determine the influence of trucks and buses on specific individual upgrades, the process is more selective. Table 5 has been prepared to present detailed passenger car equivalency factors for trucks at capacity and the several levels of service, on two-lane highways where no climbing lane is provided. Table 6 similarly presents passenger car equivalency factors for intercity buses, for use in those few cases where bus volumes are heavy and/or grades are heavy.

46. In practice, the values from these tables normally are not used directly in computations, but are used to enter Table 7, which provides truck factors that consider both the passenger car equivalent and the percentage trucks in the traffic stream.

47. In our country, where animal drawn traffic is a consistent problem on most of the rural roads, a generalized equivalency factor of 7 passenger car units may be assumed for each animal drawn vehicle. In the absence of adequate data, this equivalency factor has been assumed by the Planning Commission based up the experience of the prevalent conditions.

Climbing Lanes

48. When it is not practical to provide adequate passing sections on long grades where there are heavy percentages of trucks in the total traffic volume, it may be desirable to provide a climbing lane. Sections of two-lane highway which include uphill climbing lanes may be analyzed in the same manner as ordinary highways, with some modifications in the procedure for determining passing sight distance and adjustment factors.

49. It may be assumed that all trucks and smaller vehicles will use the climbing lane in the uphill direction so that, effectively, the available passing sight distance will be 100 percent in the uphill direction. In the downhill direction, the passing sight distance must be measured and averaged with the 100 percent effected by the climbing lane.

50. In instances where it is necessary for downhill trucks to operate in low gear, passing in the free lane should be permitted only when adequate sight distance is available.

51. Trucks in the uphill climbing lane will have little effect on the capacity of the free uphill lane and may be disregarded when determining truck adjustment factors. On normal two-lane rural highways, the single lane approach to a climbing lane section will generally govern the total capacity to the point that even relatively large percentages of trucks can be handled in the climbing

lane exclusively. Generally it is sufficient to use one-half of the actual percentages of trucks in the total volume to determine the adjustment factor. Since all trucks to be accounted for in the adjustment factor are operating in the downhill direction, it is necessary only to determine whether trucks must operate in low gear on the downhill grade or whether normal operating speeds are possible.

52. In analyzing an extended length of highway, it is important to subdivide the length into sections within which design characteristics are consistent. As a guide the control speeds should not vary more than 10 miles per hour within such sub-sections. The design speed selected should not be lower than one compatible with the character of the terrain and the land development in the area.

Conclusion

53. With a very basic under standing of the tables and procedures presented herein, one is able to estimate the effect of certain design elements upon the capacity of the highway.

54. The capacity of an existing highway with adequate passing sight distance along 20 percent of the total length can be increased as much as 40 percent (at 60 miles per hour design speed) if a vertical and horisontal alignment can be provided which will allow adequate passing sight distance along 60 percent of the length.

55. On a highway where a long grade will be necessary, construction of the steepest part of the grade at the bottom rather than at the top will reduce the effect of the grade on truck speeds and will result in a higher capacity.

56. A 24-foot roadway will normally have approximately 25 percent greater capacity than a 20-feet roadway, in addition to the many other advantages offered by the wider width, and a highway with undulating grades will have a lesser effect on trucks than one with a long continuous grade and thus will have a greater capacity.

57. It is the intent of this paper to help as a guide to our Highway and Traffic Engineers in determining the capacity of our 2-lane highways, optimising traffic flow and evaluating the ability of the roads to carry future traffic volumes, and to develop a sound basis for design of the 2-lane facilities.

TABLE 1

LEVELS OF SERVICE AND MAXIMUM SERVICE VOLUMES ON TWO-LANE HIGHWAYS UNDER UNINTERRUPTED FLOW CONDITIONS (NORMALLY REPRESENTATIVE OF RURAL OPERATION)

Level of Service	Traffic Flow Conditions		Passing Sight Distance 1,500 FT (%)	Service Volume/Capacity (v/c) Ratio						Maximum Service Volume Under Ideal Conditions Including —MPH ARS (Passenger Cars, Total, Both Directions. per Hour)
	Description	Operating Speed[a] (MPH)		Basic Limiting Value[a] for Ahs of 70 MPH	Working Value for Restricted Average Highway Speed of					
					60 MPH	50 MPH	45 MPH	40 MPH	35 MPH	
A	Free flow	≥60	100	≦0.20	—	—	—	—	—	400
			80	0.18	—	—	—	—	—	
			60	0.15	—	—	—	—	—	
			40	0.12	—	—	—	—	—	
			20	0.08	—	—	—	—	—	
			0	0.04	—	—	—	—	—	
B	Stable flow (uper speed range)	≥50	100	≦0.45	≦0.40	—	—	—	—	900
			80	0.42	0.35	—	—	—	—	
			60	0.38	0.30	—	—	—	—	
			40	0.34	0.24	—	—	—	—	
			20	0.30	0.18	—	—	—	—	
			0	0.24	0.12	—	—	—	—	

TABLE 1—(Contd)

C	Stable flow	≥40	100	≤0.70	≤0.66	≤0.56	≤0.51	—	—	
			80	0.68	0.61	0.53	0.46	—	—	
			60	0.65	0.56	0.47	0.41	—	—	
			40	0.62	0.51	0.38	0.32	—	—	1400
			20	0.59	0.45	0.28	0.22	—	—	
			0	0.54	0.38	0.18	0.12	—	—	
D	Approaching unstable flow	≥35	100	≤0.85	≤0.83	≤0.76	≤0.67	≤0.58	—	
			80	0.84	0.81	0.72	0.62	0.55	—	
			60	0.83	0.79	0.69	0.57	0.51	—	1700
			40	0.82	0.76	0.66	0.52	0.45	—	
			20	0.81	0.71	0.61	0.44	0.35	—	
			0	0.80	0.66	0.51	0.30	0.19		
E[c]	Unstable flow	30[d]	Not applicable[e]		≤1.00					2000
F	Forced flow	30[d]	Not applicable[e]		Not Meaningful[f]					Slightly variable (0 to capacity)

a Operating speed and basic v/c ratio are independent measures of level of service ; both limits must be satisfied in any determination of level.

b Where no entry appears, operating speed required for this level is unattainable even at low volumes.

c Capacity.

d Approximately.

e No passing.

f Demand volume/capacity ratio may well exceed 1.00, indicating overloading.

Source : Highway Capacity Manual.

TABLE 2

Capacity Manual			AASHO Policy		
Level of Service	Operating Speed	Service Vol. per Lane	Design Capacity	Average Running Speed	Location and Terrain
A	60 mph	400			
B	50 mph	900	900	45—50 mph	Rural
C	40 mph	1400	1150	40—45 mph	Suburban and Mountainous
D	35 mph	1700	1500	35—40 mph	Urban and Mountainous
E	30 mph	2000	2000	30 mph	All Locations Possible Capacity

TABLE 3

AVERAGE GENERALIZED PASSENGER CAR EQUIVALENTS OF TRUCKS AND BUSES ON TWO-LANE HIGHWAYS, OVER EXTENDED SECTION LENGTHS

(Including Upgrades, Down-grades, and Level Sub-sections)

Equivalent	Level of Service	Equivalent, For:		
		Level Terrain	Rolling Terrain	Mountainous Terrain
E_T, for trucks ..	A	3	4	7
	B and C	2.5	5	10
	D and E	2	5	12
E_B, for buses[a] ..	All levels	2	4	6

[a] Separate consideration not warranted in most problems ; use only where bus volumes are significant.

Source : Highway Capacity Manual.

TABLE 4

AVERAGE GENERALIZED ADJUSTMENT FACTORS FOR TRUCKS[b] ON TWO-LANE HIGHWAYS, OVER EXTENDED SECTION LENGTHS

Percentage of Trucks, P_T	Truck Adjustment Factor, T								
	Level Terrain			Rolling Terrain			Mountainous Terrain		
	Level of Service A	Levels of Service B and C	Levels of Service D and E[c]	Level of Service A	Levels of Service B and C	Level of Service D and E[c]	Level of Service A	Levels of Service B and C	Levels of Service D and E[c]
1	0.98	0.99	0.99	0.97	0.96	0.96	0.94	0.92	0.90
2	0.96	0.97	0.98	0.94	0.93	0.93	0.89	0.85	0.82
3	0.94	0.96	0.97	0.92	0.89	0.89	0.85	0.79	0.75
4	0.93	0.95	0.96	0.89	0.86	0.86	0.81	0.74	0.69
5	0.91	0.93	0.95	0.87	0.83	0.83	0.77	0.69	0.65
6	0.89	0.92	0.94	0.85	0.81	0.81	0.74	0.65	0.60
7	0.88	0.91	0.93	0.83	0.78	0.78	0.70	0.61	0.57
8	0.86	0.90	0.93	0.81	0.76	0.76	0.68	0.58	0.53
9	0.85	0.89	0.92	0.79	0.74	0.74	0.65	0.55	0.50
10	0.83	0.87	0.91	0.77	0.71	0.71	0.63	0.53	0.48
12	0.81	0.85	0.89	0.74	0.68	0.68	0.58	0.48	0.43
14	0.78	0.83	0.88	0.70	0.64	0.64	0.54	0.44	0.39
16	0.76	0.81	0.86	0.68	0.61	0.61	0.51	0.41	0.36
18	0.74	0.80	0.85	0.65	0.58	0.58	0.48	0.38	0.34
20	0.71	0.77	0.83	0.63	0.56	0.56	0.45	0.36	0.31

[b] Not applicable to buses where they are given separate specific consideration ; use instead Table 3 in conjunction with Table 7.
[c] Capacity.

Source **: Highway Capacity Manual.**

TABLE 5

PASSENGER CAR EQUIVALENTS OF TRUCKS ON TWO-LANE HIGHWAYS, ON SPECIFIC INDIVIDUAL SUB-SECTIONS OR GRADES

Grade (%)	Length of Grade (MI)	Passenger Car Equivalent, Et. (For All Percentages of Trucks)		
		Levels of Service A and B	Level of Service C	Levels of Service D and E (Capacity)
0–2 ..	All	2	2	2
3 ..	1/4	5	3	2
	1/3	10	10	7
	3/4	14	16	14
	1	[illegible]	21	20
	1-1/2	19	25	26
	2	21	27	29
	3	22	29	31
	4	23	31	32
4 ..	1/4	7	6	3
	1/2	16	20	20
	3/4	22	30	32
	1	24	35	39
	1-1/2	28	39	44
	2	20	42	47
	3	31	44	50
	4	32	46	52
5 ..	1/4	10	10	7
	1/2	24	33	37
	3/4	29	42	47
	1	33	47	54
	1-1/2	35	51	59
	2	37	54	63
	3	39	56	66
	4	40	57	68
6 ..	1/4	14	17	16
	1/2	33	47	54
	3/4	39	56	65
	1	41	59	70
	1-1/2	44	62	75
	2	46	65	80
	3	48	68	84
	4	50	71	87
7 ..	1/4	24	32	35
	1/2	41	63	75
	3/4	50	71	84
	1	53	74	90
	1-1/2	56	79	95
	2	58	82	100
	3	60	85	104
	4	62	87	108

Source : Highway Capacity Manual.

TABLE 6

PASSENGER CAR EQUIVALENTS OF INTERCITY BUSES ON TWO-LANE HIGHWAY, ON SPECIFIC INDIVIDUAL SUB-SECTIONS OR GRADES

Grade[a] (%)	Passenger Car Equivalent[b], F_b		
	Levels of Service A and B	Level of Service C	Levels of Service D and E (Capacity)
0—4	2	2	2
5[c]	4	3	2
6[c]	7	6	4
7[c]	12	12	10

a All lengths.
b For all percentages of buses.
c Use generally restricted to grades over 1/2 mile long.

Source : Highway Capacity Manual.

TABLE 7

ADJUSTMENT FACTORS[a] FOR TRUCKS AND BUSES ON INDIVIDUAL ROADWAY SUBSECTIONS OR GRADES ON TWO-LANE HIGHWAYS (INCORPORATING PASSENGER CAR EQUIVALENT AND PERCENTAGE OF TRUCKS OR BUSES)[b]

Passenger Car Equivalent, E_T Or E_B[c]	Truck Adjustment Factor T_C Or T_L (B_C Or B_L for Buses)[d]														
	Percentage of Trucks, P_T (Or of Buses, P_B) of :														
	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
2	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.93	0.92	0.91	0.89	0.88	0.86	0.85	0.83
3	0.98	0.96	0.94	0.93	0.91	0.89	0.88	0.86	0.85	0.83	0.81	0.78	0.76	0.74	0.71
4	0.97	0.94	0.92	0.89	0.87	0.85	0.83	0.81	0.79	0.77	0.74	0.70	0.68	0.65	0.63
5	0.96	0.93	0.89	0.86	0.83	0.81	0.78	0.76	0.74	0.71	0.68	0.64	0.61	0.58	0.56
6	0.95	0.91	0.87	0.83	0.80	0.77	0.74	0.71	0.69	0.67	0.63	0.59	0.56	0.53	0.58
7	0.94	0.89	0.85	0.81	0.77	0.74	0.70	0.68	0.65	0.63	0.58	0.54	0.51	0.48	0.45
8	0.93	0.88	0.83	0.78	0.74	0.70	0.67	0.64	0.61	0.59	0.54	0.51	0.47	0.44	0.42
9	0.93	0.86	0.81	0.76	0.71	0.68	0.64	0.61	0.58	0.56	0.51	0.47	0.44	0.41	0.28
10	0.92	0.85	0.79	0.74	0.69	0.65	0.61	0.58	0.55	0.53	0.48	0.44	0.41	0.38	0.36
11	0.91	0.83	0.77	0.71	0.67	0.63	0.59	0.56	0.53	0.50	0.45	0.42	0.38	0.36	0.33
12	0.90	0.82	0.75	0.69	0.65	0.60	0.57	0.53	0.50	0.48	0.43	0.39	0.36	0.34	0.31
13	0.89	0.81	0.74	0.68	0.63	0.58	0.54	0.51	0.48	0.45	0.41	0.37	0.34	0.32	0.29
14	0.88	0.79	0.72	0.66	0.61	0.56	0.52	0.49	0.46	0.43	0.39	0.35	0.32	0.30	0.28
15	0.88	0.78	0.70	0.64	0.59	0.54	0.51	0.47	0.44	0.42	0.37	0.34	0.31	0.28	0.26
16	0.87	0.77	0.69	0.63	0.57	0.53	0.49	0.45	0.43	0.40	0.36	0.32	0.29	0.27	0.25
17	0.86	0.76	0.68	0.61	0.56	0.51	0.47	0.44	0.41	0.38	0.34	0.31	0.28	0.26	0.24
18	0.85	0.75	0.66	0.60	0.54	0.49	0.46	0.42	0.40	0.37	0.33	0.30	0.27	0.25	0.23
19	0.85	0.74	0.65	0.58	0.53	0.48	0.44	0.41	0.38	0.36	0.32	0.28	0.26	0.24	0.22
20	0.84	0.72	0.64	0.57	0.51	0.47	0.42	0.40	0.37	0.34	0.30	0.27	0.25	0.23	0.21
22	0.83	0.70	0.61	0.54	0.49	0.44	0.40	0.37	0.35	0.32	0.28	0.25	0.23	0.21	0.19
24	0.81	0.68	0.59	0.52	0.47	0.42	0.38	0.35	0.33	0.30	0.27	0.24	0.21	0.19	0.18
26	0.80	0.67	0.57	0.50	0.44	0.40	0.36	0.33	0.31	0.29	0.25	0.22	0.20	0.18	0.17
28	0.79	0.65	0.55	0.48	0.43	0.38	0.35	0.32	0.29	0.27	0.24	0.21	0.19	0.17	0.16
30	0.78	0.63	0.53	0.36	0.41	0.36	0.33	0.30	0.28	0.26	0.22	0.20	0.18	0.16	0.15
35	0.75	0.60	0.49	0.42	0.37	0.33	0.30	0.27	0.25	0.23	0.20	0.17	0.16	0.14	0.13
40	0.62	0.56	0.46	0.39	0.34	0.30	0.27	0.24	0.22	0.20	0.18	0.15	0.14	0.12	0.11
45	0.69	0.53	0.43	0.36	0.31	0.27	0.25	0.22	0.20	0.19	0.16	0.14	0.12	0.11	0.10
50	0.67	0.51	0.40	0.34	0.29	0.25	0.23	0.20	0.18	0.17	0.15	0.13	0.11	0.10	0.09
55	0.65	0.48	0.38	0.32	0.27	0.24	0.21	0.19	0.17	0.16	0.13	0.12	0.10	0.09	0.08
60	0.63	0.46	0.36	0.30	0.25	0.22	0.19	0.17	0.16	0.15	0.12	0.11	0.10	0.09	0.08
65	0.61	0.44	0.34	0.28	0.24	0.21	0.18	0.16	0.15	0.14	0.12	0.10	0.09	0.08	0.07
70	0.59	0.42	0.33	0.27	0.22	0.19	0.17	0.15	0.14	0.13	0.11	0.09	0.08	0.07	0.07
75	0.57	0.40	0.31	0.25	0.21	0.18	0.16	0.14	0.13	0.12	0.10	0.09	0.08	0.07	0.06
80	0.56	0.39	0.30	0.24	0.20	0.17	0.15	0.14	0.12	0.11	0.10	0.08	0.07	0.07	0.06
90	0.53	0.36	0.27	0.22	0.18	0.16	0.14	0.12	0.11	0.10	0.09	0.07	0.07	0.06	0.05
100	0.50	0.34	0.25	0.20	0.17	0.14	0.13	0.11	0.10	0.09	0.08	0.07	0.06	0.06	0.05

a Computed by $100/(100 - P_T + E_T P_T)$, or $100/(100 - P_B + E_B P_B)$. Use this formula for larger percentages.

b Used to convert equivalent passenger car volumes to actual mixed traffic use reciprocal of these values to convert mixed traffic to equivalent passenger cars.

c From Table 5 or Table 6.

d Trucks and buses should not be combined in entering this table where separate consideration of buses has been established as required, because passenger car equivalents differ.

Source : Highway Capacity Manual.

TABLE 8

COMBINED EFFECT OF LANE WIDTH AND RESTRICTED LATERAL CLEARANCE ON CAPACITY AND SERVICE VOLUME OF TWO-LANE HIGHWAYS WITH UNINTERRUPTED FLOW

Distance From Traffic Lane Edge to Obstruction (FT)	Adjustment Factors W_L and W_C For Lateral Clearance and Lane Width[a]															
	Obstruction on One Side Only[b]								Obstructions on Both Sides[b]							
	12-FT Lanes		11-FT Lanes		10-FT Lanes		9-FT Lanes		12-FT Lanes		11-FT Lanes		10-FT Lanes		9-FT Lanes	
	Level B	Level E[c]	Level B	Level E[c]	Level B	Level E[c]	Level B	Level E[c]	Level B	Level E[c]	Level B	Level E[c]	Level B	Level E[c]	Level B	Level E[c]
6	1.00	1.00	0.86	0.88	0.71	0.81	0.70	0.76	1.00	1.00	0.86	0.88	0.77	0.81	0.70	0.76
4	0.96	0.97	0.83	0.85	0.74	0.79	0.68	0.74	0.92	0.94	0.79	0.83	0.71	0.76	0.65	0.71
2	0.91	0.93	0.78	0.81	0.70	0.75	0.64	0.70	0.81	0.85	0.70	0.75	0.63	0.69	0.57	0.65
0	0.85	0.88	0.73	0.77	0.66	0.71	0.60	0.66	0.70	0.76	0.60	0.67	0.54	0.62	0.49	0.58

a Adjustment W_C given for level E, capacity and W_L for level B; interpolate for others.

b Includes allowance for opposing traffic.

c Capacity.

Source : **Highway Capacity Manual.**

TABLE 9

DESIGN CAPACITIES OF 2-LANE, TWO-WAY FOR AVERAGE RUNNING SPEED OF 45—50 MPH IN VPH

Applicable for most main rural 2-lane highways in level and in rolling terrain

Terrain	Alignment: Percentage of total length of highway on which sight distance is restricted to less than 1500 feet*	Design capacity of 2-lane highway, total both directions L=width of lane and T=percentage of trucks, peak hour					
		L=12			L=11		
		0	T=10	20	0	T=10	20
		1. Design Speed 65 or 70 mph					
level	0	900	780	690	11-foot lanes not appropriate for high design speed with heavy volume.		
	20	860	750	660			
	40	800	700	620			
Rolling	20	860	615	485			
	40	800	570	450			
	60	720	510	400			
		2. Design Speed 60 mph					
Level	0	900	780	690	775	670	590
	20	810	705	625	700	605	540
	40	700	610	540	600	525	465
	60	585	510	450	500	440	390
Rolling	80	810	580	450	700	500	390
	20	700	500	390	600	430	340
	60	585	520	320	600	360	280
	80	480	340	270	410	290	230

3. Design Speed 50 mph

Highways with design speed no higher than 50 mph are not capable for providing 45—50 mph running speed except when tarffic volume is very low.

*Sight distance measured from height of eye to road surface, both vertical and horizontal alignment considered.

Note.—To obtain possible capacity, use values in table for zero sight distance restriction and multiply by 2.22 for 12-foot lanes and 2.27 for 11-foot lanes.

Tabular values are for conditions with no restrictive lateral clearance ; with clearances of less than 6 feet, edge of lane to osbtruction, or with shoulders narrower than 6 feet, multiply above values by factor from table 10.

Source : AASHO Policy.

TABLE 10

CAPACITY REDUCTION FACTOR FOR RESTRICTIVE LATERAL CLEARANCE BETWEEN PAVEMENT EDGE AND OBSTRUCTION ON SHOULDER OR FOR NARROW SHOULDERS.

(To be applied directly to design or possible capacity values)

	Capacity reduction factor due to restrictive lateral clearances			
	Obstruction on one side for		Obstruction on both sides for	
Clearance from pavement edge to obstruction feet	2-lane highway	2-lane in one direction of a 4-lane highway	2-lane highway	2-lane in one direction of a 4-Lane highway
6	1.00	1.00	1.00	1.00
5	.98	1.00	.96	.99
4	.96	.99	.92	.98
3	.93	.98	.86	.87
2	.91	.97	.81	.94
1	.88	.95	.75	.90
0	.85	.90	.70	.81

Source : AASHO Policy.

TABLE 11

ADT CAPACITY OF 2-LANES, TWO-WAY HIGHWAYS IN RURAL AREAS LIKELY RANGES FOR UNINTERRUPTED FLOW

Terrain	K= peak hour volume (two-way) as % of ADT	Capacity of 2-lane highways: two-way ADT volume in thousands when L=width of lane in feet.					
		L=12		L=11		L=10	
		Design*	Possible**	Design*	Possible**	Design*	Possible**
Level	10	9.0—6.2	20—15	7.7—5.3	18—13	6.9—4.8	15—12
	12	7.5—5.2	17—13	6.4—4.4	15.11	5.8—4.0	13—10
	15	6.0—4.1	13—10	5.1—3.5	12—9	4.6—3.2	11—8
	18	5.0—3.4	11—9	4.3—2.9	10—8	3.8—2.7	9—7
Rolling	10	8.0—3.5	20—11	6.9—3.0	18—10	6.2—2.7	15—9
	12	6.7—2.9	17—9	5.7—2.5	15—8	5.2—2.3	13—8
	15	5.3—2.3	13—7	4.6—2.0	12—7	4.1—1.8	11—6
	18	4.4—1.9	11—6	3.8—1.7	10—5	3.4—1.5	9—5

*Design capacity based on average running speed of 45—50 mph during design hour. For design capacity based on running speed of 40—45; multiply values shown by 1.3 ; for running speed of 35—40, multiply by 1.7.

**Indicative of maximum volumes possible of attainment only with high density, slow and uniform operation, and with inability to pass ; not to be considered for design.

Note.—Capacity range results from different values of T (the percentage of trucks) and the percentage of length with sight distance restriction.

In each case the higher value of the range is for T=0% and the lower value is for T=20%.

In each case for level terrain, the higher value of the range is for 0% sight restriction and the lower value is for 40%.

In each case for rolling terrain, the higher value of the range is for 40% sight restriction and the lower value is for 80%.

Source : AASHO Policy.

TABLE 12
AVERAGE SPEED OF TYPICAL TRUCK ON INDIVIDUAL GRADES ENTERING SPEED 40 MPH

Length of grade, miles	Average speed, mph				
	Grade				
	3%	4%	5%	6%	7%
0.1	37.3	36.1	35.2	34.0	32.6
0.2	34.6	31.7	29.3	25.8	21.4
0.4	28.4	23.4	18.2	14.5	11.8
0.6	24.6	18.5	14.9	12.4	10.2
0.8	21.9	16.6	13.7	11.5	9.5
1.0	20.4	15.7	13.1	11.0	9.2
1.5	18.7	14.6	12.3	10.5	8.8
2.0	17.9	14.1	11.9	10.2	8.5
3.0	17.3	13.6	11.6	10.0	8.4
4.0	16.9	13.4	11.5	9.8	8.3
5.0	16.7	13.3	11.4	9.8	8.2
6.0	16.6	13.2	11.3	9.7	8.2
Sustained speed	16.0	12.8	11.0	9.5	8.0
Distance to reach sustained speed, mile	0.78	0.50	0.37	0.28	0.24

Source : Highway Research Board Bulletin 167, page 25.

TABLE 13

PASSENGER CAR EQUIVALENTS FOR TRUCKS AT VARIOUS AVERAGE TRUCK SPEEDS AS RELATED TO PASSENGER CAR SPEEDS FOR INDIVIDUAL GRADES ON TWO-LANE ROADS

Truck speed mph	Number of passenger cars to which one truck is equivalent		
	For average passenger car running speed of 45—50 mph	For average passenger car running speed of 40—45 mph	For average passenger car running speed of 35—40 mph
35	3.0	2.7	2.5
30	5.0	4.9	3.6
25	8.6	7.6	5.0
20	13.9	11.7	8.6
15	22.6	18.7	15.8
10	40.5	32.5	25.2
5	94.5	75.0	50.0

Source : Highway Research Board Bulletin 167, page 22

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