Level of Service of Two-Lane Rural Highways with Low Design Speeds

JAN L. BOTHA, EDWARD C. SULLIVAN, AND XIAOHONG ZENG

The parameters and approach to the evaluation of levels of service for two-lane highways were changed substantially from the 1965 *Highway Capacity Manual* (HCM) to the 1985 HCM. A principal change was the introduction of percentage time delay as a parameter used to describe service quality. Another significant change was the elimination of an explicit and fully defined methodology to analyze two-lane highways with design speeds lower than 96 km/hr (60 mph). Although the 1985 HCM can be applied to highways with low design speeds, the procedure is acknowledged to be incomplete, at least as far as speed is concerned. Alternative methods are proposed to analyze the level of service for two-lane highways with design speeds of 80 km/hr (50 mph); the methods are based on relationships among speed, volume, density, and percentage time delay. The relationships were developed with the aid of the TWOPAS computer model, which is the same model used for the development of the basic relationships used in the HCM. In conclusion, a strategy for future development is proposed.

The parameters and approach to the evaluation of levels of service (LOS) for two-lane highways were changed substantially from the 1965 to the 1985 *Highway Capacity Manual* (HCM) (*1,2*). A principal change was the introduction of percentage time delay as a parameter used to describe service quality. Another significant change was the elimination of an explicit and fully defined methodology to analyze two-lane highways with design speeds lower than 96 kph (60 mph). According to AASHTO (*3*), the design speed "is the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern." Although the 1985 HCM can be applied to highways with low design speeds, the procedure is acknowledged to be incomplete, at least as far as speed is concerned.

It was also found that many highways with low design speeds, which had been evaluated using the 1965 HCM, needed to be reclassified in some cases to much higher LOS categories when the 1985 HCM procedure was applied. This discovery led to concern over the lack of consistency between the 1965 and 1985 methods when applied to low-design-speed highways and raised doubts about whether the new procedure is adequate for such facilities.

Another question was whether, for low-design-speed highways, the 1985 HCM procedure is true to the LOS concept presented in the 1985 HCM, which defines LOS as a measure describing operational conditions within a traffic stream "in terms of such factors as speed and travel time, freedom to maneuver, traffic interruptions, comfort and convenience, and safety."

J. L. Botha and X. Zeng, Department of Civil Engineering and Applied Mechanics, San Jose State University, One Washington Square, San Jose, Calif. 95192. E.C. Sullivan, Civil and Environmental Engineering Department, California Polytechnic State University, San Luis Obispo, Calif. 93407.

As a result of these changes and concerns, the California Department of Transportation (Caltrans) initiated a research project to investigate LOS for two-lane highways with design speeds lower than 96 km/hr (60 mph). The focus was on roads with design speeds of 80 km/hr (50 mph).

The first goal of the study was to review different ways in which the LOS for two-lane highways can be defined, explore the implications of these alternatives, and use these findings to scope appropriate later study. The second goal was to conduct an empirical investigation of traffic on selected two-lane highways with low design speeds in order to extend the 1985 HCM methodology.

The study included the following tasks:

- Field data characterizing traffic operations on selected sections of low-design-speed state highways in Northern California were collected.
- Two microscopic simulation models, TWOPAS and TRARR, were calibrated and compared in terms of their abilities to reproduce the traffic conditions observed in the field. Both models generally performed well, but TWOPAS matched the field data more closely and was selected as the analysis tool for this study. The results of this model comparison are documented in a separate paper (*4*).
- The existing 1985 HCM methodology and its usage were critiqued, with a discussion of alternative methodologies and desirable properties for such methodologies.
- Several methodological alternatives were evaluated in detail, including the current HCM general terrain methodology, which uses percentage time delay to define LOS for two-lane, two-way highways.

The complete study is documented in a final report (*5*). The focus of this paper is the evaluation of methodological alternatives for defining the LOS for two-lane highways with 80-km/hr (50-mph) design speeds. These alternatives are

- Percentage time delay as basic parameter,
- Density as basic parameter,
- Functional classification of road as basis,
- Limitation on LOS at low design speeds, and
- Combined percentage time delay–density as basis.

These options will be discussed in terms of possible parameters (where not already specified), possible boundary values between LOS, and their implications regarding high LOS. To discuss the advantages and shortcomings of the various options, fundamental relationships among the different variables, developed with the aid of the TWOPAS computer model, are first presented. A discussion of a possible strategy for future development follows.

FUNDAMENTAL RELATIONSHIPS FOR ROADS WITH 80-KM/HR DESIGN SPEEDS

Fundamental traffic flow relationships for highways with 80-km/hr (50-mph) design speeds were produced with the TWOPAS model, which is the same model used to produce the values used in the 1985 HCM.

The 1985 HCM values were produced using a tangent section of highway. Values for traffic variables were obtained by varying the grade. For roads with low design speeds, the horizontal alignment is often the factor determining those lower design speeds. It was therefore not considered representative of field conditions to use a tangent section of highway to produce the required values.

Instead, two actual sections of highway with design speeds of 80 km/hr (50 mph)—or, more specifically, an average highway speed (AHS) of 80 km/hr (50 mph)—were used for this purpose. The AHS is the weighted average of the design speeds within a highway section. The results should be generally applicable to other highways with 80-km/hr (50-mph) design speeds and similar geometric properties.

The two sections have geometric characteristics that correspond to roadways in rolling and level terrain, respectively. No passing was allowed on the rolling terrain, whereas passing was allowed over 6 percent of the level terrain.

Although it is realistic to impose no-passing zones on roads that are designed for passing, it is not realistic to do the opposite. Since the model produced good results with the actual road sections, where very little passing is allowed, it was considered appropriate only to impose 100 percent no-passing on the level terrain. The types of road for which relationships were produced were, therefore,

- Rolling terrain, 100 percent no-passing;
- Level terrain, 95 percent no-passing; and
- Level terrain, 100 percent no-passing.

The directional split was 50/50. Both road sections had lane widths of 3.4 m (11 ft) and shoulder widths of 0.6 m (2 ft).

The TWOPAS simulation model was used to establish the following relationships for these road sections for a vehicle population of all passenger cars: speed-volume, density-volume, density-speed, percentage time delay–volume, percentage time delay–speed, and percentage time delay–density.

The fundamental relationships are presented in Figures 1 through 6 (NPZ = no-passing zone). In each case the simulation was run for 1 hr. Each density value was calculated as flow rate divided by speed.

The following items related to the fundamental relationships are noteworthy:

- The speed-volume relationship (Figure 1) has the same overall shape as the relationship presented in the HCM, but, as expected, speeds are lower, especially in the case of rolling terrain. The model could not produce the maximum flow rates of 2,800 passenger cars per hour (pcph) used in the HCM. A high value of approximately 2,360 pcph was attained. However, this should not necessarily be viewed as the capacity of these roads, since the values obtained in the high ranges of flow were not verified in the field. The model was validated for field flow rates of 500 to 800 vehicles per hour in both directions.
- The percentage time delay–volume relationship (Figure 2) also has the same overall shape presented in the 1985 HCM. However, the fact that the percentage time delay values for rolling terrain are about 8 percent lower than for level terrain, for the same flow rate, is unexpected. This may indicate that the model does not replicate passing behavior adequately to produce accurate results for percentage time delay. Another possible explanation is that the performance of vehicles is more likely to be constrained on the rolling terrain and may therefore not catch up to the leading vehicles. Experimentation with the model showed that rolling terrain continued to yield lower percentage time delay values than level terrain, even when increased passing opportunities were provided. However, in a separate experiment on a tangent section, the percentage time delay was higher for rolling terrain. This phenomenon warrants further investigation. Because of the relative inaccuracy of the

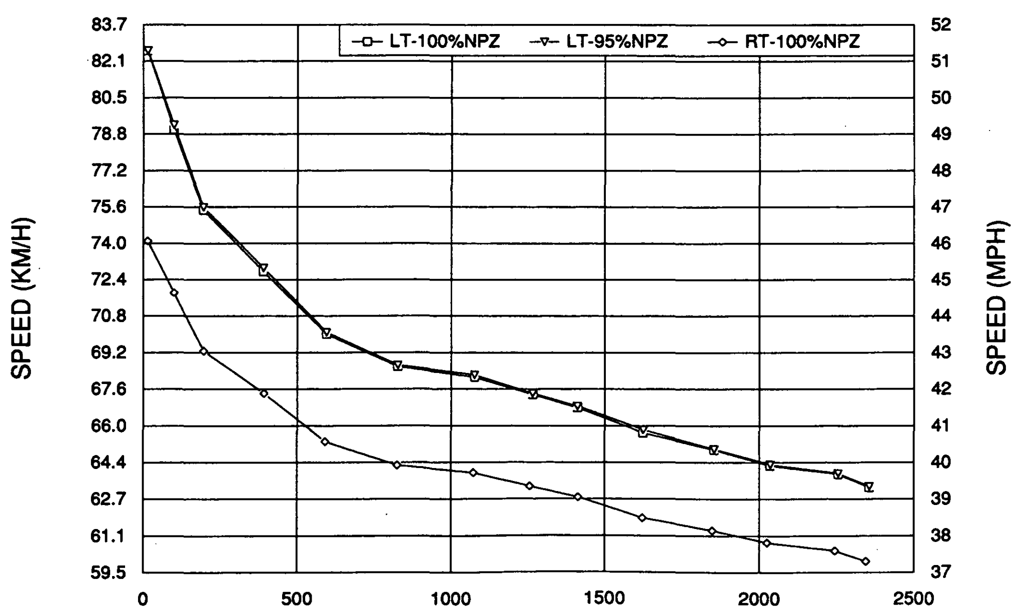

FIGURE 1 Speed-volume relationship, 80-km/hr design speed.

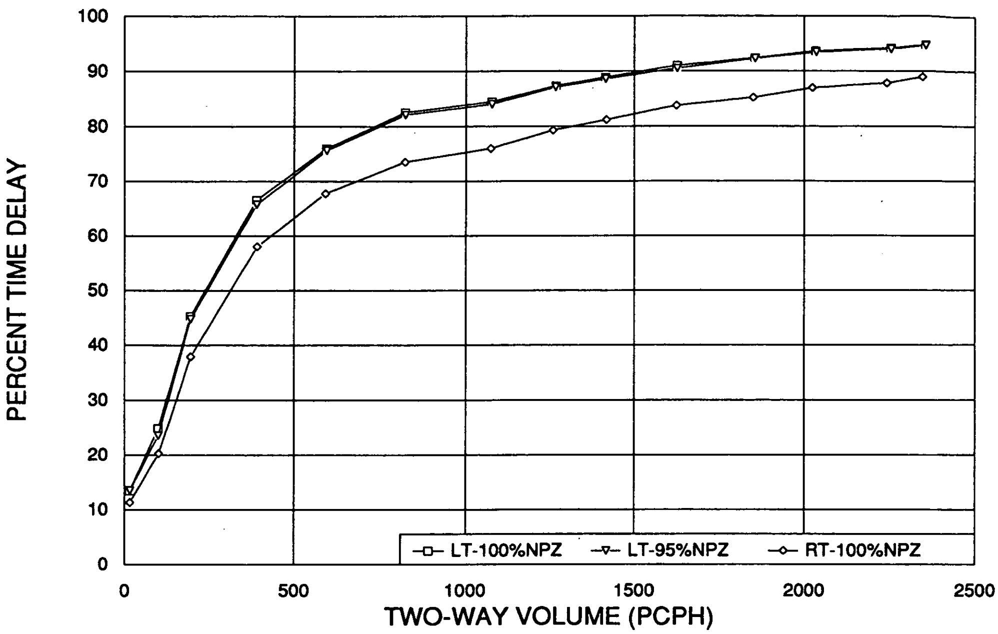

FIGURE 2 Percentage time delay–volume relationship, 80-km/hr design speed.

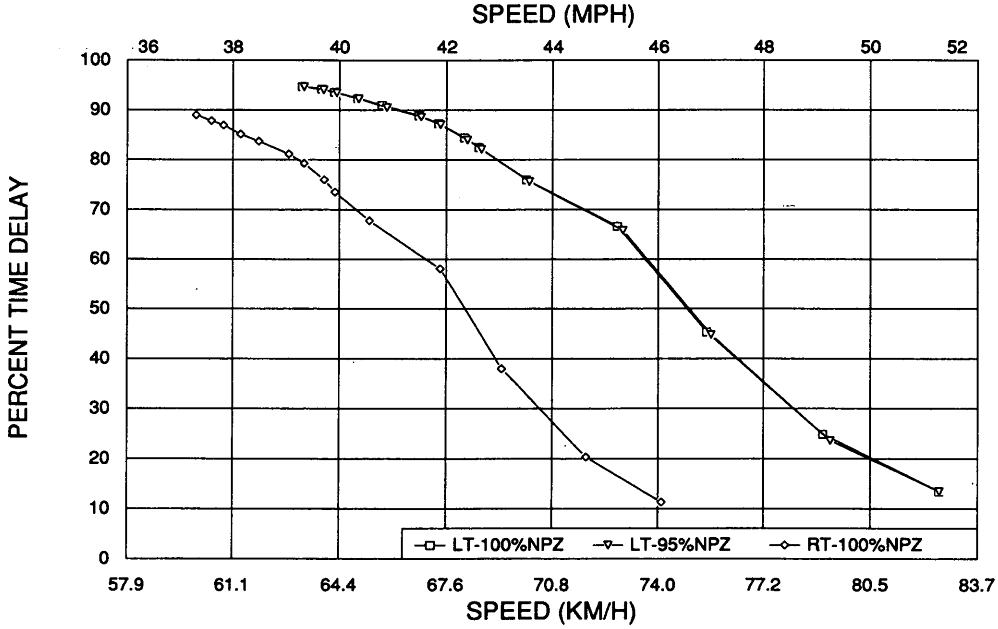

FIGURE 3 Percentage time delay–speed relationship, 80-km/hr design speed.

model predictions of percentage time delay (as found during the model calibration and validation stage) and the unexpected results discussed here, the accuracy of percentage time delay values should be questioned, even though the general shape of the percentage time delay–volume relationship appears to be reasonable.

- The percentage time delay–speed relationship (Figure 3) appears to be reasonable. It is also evident that increasing freedom to pass does not lead to substantial increases in average speed. It is noteworthy that there is a greater difference in speed due to changes in terrain than is exhibited for highways with 96-km/hr (60-mph) design speeds (*2*).

METHODOLOGICAL ALTERNATIVES FOR LOS ANALYSIS

In this section, a number of methodological alternatives for LOS analysis on roads with 80-km/hr (50-mph) design speeds are presented and discussed.

Percentage Time Delay as Basic Parameter

To be as consistent as possible with currently accepted practice, it could be argued that percentage time delay should remain the

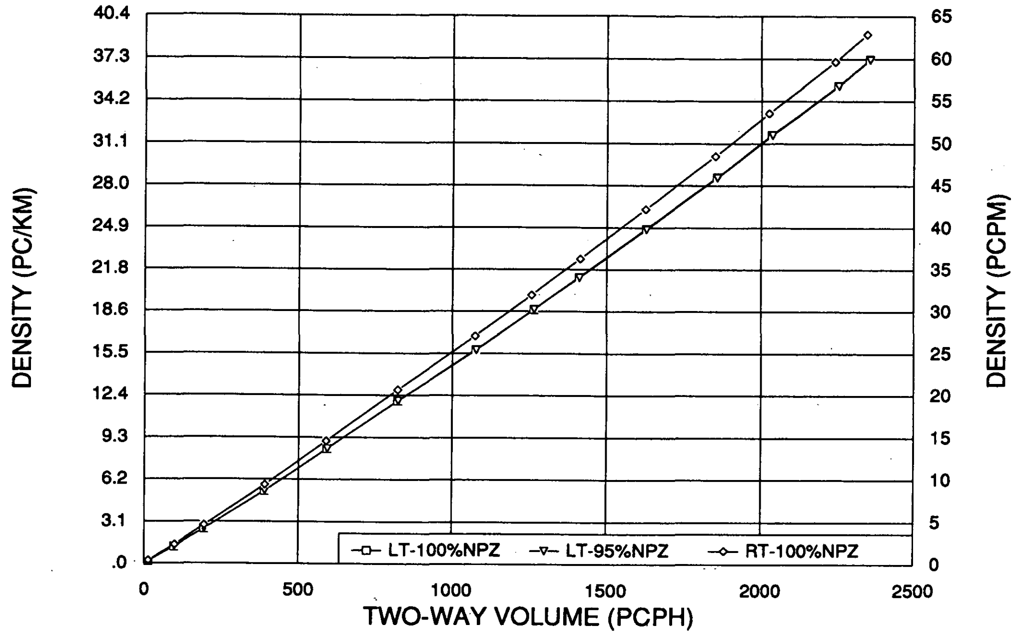

FIGURE 4 **Density-volume relationship, 80-km/hr design speed.**

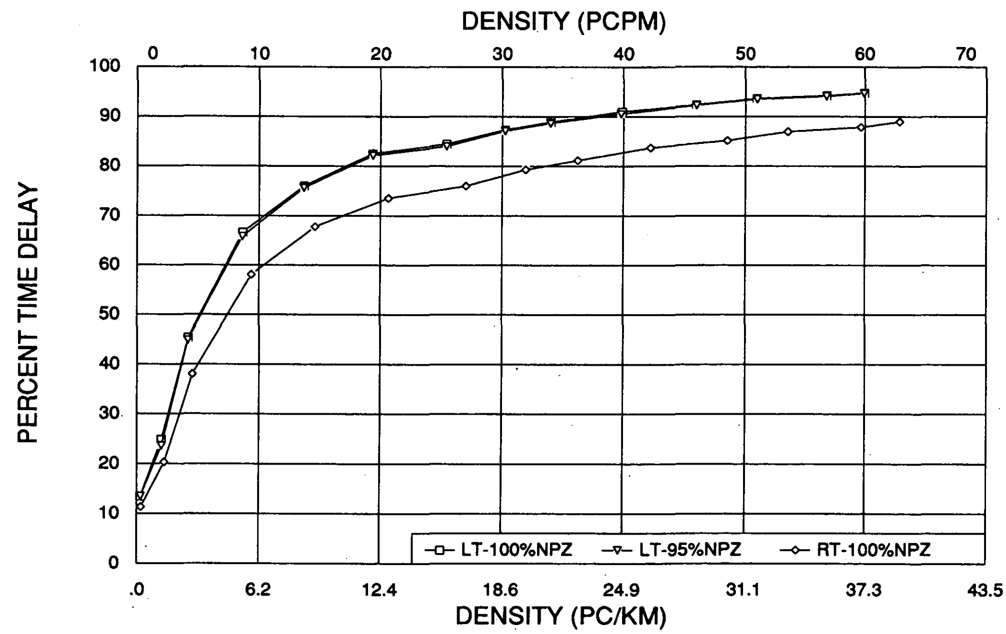

FIGURE 5 **Percentage time delay–density relationship, 80-km/hr design speed.**

primary parameter for general terrain applications for roads with low design speeds. Using the fundamental relationships depicted in Figures 2 and 3, the values in Table 1 were derived. The percentage time delay boundaries for LOS are identical to those in the 1985 HCM. The density values were calculated from the volume and speed.

It should be recalled that the accuracy of these percentage time delay values are questionable. A comparison of these results with the corresponding values in the 1985 HCM for 95 and 100 percent no-passing zones indicates that attainable flow rates for the 80-km/hr (50-mph) design speed are higher than those for the 96-km/hr (60-mph) speed. However, it is not necessarily only the 96-km/hr flow rates that should be questioned. The HCM gives LOS A service flow rates of 112 and 84 pcph, respectively, for rolling terrain with 80 and 100 percent no-passing zones. When adjusted for lane and shoulder width, the flow rates become 84 and 63 pcph, which yield densities of 0.9 and 0.7 passenger cars per kilometer (pc/km) [1.5 and 1.1 passenger cars per mile (pcpm)] at a speed of 91 km/hr (57 mph). The corresponding average headways are 42 and 52 sec. Perhaps it should be questioned whether such low

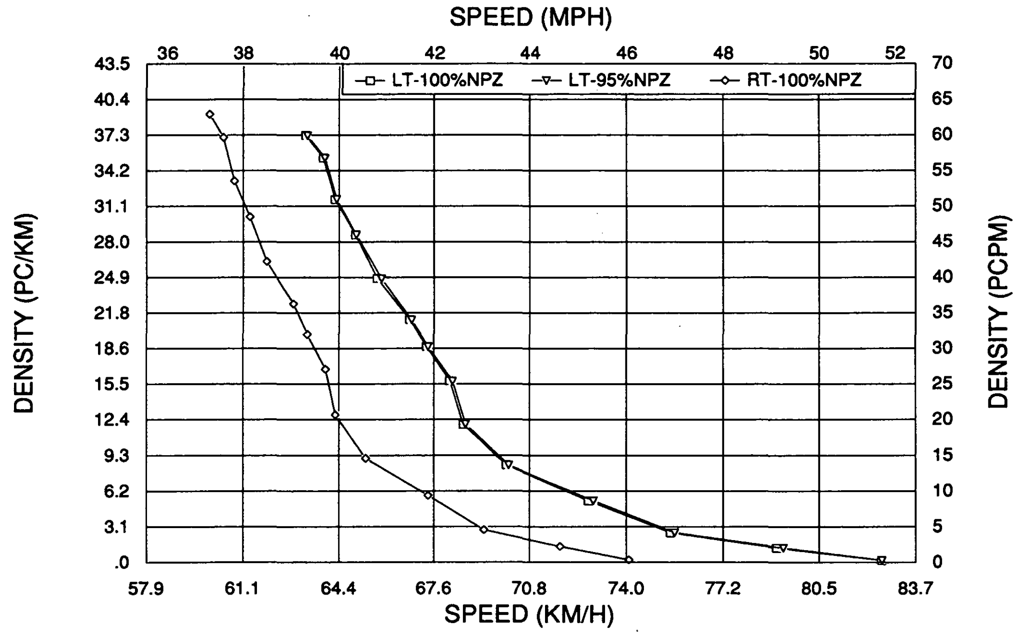

FIGURE 6 Density-speed relationship, 80-km/hr design speed.

densities and large average headways are indeed necessary to satisfy the operational standard of LOS A.

To make a completely correct comparison, an adjustment should be made to the 80-km/hr (50-mph) values to account for the narrower shoulders and lane widths. The model does not, however, explicitly take into account the lane and shoulder widths; therefore, no insights could be gained from applying the model in this respect.

Density as Basic Parameter

One of the advantages of using density as a parameter is that comparisons of LOS with other types of facilities become easier. This can be an important consideration in planning or when conducting a congestion management program. To accomplish this end, boundaries between the LOS should be established in such a way that the same quality of service is experienced at a given LOS, regardless of facility type.

The boundary values for a density-based LOS definition for two-lane highways should probably not be the same as those for multilane highways, since the operational characteristics of the facilities are very different. All else being equal, for comparable service quality, the densities on two-lane highways should be much lower than on freeways.

As a starting point, the density boundary values can be derived from the percentage time delay boundaries in the HCM. The percentage time delay boundaries and corresponding values for speeds and volumes are given in Table 2. Corresponding density values

TABLE 1 LOS Criteria[a] for 80-km/hr AHS Two-Lane Highway Sections, Percentage Time Delay

LOS	% Time Delay	Level Terrain						Rolling Terrain		
		95% No Passing Zones			100% No Passing Zones			100% No Passing Zones		
		Density (PC/KM)[d]	Speed (KM/H)[e]	Volume (PCPH)	Density (PC/KM)[d]	Speed (KM/H)[e]	Volume (PCPH)	Density (PC/KM)[d]	Speed (KM/H)[e]	Volume (PCPH)
A	≤30	≤1.7	≥77.8	130	≤1.6	≥77.8	120	≤2.1	≥70.1	150
B	≤45	≤2.7	≥75.2	200	≤2.6	≥75.0	190	≤3.9	≥68.2	265
C	≤60	≤4.6	≥73.3	340	≤4.5	≥73.1	330	≤6.4	≥66.6	430
D	≤75	≤8.3	≥69.9	580	≤8.3	≥69.9	575	≤15.3	≥63.7	975
E	>75	≤37.5	≥62.9[c]	2360[b]	≤37.5	≥62.9[c]	2360[b]	≤39.3	≥59.7[c]	2345[b]
F	100									

[a] For 3.4 m lane width and 0.6 m shoulder width
[b] Rough estimate of maximum volume
[c] Speed at maximum volume
[d] PCPM = PC/KM * 1.6
[e] MPH = KM/H * 0.625
Note: Expression q=ku may not hold exactly due to round-off in converting units.

TABLE 2 LOS Boundaries for Ideal Conditions, 1985 HCM Values

LOS	Percent Time Delay	Level Terrain			
		0% No Passing Zones			
		Speed (KM/H)[a]	V/C	Volume (PCPH)	Density (PC/KM)[b]
A	≤30	≥92.8	0.15	420	≤4.5
B	≤45	≥88.0	0.27	756	≤8.6
C	≤60	≥83.2	0.43	1204	≤14.5
D	≤75	≥80.0	0.64	1792	≤22.44
E	>75	≥72.0	1.00	2800	≤38.9
F	100	<72.0	-	-	>38.9

[a] MPH = KM/H * 0.625
[b] PCPM = PC/KM * 1.6

were calculated from speed and volume. Subsequently, these boundary values for density were used to find values for volume (from Figure 4) and percentage time delay (from Figure 5) for the 80-km/hr (50-mph) facilities. Speed values were calculated from volume and density. The results are presented in Table 3.

The volumes produced by this method for the various LOS are probably too high. This may suggest the need for an adjustment of the boundary values. It should be noted that the percentage time delay boundary values used in the 1985 HCM can be considered somewhat arbitrary since the categories coincide with 15 percent increments. Perhaps these boundaries could be selected so that the same operational quality of service is rendered as would be rendered by multilane facilities at the same LOS but at different values of density. A suggested revision in these boundaries is discussed later with the combined percentage time delay–density option.

Functional Classification of Road as Basis

Another option is to first define the function of the road (i.e., whether the road is to serve as an arterial, collector, local access, etc.). Arterials usually have higher design speeds than local access roads. The design speed reflects what is considered to be a safe comfortable speed consistent with the use and objectives of the facility. If vehicles operate at or near the design speed of the facility, then LOS A can be attained, whatever that design speed may be. Reductions in LOS can then be measured in terms of decreases in speed. If this notion is carried further, the reduction in speed could be equated with delay, which can be converted directly into economic impacts.

Boundary values could be established in terms of the percentage delay values. It appears that 5 percent increments in delay correspond approximately to 2 percent decreases in operating speed. Using 64 km/hr (40 mph) as the speed at capacity for facilities with 80-km/hr (50-mph) design speeds (which is close to the speed at the maximum flow rate produced by the model for level terrain), then LOS A could be defined as more than 77 km/hr (48 mph) and other LOS in equal descending increments. The corresponding values for volumes and percentage time delay were derived with the aid of Figures 1 and 3. The corresponding densities were calculated from the volumes and speeds. The results are given in Table 4.

Table 4 indicates that LOS A cannot be attained for rolling terrain. It should be noted that these boundaries are somewhat arbitrary (in the same way as the percentage time delay boundaries in the HCM) and that it would have been better to determine the speed at LOS E for a road with 0 percent no-passing zones. However, the 64-km/hr (40-mph) value is probably very close to the value that would be obtained for a road with 0 percent no-passing, since at flow rates approaching capacity, there are probably few passing opportunities.

Limitation on LOS for Low Design Speeds

Several options can be considered if high LOS are going to be limited for low design speed highways. One proposal is to limit LOS in the same way that it is limited for ramps in the 1985 HCM (Table 5-5 in the HCM). According to this proposal, the attainable LOS would be as follows:

TABLE 3 LOS Criteria[a] for 80-km/hr AHS Two-Lane Highway Sections, Densities Corresponding to HCM Percentage Time Delay

LOS	Density (PC/KM)[e]	Level Terrain						Rolling Terrain		
		95% No Passing Zones			100% No Passing Zones			100% No Passing Zones		
		% Time Delay	Speed (KM/H)[e]	Volume (PCPH)	% Time Delay	Speed (KM/H)[e]	Volume (PCPH)	% Time Delay	Speed (KM/H)[e]	Volume (PCPH)
A	≤4.4	≤58	≥73.1	320	≤59	≥73.1	320	≤48	≥68.6	300
B	≤8.8	≤76	≥69.8	610	≤76	≥69.8	610	≤67	≥65.1	570
C	≤14.4	≤83	≥68.2	980	≤84	≥68.2	980	≤74	≥63.7	915
D	≤22.5	≤89	≥66.1	1485	≤90	≥66.1	1485	≤81	≥62.4	1405
E	≤38.8	≤95[d]	≥62.9[c]	2360[b]	≤95[d]	≥62.9[c]	2360[b]	≤90	≥59.7[c]	2345[b]
F	>38.8									

[a] For 3.4 m lane width and 0.6 m shoulder width
[b] Rough estimate of maximum volume
[c] Speed at maximum volume
[d] Approximate
[e] PCPM = PC/KM * 1.6
[f] MPH = KM/H * 0.625

TABLE 4 LOS Criteria[a] for 80-km/hr AHS Two-Lane Highway Sections, Speed

LOS	Speed (KM/H)[d]	Level Terrain						Rolling Terrain		
		95% No Passing Zones			100% No Passing Zones			100% No Passing Zones		
		Density (PC/KM)[e]	% Time Delay	Volume (PCPH)	Density (PC/KM)[e]	% Time Delay	Volume (PCPH)	Density (PC/KM)[e]	% Time Delay	Volume (PCPH)
A	≥76.8	≤1.9	≤35	150	≤1.9	≤35	150	-	-	-
B	≥73.6	≤4.2	≤57	310	≤4.1	≤57	300	≤0.3	≤12	20
C	≥70.4	≤7.8	≤73	545	≤7.6	≤73	535	≤2.0	≤27	140
D	≥67.2	≤18.1	≤86	1220	≤17.9	≤86	1205	≤5.5	≤56	370
E	≥64.0	≤37.5[c]	≤93	2360[b]	≤37.5[c]	≤93	2360[b]	≤39.3[c]	≤73	2345[b]
F	<64.0									

[a] For 3.4 m lane width and 0.6 m shoulder width
[b] Rough estimate of maximum volume
[c] Density based on maximum volume and maximum speed
[d] MPH = KM/H * 0.625
[e] PCPM = PC/KM * 1.6

Design Speed [km/hr (mph)]	*Attainable LOS*
81 (51) or greater	A through F
65 to 80 (41 to 50)	B through F
49 to 64 (31 to 40)	C through F
33 to 48 (21 to 30)	D through F
32 (20) or less	E and F

Using these criteria, any of the values presented in Tables 1, 3, or 4 can be used for highways with 80-km/hr (50-mph) design speeds, but LOS A cannot be achieved.

It has also been proposed that both a percentage time delay and a speed criterion should be met together to attain a given LOS. For this purpose, it has been proposed to use the percentage time delay boundary values for general terrain segments and the upgrade speed criteria used in the 1985 HCM. The results of this approach are presented in Table 5. Volumes and densities corresponding to the percentage time delay values were obtained from Figures 2 and 5, respectively. Figure 3 was used to determine whether the speed requirement was met. Although the speed requirement was not met for rolling terrain at LOS D, it was considered sufficiently close to warrant inclusion in the table.

A similar exercise was carried out using the density boundaries presented in Table 3, in conjunction with speed; the volumes were obtained from Figure 4. Figure 6 was used to check whether the speed requirement was met; the results are presented in Table 6. As noted previously, the volumes in this table are probably too high and the LOS E density boundary value is unattainable, suggesting that adjustments are needed if density is to be used as a LOS criterion.

Combined Percentage Time Delay–Density as Basis

Because of apparent problems with the accuracy of the percentage time delay values in the model and the problem of determining appropriate density boundary values, an approach was devised whereby the advantages of using percentage time delay were retained without having to deal with the problem of inaccurate values.

When the HCM calculation procedures are applied, the focus is usually on the flow rate or volume-capacity (*V/C*) ratio. The percentage time delay is not usually relevant at this time, except insofar as the percentage time delay boundary values establish the *V/C*

TABLE 5 LOS Criteria[a] for 80-km/hr AHS Two-Lane Highway Sections, Time Delay and Speed

LOS	% Time Delay	Speed (KM/H)[c]	Level Terrain				Rolling Terrain	
			95% No Passing Zones		100% No Passing Zones		100% No Passing Zones	
			Density (PC/KM)[d]	Volume (PCPH)	Density (PC/KM)[d]	Volume (PCPH)	Density (PC/KM)[d]	Volume (PCPH)
A	≤30	≥88	-	-	-	-	-	-
B	≤45	≥80	-	-	-	-	-	-
C	≤60	≥72	≤4.6	340	≤4.6	330	-	-
D	≤75	≥64	≤8.3	580	≤8.2	575	≤15.3	975
E	>75	≥40	≤37.5	2360[b]	≤37.5	2360[b]	≤39.3	2345[b]
F	100	≤40						

[a] For 3.4 m lane width and 0.6 m shoulder width
[b] Rough estimate of maximum volume
[c] MPH = KM/H * 0.625
[d] PCPM = PC/KM * 1.6

TABLE 6 LOS Criteria[a] for 80-km/hr AHS Two-Lane Highway Sections, Density and Speed

LOS	Density (PC/KM)[d]	Speed (KM/H)[e]	Level Terrain				Rolling Terrain	
			95% No Passing Zones		100% No Passing Zones		100% No Passing Zones	
			% Time Delay	Volume (PCPH)	% Time Delay	Volume (PCPH)	% Time Delay	Volume (PCPH)
A	≤4.4	≥88	-	-	-	-	-	-
B	≤8.8	≥80	-	-	-	-	-	-
C	≤14.4	≥72	-	-	-	-	-	-
D	≤22.5	≥64	≤89	1485	≤90	1485	-	-
E	≤38.8	≥40	≤95[c]	2360[b]	≤95[c]	2360[b]	≤90	2345[b]
F	>38.8	<40						

[a] For 3.4 m lane width and 0.6 m shoulder width
[b] Rough estimate of maximum volume
[c] Approximate
[d] PCPM = PC/KM * 1.6
[e] MPH = KM/H * 0.625

values at the various LOS. It stands to reason then that the understanding gained through using percentage time delay can be used to determine LOS boundary values in terms of density, which can then be used for purposes of calculation and field measurement. Density is easier to calculate or obtain from field measurements, and it is also more readily convertible into speed and economic impact measures. Since the LOS boundaries in terms of percentage time delay, as currently stated in the HCM, are rarely if ever used directly, the absence of percentage time delay in the calculation procedures should not detract from the understanding gained through the continued use of percentage time delay.

With reference to Figures 2 and 5, it can be seen that the sensitivity of percentage time delay is far less at the higher ranges of volume and density than at the lower ranges. If LOS boundaries are to be defined in terms of the deterioration of service quality as volume and density increase, then smaller increments of volume and density would cause more change in LOS at the lower levels than at the higher levels. Density values corresponding to the "bending points" on the percentage time delay–density relationship, in Figure 5, are presented in Table 7. It is recognized that the boundary values are somewhat influenced by the shape of the curve as well as by the specific conditions simulated. The density boundary for LOS E was directly obtained from Table 2.

Corresponding values for percentage time delay and volume were obtained from Figures 5 and 4, respectively. Speed was calculated from density and volume. The results are also presented in Table 7.

The volumes obtained through this procedure appear to be reasonable. It is also noteworthy that the values for percentage time delay at the LOS boundaries are very close to those used in the 1985 HCM. This approach is therefore consistent to a degree with the percentage time delay–based LOS definition used in the 1985 HCM (reflected in Table 1 of this paper).

STRATEGY FOR FUTURE DEVELOPMENT

Given the widely divergent views held by the parties involved, it will take some time for consensus to be achieved on how to improve

TABLE 7 LOS Criteria[a] for 80-km/hr AHS Two-Lane Sections, Densities and HCM Percentage Time Delay Values

LOS	Density (PC/KM)[e]	Level Terrain						Rolling Terrain		
		95% No Passing Zones			100% No Passing Zones			100% No Passing Zones		
		% Time Delay	Speed (KM/H)[f]	Volume (PCPH)	% Time Delay	Speed (KM/H)[f]	Volume (PCPH)	% Time Delay	Speed (KM/H)[f]	Volume (PCPH)
A	≤1.9	≤33	≥77.3	145	≤34	≥77.3	145	≤26	≥69.3	130
B	≤3.1	≤49	≥73.6	230	≤49	≥73.6	230	≤40	≥65.6	205
C	≤5.6	≤66	≥72.0	405	≤67	≥72.0	405	≤57	≥67.5	380
D	≤12.5	≤82	≥68.0	850	≤83	≥68.0	850	≤73	≥64.0	800
E	≤38.8	≤95[d]	≥62.9[c]	2360[b]	≤95[d]	≥62.9[c]	2360[b]	≤90	≥59.7[c]	2345[b]
F	>38.8									

[a] For 3.4 m lane width and 0.6 m shoulder width
[b] Rough estimate of maximum volume
[c] Speed at maximum volume
[d] Approximate
[e] PCPM = PCPK * 1.6
[f] MPH = KPH * 0.625

the capacity and LOS analysis methodology for two-lane highways with low design speeds. In the meantime, the need remains for a fully defined procedure for analyzing the capacities and LOS for these facilities. The obvious solution would be to proceed with percentage time delay as the primary parameter until the necessary decisions can be made in forums such as TRB's Committee on Highway Capacity and Quality of Service. However, in view of the inaccuracies and other problems experienced with the percentage time delay parameter, another course of action should be considered.

A course of action that may be pursued immediately, which does not deviate a great deal from using percentage time delay as the primary parameter, is to use the procedure presented in Table 7. This method retains the principle of percentage time delay while not relying specifically on the accuracy of the simulated percentage time delay values. The method is somewhat different from the 1985 HCM method and may therefore prompt the question of whether it is appropriate to use two different methods for different design speeds. However, there does appear to be a viewpoint that the LOS for low-design-speed roads could be analyzed differently, namely, by limiting high LOS at low design speeds for other facility types. The option of having to meet two criteria to attain a given LOS, such as percentage time delay and speed or percentage time delay and density, was regarded favorably by several of the consultants who reviewed the issue paper developed during this study (*6*).

Consensus should also be reached in the medium term on whether to limit the high LOS at low design speeds. In the long term, it is essential to consider system effects since, in California for instance, the 1985 HCM is used by law for congestion management purposes. The parameters and analysis procedures should therefore take cognizance of systemwide decisions. This will be a departure from the existing framework of the HCM, in which the different types of facilities are treated independently without reference to system considerations. The questions of whether to use density as the primary parameter, the effect of the functional classification of the facility, consistency of analysis (i.e., general terrain segment versus specific grade analysis), and single-direction-based analysis should all be addressed further in future research.

It should be noted that the analysis options described in this paper are by no means the only feasible options. The fundamental relationships shown in Figures 1 through 6 can be used to test other feasible options, boundary values, etc. These results are presented in the spirit of encouraging additional exploration into methodological alternatives and constructive debate over the best direction for further evolution of the HCM.

ACKNOWLEDGMENTS

The research was funded by Caltrans and the Department of Civil Engineering and Applied Mechanics, San Jose State University. The authors would like to thank Fred Rooney, Rick Knapp, Pat Secoy, Guy Luther, Ken DeCrescenzo and Paul Vonada, all of Caltrans, for their help throughout the project. A special word of thanks is also due to Doug Harwood of the Midwest Research Institute for his interest and help with the implementation of the TWOPAS model. In addition, the authors gratefully acknowledge the assistance of Robert Layton of Oregon State University, John McLean of the Australian Road Research Board, and John Morrall of the University of Calgary for their valuable service as consultants to this project.

REFERENCES

1. *Special Report 87: Highway Capacity Manual.* HRB, National Research Council, Washington, D.C., 1965.
2. *Special Report 209: Highway Capacity Manual.* TRB, National Research Council, Washington, D.C., 1985.
3. *A Policy on Geometric Design of Highways and Streets.* AASHTO, Washington, D.C., 1990.
4. Botha, J. L., X. Zeng, and E. C. Sullivan. Comparison of Performance of TWOPAS and TRARR Models When Simulating Traffic on Two-Lane Highways with Low Design Speeds. In *Transportation Research Record 1398,* TRB, National Research Council, Washington, D.C., 1993.
5. Botha, J. L., E. C. Sullivan, and X. Zeng. *Level of Service of Two-Lane Highways With Design Speeds Less than 60 mph.* Final Report, Vols. 1 and 2. California Department of Transportation, Sacramento, June 1993.
6. Botha, J. L., and E. C. Sullivan. *Level of Service Concept for Two-Lane Roads Revisited.* Working Paper. San Jose State University; California Polytechnic University, San Luis Obispo, May 1992.

Publication of this paper sponsored by Committee on Highway Capacity and Quality of Service.