Measuring Level of Service of Two-Lane Highways by Overtakings

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A level-of-service concept that is based on the supply of passing opportunities and demand for overtaking is presented. A driver is hypothesized to perceive level of service on a two-lane highway on the basis of his or her ability to overtake slower vehicles. The demand for overtaking is a function of volume and the speed distribution characteristics of the traffic stream. The supply of opportunities for vehicles to overtake is a function of the number of gaps adequate for safe overtaking maneuvers in the opposing traffic stream and the percentage of passing zones of the highway section under consideration. The relationship between supply and demand for overtaking forms the basis of a level-of-service measure defined by the overtaking ratio. The overtaking ratio is defined as the ratio of the achieved number of overtakings on a two-lane highway to the desired number (or to the total number of overtakings possible on a two-lane highway with continuous passing lanes and with vertical and horizontal geometry similar to the two-lane highway). Various level-of-service measures and procedures including the method of the 1965 and 1985 *Highway Capacity Manuals*, the percent-following count generated by simulation modeling, and the overtaking ratio, are compared. The overtaking ratio decreased much faster than the percentage of time delayed increased for those ranges of level of service to which motorists are most sensitive on two-lane highways. The overtaking ratio is suggested as another dimension of level of service to be considered for two-lane highways in addition to existing measures such as percentage of time delayed, capacity use, and speed.

Although many level-of-service measures for two-lane highways have been developed, international agreement on a specific measure has not yet been reached. Further, the two-lane highway problem has not been clearly formulated, according to the 1987 World Road Congress (*1*). However, the lack of consensus is not surprising, given the complex nature of traffic flow on two-lane highways.

Basic to this level-of-service concept is the premise that the problem can be broken into supply and demand components of the ability to overtake. The supply side is dependent on fixed roadway geometric characteristics, such as passing sight distance, barrier lines, and auxiliary lanes. The supply side is tempered according to the distribution of gaps, adequate for overtaking, between vehicles in the oncoming lane. Demand, on the other hand, is highly variable, being dependent on lane, speed, speed variation, and vehicle and driver characteristics. Although the concept of overtaking as a measure of level of service has not been exploited to date, it is not new and in fact predates the 1950 *Highway Capacity Manual* (HCM) (*2*). Overtaking is being reintroduced here as one of the measures of level of service for two-lane highways.

EVOLUTION OF LEVEL OF SERVICE

The evolution of level-of-service measures in Canada and the United States can be traced through the three HCMs (*2–4*). The 1950 HCM (*2*) represented the consolidation of three decades of research, some of which is still pertinent to two-lane highways today. Although the 1950 HCM (*2*) stated that the most significant index of traffic congestion for different volumes was overall speed, it also recognized passing opportunities as an index of congestion. The 1950 HCM (*2*) defined the passing opportunities index as follows:

> The availability of opportunities for vehicles to overtake and pass slower vehicles in the same direction. The ratio of the number of passings required per mile of highway for drivers to maintain their desired speeds, to the number of passings that they can eventually perform, is a measure of traffic congestion.

Figure 1 shows a comparison of the desired number of passings with the actual number of passings. McLean (*5*) has traced the origins of this concept to a 1923 report that recognized the deleterious effect of slow-moving vehicles on two-lane traffic operations. McLean observed that two-lane capacity research might have followed a much different course if attempts had been made to fully investigate the effects of slow-moving vehicles instead of concentrating on speed as the measure of traffic performance.

The 1965 HCM (*3*) provided more flexibility than the 1950 HCM (*2*) by introducing a range of levels of service and corresponding service volumes. Six levels of service, A to F, were defined. Operating speed was the main descriptor in the 1965 HCM (*3*), with Level of Service E corresponding to capacity conditions. In addition to speed's being an inadequate level-of-service indicator, the changing relationship between operating speed and the volume-to-capacity ratio (which defined level-of-service regions) was identified as a weakness of the manual.

Level of service on two-lane highways in the 1985 HCM (*4*) is described by three parameters: (a) average travel speed, (b) percentage of time delayed, and (c) capacity use. Percentage of time delayed, the primary measure of service, was defined as the average percentage of time that all vehicles are delayed while traveling in platoons because of their inability to pass. The 1985 HCM (*4*) introduced a quality-of-service criterion that is more sensitive than speed variations in traffic flow and more accurately reflects the perceived freedom to maneuver than the measures of the 1965 HCM (*3*). The concept of percentage of time delayed as a level-of-service measure has usefully underscored the importance of providing passing opportunities on two-lane highways.

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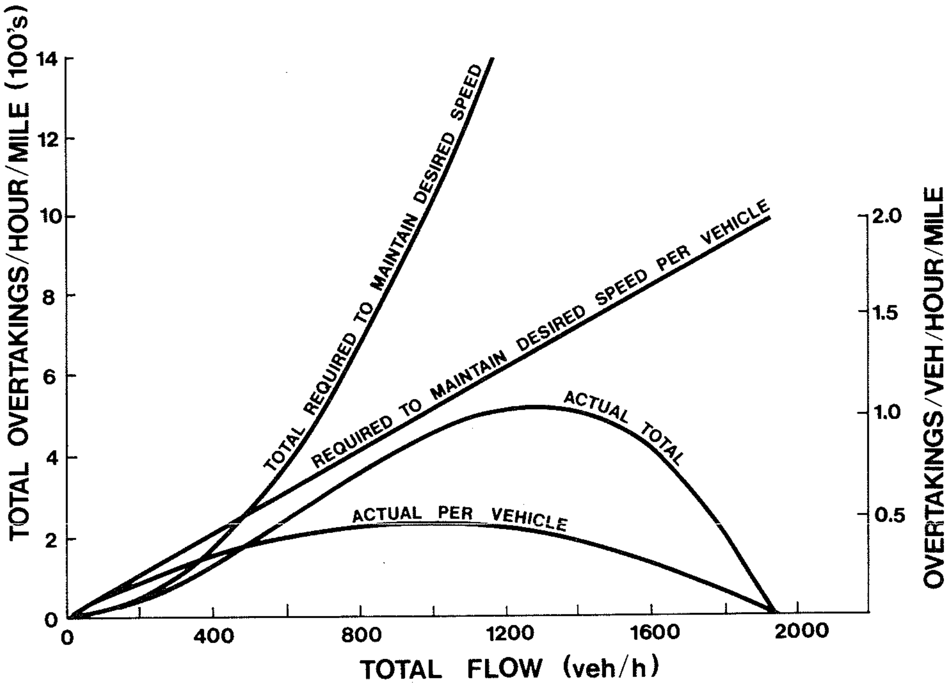

FIGURE 1 Comparison of actual numbers of passings performed with numbers required for vehicles to maintain free speeds (*2*).

SUPPLY AND DEMAND FOR OVERTAKING AS A MEASURE OF LEVEL OF SERVICE

The concept of supply and demand functions for highways with different passing opportunities, as defined by Werner and Morrall (*6*) as part of the unified traffic flow theory model, is shown in Figure 2. The model hypothesizes that drivers perceive level of service as the ability or inability to pass slower vehicles and that this ability to overtake is dependent on the supply of sufficient gaps for passing in the opposing stream, provided sufficient sight distance is available as dictated by road geometry.

The demand for overtaking is a function of the characteristics of drivers and vehicles. Demand also varies in time and space. For example, automobiles, recreational vehicles, and trucks generally travel close to the same speed on level terrain. They do not compete or interact with each other as much as do vehicles in mountainous terrain, where performance can differ considerably and slower vehicles, such as heavy trucks, impede faster ones. Although these interactions have not been completely quantified, the following observations have been made:

- As vertical road geometry becomes more severe (i.e., includes steeper grades), the demand for overtaking increases;
- As traffic composition changes from a predominance of automobiles to include significant volumes of recreational vehicles and heavy trucks, the demand for overtaking increases; and
- As tne number and frequency of no-passing zones increase, less overtaking is achieved and vehicles are constrained to travel in platoons.

The supply of overtaking opportunities is a function of the percentage of highway length with no-passing zones and the distribution of gaps in the opposing traffic stream adequate for overtaking. Passing zones are determined by horizontal and vertical geometry and are also limited in those areas where the highway has been barrier lined to restrict passing and to channel left-turn bays at intersections. The combination of passing zones and gaps results in overtaking opportunities' being discontinuous and distributed along the highway in time and space.

Ensured overtaking opportunities can, however, be provided by passing lanes. Passing lanes, in effect, guarantee a continuous, uninterrupted supply of overtaking opportunities similar to that offered by a continuous auxiliary lane or a four-lane highway.

The concept of the overtaking ratio is introduced as a further measure of level of service. The overtaking ratio is defined as the ratio of the number of overtakings achieved on a section of two-lane highway of given horizontal and vertical alignment and barrier-line marking to the number of overtakings on a two-lane highway with continuous passing lanes of similar horizontal and vertical alignment. The overtaking ratio is also defined as follows:

$$\text{Overtaking ratio} = \text{AO}/\text{DO} \tag{1}$$

where

AO = achieved overtakings (the total number of overtakings for a given two-lane highway); and
DO = desired overtakings (the total number of overtakings for a two-lane highway with continuous passing

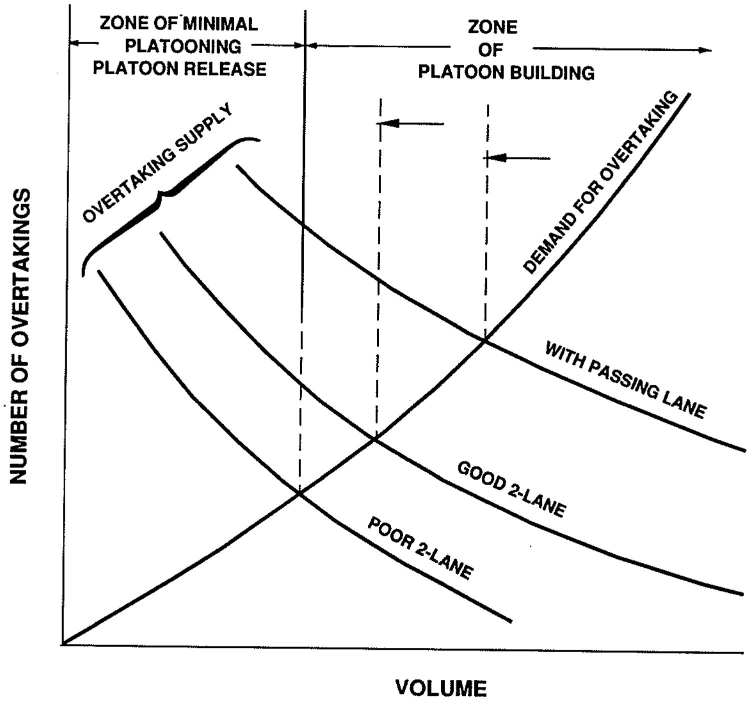

FIGURE 2 Supply and demand functions (*8*) for highways with different passing opportunities.

lanes with vertical and horizontal geometry similar to the given two-lane highway).

Driver attitude surveys on the arterial system of the mountain national parks in Canada, where drivers have had the opportunity to experience ensured passing opportunities on a two-lane highway, have indicated a strong preference for more passing lanes as a means for enhancing their driving experience.

DETERMINATION OF THE OVERTAKING RATIO

A traffic simulation model was used to investigate the effect of road geometry and traffic characteristics on overtaking and percent following. The Traffic on Rural Roads (TRARR) simulation model developed at the Australian Road Research Board (*7*) was chosen for this project on the basis of its user friendliness and its capability to handle a wide range of road traffic and driver characteristics. The TRARR model requires four data input files: a traffic file, a vehicles file, a road file, and an observing file. The traffic file specifies volume, traffic composition, directional split, and desired speeds. The vehicles file specifies a large number of driver and vehicle characteristics, such as acceleration, following, and overtaking behavior. The road file contains information such as grades, barrier lines, sight distance, a speed index based on curvature, and auxiliary lanes. The observation file specifies the type of output required and the location of observation points along the road. Model output includes speed distributions, overtakings, the percentage of time spent following, and bunch size distributions. The TRARR model has been calibrated to driver and vehicle characteristics typical to Western Canada, and model outputs such as speed, number of platoons, percentage of time spent following, and overtakings were validated with field measurements (*8*).

The basic input road file used for the analysis was an 18.1-mi section of the Trans-Canada Highway in Yoho National Park. The existing file for the road, which is a two-lane highway with some passing zones in rolling terrain, was modified as indicated in Table 1 to emulate a range of two- and four-lane highways in level, rolling, and mountainous terrain. In total, three road files were created, as presented in Table 1: a two-lane road, of which 51.6 percent allows no passing; a two-lane road with no passing on 47.2 percent, but 28.1 percent (5.1 mi) of its length with passing lanes; and a two-lane highway with continuous passing lanes in both directions (in effect, a four-lane highway). These examples were selected because they were representative of high-type design standards found on the primary highway system of Western Canada. Also presented in Table 1 is the traffic composition used: all cars, mixed traffic, and mixed traffic with a high percentage of heavy vehicles. Desired mean speeds used in the model input were based on field-measured mean free speeds for each vehicle class. Speeds were reduced according to increasing volume on the basis of an observed speed-volume relationship for the Trans-Canada Highway. All computer simulation runs were performed with a 50-50 directional split of traffic.

OVERTAKING RATIO RELATIONSHIPS

The simulation model was used to generate a series of relationships of overtaking ratio versus volume to determine the effect of the percentage of no-passing zones, traffic compo-

TABLE 1 SIMULATION MODEL INPUT

Road Files

Lanes	Terrain	% No. Passing Zones
2	Level	0
2	Rolling	51.6
2	Mountainous	51.6
2+ passing lanes *	Level	47.2
2+ passing lanes *	Rolling	47.2
2+ passing lanes *	Mountainous	47.2
4	Level	0
4	Rolling	0
4	Mountainous	0

*28.1% Passing Lanes (5.1 miles)

Traffic Files

Vehicle Mix	Cars & Light Trucks	Cars With Trailers	Recreational Vehicles & Single Unit	Heavy Trucks
All cars	100%	-	-	-
Mixed Traffic	80%	8%	7%	5%
Mixed Heavy Traffic	60%	10%	10%	20%

sition, and terrain on level of service. Figure 3 shows the effect of traffic composition on the overtaking ratio. The effect of more trucks and recreational vehicles in the traffic stream reduces the ratio, especially at the lower-volume ranges between 100 and 600 veh/hr, and hence lowers the level of service. Also shown are level-of-service boundaries as determined by the 1985 HCM's (*4*) two-lane analysis procedures.

Figure 4 shows the effects of the percentage of no-passing zones and ensured passing opportunities on the ratio. The percentages of no-passing zones for the two-lane case and the two-lane-with-passing-lanes case are 51.6 and 47.2 percent, respectively. The ideal case includes no no-passing zones (0 percent). The passing-lane case has a higher ratio of achieved to desired overtakings, indicating that the effect of passing lanes is much greater than that of 0-percent no-passing zones. This finding demonstrates that the percentage of no-passing zones alone cannot be used to measure the impact of passing lanes on level of service. The greatest benefits in terms of overtakings appear to be in the 200- to 800-veh/hr range. This volume range is also the one in which drivers on two-lane highways are most sensitive to changes in level of service.

The effect of no-passing zones on the heavy-vehicle mix in level terrain is shown in Figure 5. This figure shows a pattern similar to that of the previous figure, with the greatest benefits in the 400- to 1,200-veh/hr range.

Figure 6 shows the effects of terrain on a heavy-vehicle mix. One finding from the simulation runs was that the overtaking ratio is sensitive to whether the no-passing zones are on level sections or on grades. In this case, the curves for rolling terrain fell above those for level terrain, contrary to expectations. A substantial proportion of the passing zones and passing lanes were on grades, allowing many overtakings. An all-car simulation indicated that terrain had little effect on the overtaking ratio. However, the impact of passing lanes on the overtaking ratio has much more effect in rolling or mountainous terrain, as shown in Figure 6.

COMPARISON WITH THE 1985 HCM (*4*)

The percentage of time delayed versus two-lane volume is shown in Figure 7 for the simulated model and the 1985 HCM (*4*). Also shown is the overtaking ratio. Table 2 presents a

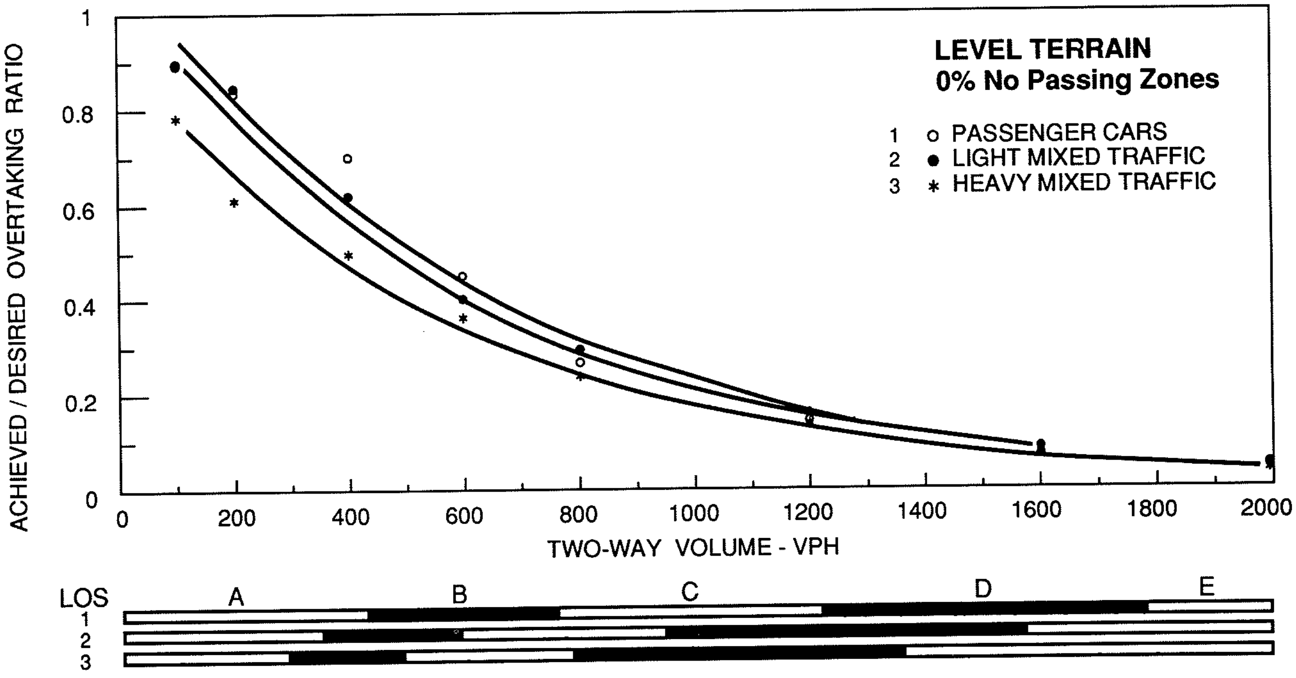

FIGURE 3 Effect of traffic composition on the overtaking ratio.

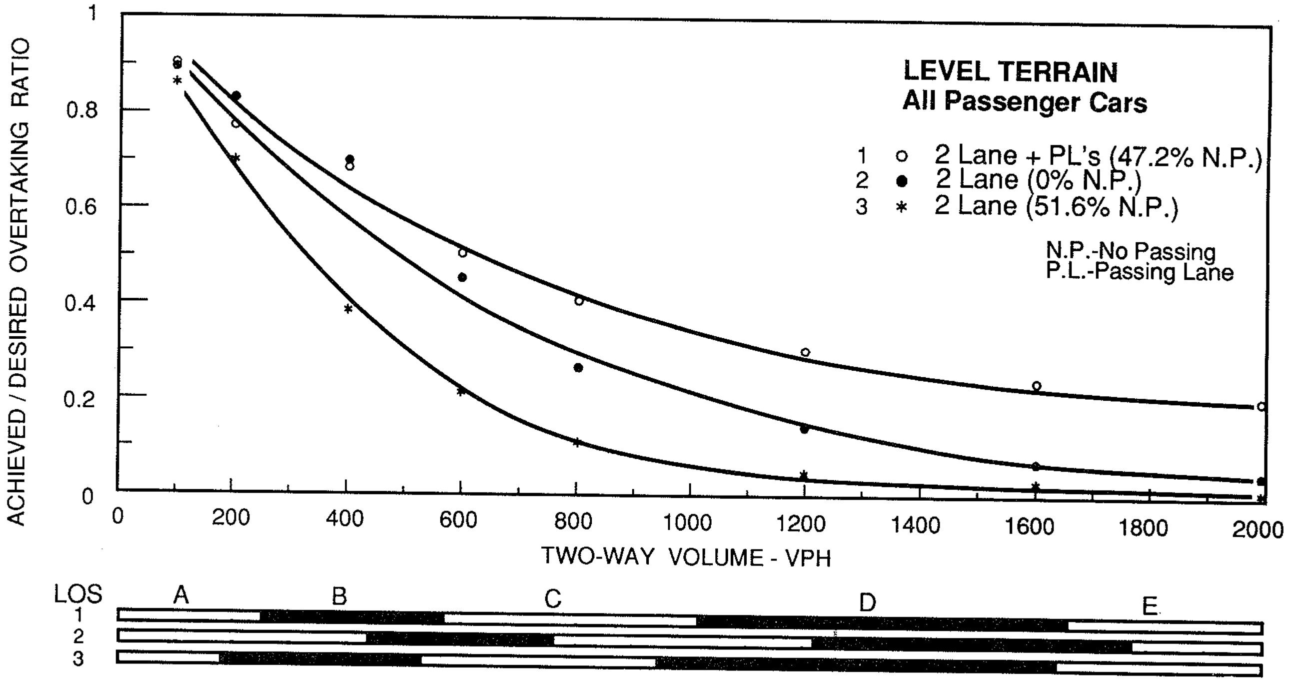

FIGURE 4 Effect of the percentage of no-passing zones and passing lanes on the overtaking ratio.

comparison between percentage of time delayed and overtaking ratios for Levels of Service A through D, as defined by the 1985 HCM (*4*).

Figure 7 and Table 2 indicate that the overtaking ratio decreases faster than the percentage of time delayed increases through the ranges of level of service that are most critical for a two-lane highway, namely the midrange of B to the midrange of C. Percentage of time delayed doubles from the bottom of Level of Service A to Level of Service C, whereas the overtaking ratio decreases fivefold for the same interval. Motorists are most sensitive to the lack of overtaking opportunities in this volume range, although they are still able to maintain a relatively high rate of speed.

These findings support the 1985 HCM's (*4*) two-lane procedures, which reduced service levels from those in the 1965 HCM (*3*) for the higher levels of service (*9*). For example, under ideal conditions—all passenger cars, level terrain, and 0-percent no-passing zones—the limiting service volumes for

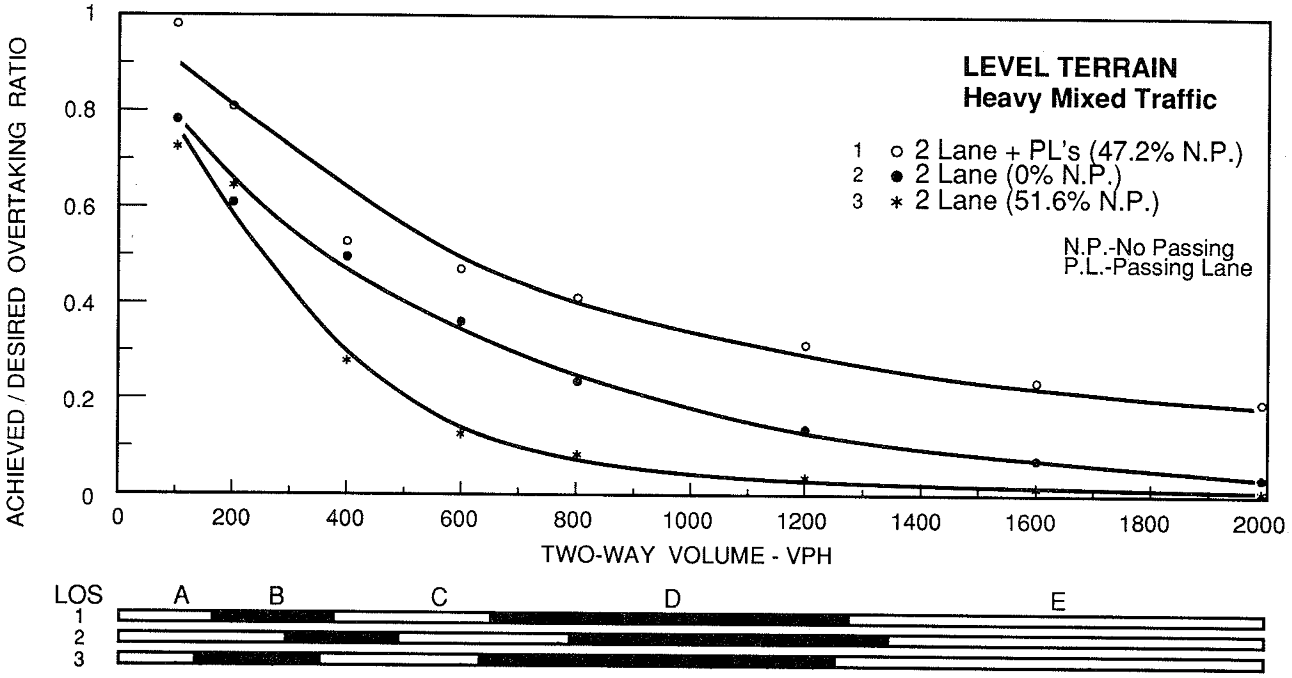

FIGURE 5 Effect of no-passing zones and heavy-vehicle mix on the overtaking ratio.

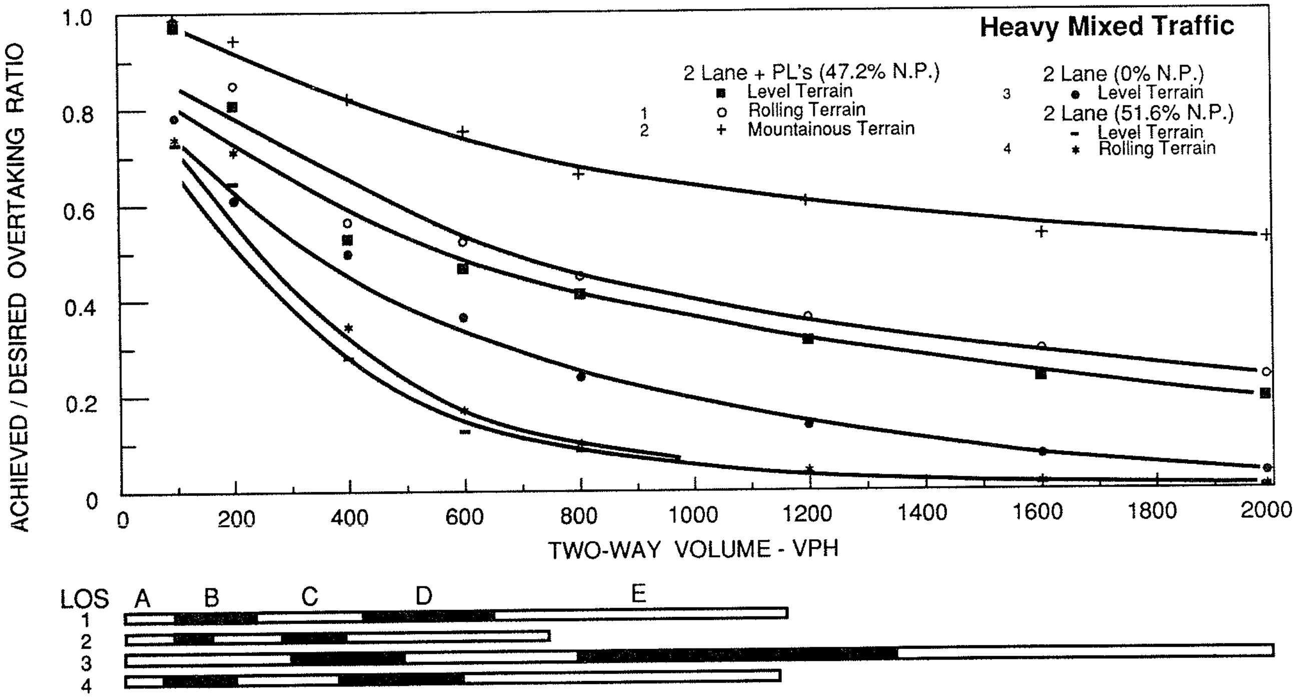

FIGURE 6 Effect of terrain and heavy-vehicle mix on the overtaking ratio.

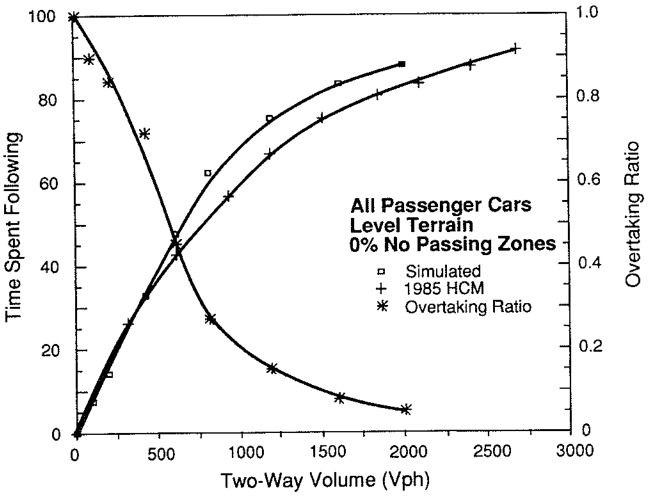

FIGURE 7 Overtaking ratio and percent time delay versus two-way volume for ideal conditions.

Levels of Service B and C in the 1965 HCM (*3*) are 900 and 1,400 veh/hr, respectively. The volumes for the same levels of service are 760 and 1,200 veh/hr in the 1985 HCM (*4*).

OVERTAKING RATIO AS A MEASURE OF LEVEL OF SERVICE

If the overtaking ratio is used as a measure of level of service, it could serve as a guide in the initial planning or upgrading of two-lane highways. The overtaking ratio takes into account the effect of percentage of no-passing zones and passing lanes on a level-of-service measure to which drivers are particularly sensitive, namely, overtaking.

At this time, no specific ratios are assigned to level of service; however, the lower limits for Levels of Service A, B, and C as defined by the 1985 HCM (*4*) would apparently have lower volumes if measured by the overtaking ratio. Further research is required to determine the specific relationship between the overtaking ratio and level of service as perceived by motorists.

The use of the overtaking ratio in evaluating the effectiveness of passing lanes is illustrated with the following examples. The first example is for only passenger cars in level terrain, with three ranges of no-passing zones. Table 3 presents the volume and level of service for an overtaking ratio of 0.4. For the existing highway with 51.6-percent no-passing zones, an overtaking ratio of 0.4 corresponds to a volume of 400 veh/hr and Level of Service B. The same highway with 0-percent no-passing zones could accommodate 630 veh/hr, an increase of 58 percent, at the same overtaking ratio. The addition of passing lanes would permit the volume to increase to 840 veh/hr, an increase of 100 percent, at the same overtaking ratio. The level of service for the 0-percent no-passing zone highway is B, whereas the same highway with passing lanes is one level lower (C). The conclusion drawn is that the 1985 HCM (*4*) underestimates the beneficial impact of passing lanes.

The second example is for heavy mixed traffic in level terrain (Table 3). This example is similar to the all-cars example except that the volumes are lower. The example shows that rebuilding the existing highway would allow volumes to increase by 59 percent for an overtaking ratio of 0.4. However, the addition of passing lanes, a more cost-effective alternative, would permit volumes to increase by 150 percent for the same overtaking ratio. As in the first example, the 1985 HCM (*4*)

TABLE 2 COMPARISON OF PERCENT TIME DELAY WITH OVERTAKING RATIO

Level* of Service	Two-Way* Volume	Percent* Time Delay	Volume/* Capacity Ratio	Achieved/ Desired Overtaking Ratio
A	420	30	0.15	0.70
B	760	45	0.27	0.31
C	1200	60	0.43	0.14
D	1800	75	0.64	0.06

* *Ratio of flow to an ideal capacity of 2,800 pcph in both directions in level terrain, 0% no passing zones and ideal conditions for all cars (1985 HCM).*

TABLE 3 IMPACT OF PASSING OPPORTUNITIES ON OVERTAKING RATIO AND LEVEL OF SERVICE*

Vehicle Mix	Road Description	Volume (VPH)	Level of Service	Overtaking Ratio
All Cars (Fig. 4)	2-Lane 51.6% N.P.	400	B	0.4
	2-Lane 0% N.P.	630	B	0.4
	2-Lane with P.L.'s 47.2%	840	C	0.4
Heavy Mixed Traffic (Fig. 5)	2-Lane 51.6% N.P.	320	B	0.4
	2-Lane 0% N.P.	510	C	0.4
	2-Lane with P.L.'s 47.2%	810	D	0.4

* *Refer to Figures these were derived from.*

procedures result in a level of service one level lower for the passing-lane alternative than for the 0-percent no-passing zones alternative.

In summary, these examples show that the effect of passing lanes on level of service as measured by the overtaking ratio is much greater than that estimated by the 1985 HCM (*4*). The impact is in those volume ranges (200 to 800 veh/hr) in which drivers are most sensitive to deterioration in quality of service.

CONCLUSIONS

1. The overtaking ratio is introduced for consideration as a measure of level of service to supplement existing measures such as percentage of time delayed, capacity use, and speed.

2. These findings support the 1985 HCM (*4*), which reduced service volumes from those in the 1965 HCM (*3*) for the higher levels of service. Because the overtaking ratio decreases much faster than the percentage of time delayed increases, in those levels of service to which motorists are most sensitive the service volumes for the higher levels of service should be even lower.

3. The overtaking ratio concept could be used to assist in the measurement of the effect of passing lanes on the level of service. This application is envisaged as a supplement to, not a replacement of, existing two-lane analysis procedures. Simulation modeling should not be used to determine the overtaking ratio for every road condition being analyzed. Instead, a series of graphs could be developed using simulations to represent a wide range of traffic, road, and vehicle

characteristics from which highway design engineers could determine the overtaking ratio.

4. Further research should include a comparison of percentage of time delayed and overtaking ratio for a wide range of directional splits, no-passing zones, and traffic composition for highways with varying lengths of passing lanes in level, rolling, and mountainous terrain. As part of this comparative analysis, other two-lane models, such as TWOPAS or ROADSIM, are recommended to check the findings presented here.

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