Characteristics and Level-of-Service Estimation of Traffic Flow on Two-Lane Rural Roads in Finland

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An analysis of speed-flow relationships, time headways, and platooning of traffic on two-lane rural roads in Finland was conducted. In addition, the 1985 *Highway Capacity Manual* (HCM) level-of-service (LOS) calculation procedure was evaluated under Finnish road and traffic conditions. The speed-flow relationship on Finnish roads was found to be linear and not as steep as that given in the HCM. Simple loglinear regression models were estimated for the percentage of vehicles in platoons and mean platoon length as a function of a 15-min flow rate. A hyperbolic relationship was estimated between the platoon percentage and mean platoon length. The percentage of vehicles in platoons (headway less than 5 sec) was used as an approximation of the percent time delay (PTD) of the 1985 HCM. The analysis of the HCM LOS calculation procedure suggests that the service flow rates corresponding to the PTD values given in the HCM are clearly higher in Finland than in the United States. One reason for this finding may be that the speed-flow relationship and the adjustment factors of the HCM are both calibrated for U.S. road and traffic conditions.

A series of point measurements was carried out in the summer of 1984 to obtain information about the basic characteristics of traffic flow on two-lane rural roads in Finland. The aim of the measurements was to analyze the relationship between speed and flow and to determine the distribution of speeds and headways. After publication of the 1985 *Highway Capacity Manual* (HCM) (*1*), a further analysis was carried out to study the platoon characteristics and to evaluate the HCM level-of-service calculation procedure using these measurements.

The methods and results of these studies (*2–4*) are described in the following paragraphs.

STUDY MATERIAL

Study Locations

The results are based on data gathered at 10 points along the southern part of the Finnish trunk road network. The study locations were chosen to provide information from different kinds of roads. Roads with speed limits of 80 and 100 km/hr, roads with good and poor visibility, and roads of different widths and hilliness were included.

On the road sections where the measurement points were located (section length 2 to 3 km), the road width varied between 8.0 and 10.8 m, the pavement width between 7.2 and 9.6 m, and the lane width between 3.35 and 3.75 m. The hilliness index of the sections was 7 to 23 m/km and the curvature index 2 to 40 rad/km. The percentage of 460-m sight distance varied between 4 and 75 percent.

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Measuring Techniques

The measurements were carried out using a traffic analyzer developed at the Laboratory of Transportation Engineering of Helsinki University of Technology. The equipment is able to measure and store the speed, time headway, and length of consecutive vehicles on the road. A pair of induction loops on both lanes were used as sensors.

At least two measurements were carried out in each location: one in the peak traffic period (mainly on Friday evenings) and one in normal weekday traffic. A total of about 5 hr of measurements were done at each point.

Basic Data Processing

The data were transferred to a mainframe computer and analyzed with special programs to give the mean speeds, flows, densities, and time headways at time intervals chosen for the analysis. The results presented are mainly based on 15-min intervals.

Most analyses were carried out both in the two directions of traffic separately (one-way traffic) and in the two directions together (two-way traffic). The highest 15-min flow rates measured were 1,500 to 1,600 vehicles per hour (vph) in the main direction and 1,900 to 2,000 vph in both directions together. The directional distribution of the traffic was about 50-50 on weekdays. On Friday evenings, the main direction carried about 70 to 80 percent of the traffic.

The percentage of heavy vehicles (measured vehicle length over 6 m) varied between 4 and 23 percent. In peak traffic, the share of heavy vehicles was about 5 to 8 percent.

SPEED-FLOW CURVES AND SPEED VARIATION

The relationship between speed and flow was found to be linear (see Figure 1). The average speed in one-way traffic decreased by 3 to 9 km/hr when the flow increased by 1,000 vph. The free speed was 89 to 92 km/hr on roads with 100-km/hr speed limit and 71 to 86 km/hr on 80-km/hr roads.

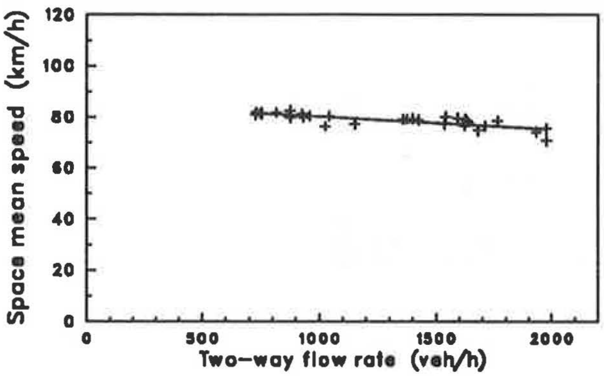

FIGURE 1 Example of measured speed-flow relationship for two-way traffic: Trunk Road 3, Riihimäki.

The speed-flow relationship was also studied in both directions together. The results were much the same. On roads with a speed limit of 100 km/hr, the mean free speed was about 87 to 92 km/hr, and on 80-km/hr roads about 75 to 85 km/hr. For every 1,000 vph flow increase, the speed decreased by 4 to 6 km/hr on the 100-km/hr roads and by 2 to 8 km/hr on the 80-km/hr roads.

The variation in mean speeds between different sites was considerable, as can be seen from Figure 2. However, no clear connection between the road width or other indicators of road standard and the speed values could be found.

In the 1985 HCM, under ideal conditions, the speed decreases by about 8 km/hr when flow increases by 1,000 vph. This decrease is larger than that found in most of the measuring points of this study (see Figure 2). According to the HCM, the decrease in speed is even faster when traffic and road conditions differ from the ideal ones. Hence, the speed-flow relationship in the HCM seems to be steeper than the one measured on Finnish two-lane roads.

The speed-flow relationship (one-way traffic) on long highway sections in Finland has been measured in other studies (*5*). The decrease of speed for a flow increase of 1,000 vph

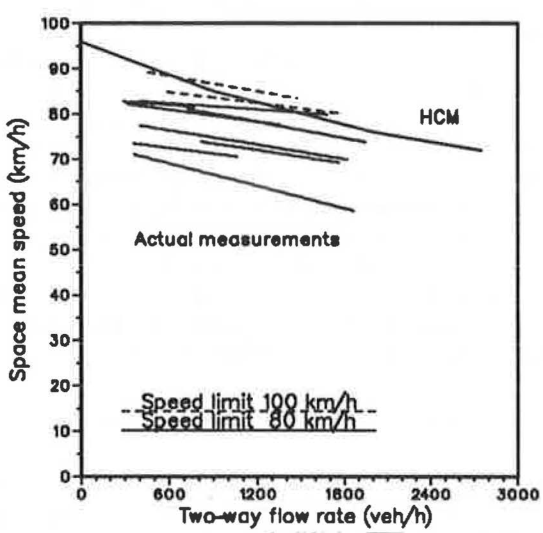

FIGURE 2 Comparison of speed-flow curve of 1985 HCM (ideal conditions) with actual measurements at 10 different locations on two-lane Finnish roads.

was found to be 6 to 10 km/hr, and the mean free speed was about 93 to 94 km/hr in 100-km/hr speed limit areas and about 87 to 88 km/hr in 80-km/hr speed limit areas.

In general, the measured free speeds are tied to the traffic behavior of the time of the measurements. In Finland the free speed of all vehicles on 80- and 100-km/hr speed limit areas has risen about 1.2 km/hr from 1984 to 1988 (*6*).

The standard deviation of speed distributions varied between 5 and 12 km/hr. In the 100-km/hr speed limit areas, about 85 to 90 percent of the vehicles were driven with a speed below the limit. In 80-km/hr speed limit areas, there were some locations where only 50 percent of the drivers maintained a speed below the limit and others where practically all vehicles were driven with speeds under the limit. An example of the speed variation is shown in Figure 3.

The data gathered did not provide a direct opportunity to estimate the capacity values of the road at the measuring points because no breakdown conditions existed. The capacities estimated with flow-density models varied substantially. The general conclusion of the material was that the capacity in good road conditions is about 2,800 to 3,000 vph in both directions together. In other studies on long highway sections, an actual capacity of 1,400 to 1,500 vph in the main direction has been measured on two-lane trunk roads in Finland (*5*).

HEADWAY DISTRIBUTIONS

The time headway distributions of one-way traffic were analyzed graphically. That is, a number of distribution curves were drawn to determine the characteristics of the distributions, but no curve fitting was done. Figure 4 shows an example of these distributions. The mode of the curve is always between 1 and 2 sec. Also, the higher the volume, the higher the curve maximum.

The characteristics of the headway curves are quite similar to those found in international studies. The curves indicate that, at flow levels analyzed in this study, the headways do not follow the negative exponential distribution. Thus, traffic on a two-lane road is not free of interactions between vehicles, which is natural because of the passing problems on two-lane roads.

The usual variation area of the standard deviations of the headway distributions is shown in Figure 5. The variation of

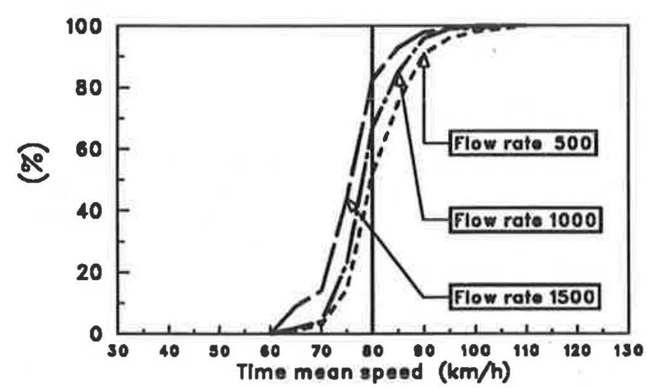

FIGURE 3 Example of cumulative speed distributions on a two-lane rural road: Trunk Road 3, Riihimäki.

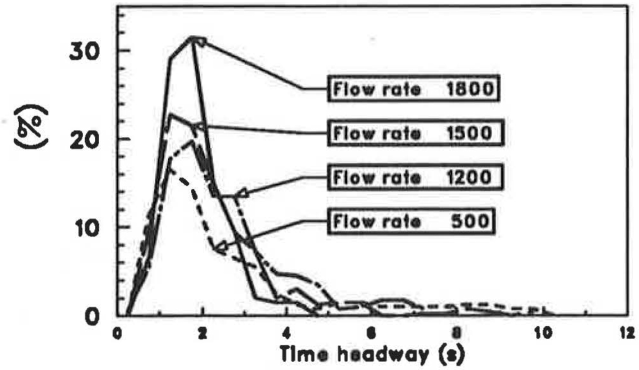

FIGURE 4 Example of measured time headway distribution curves for one-way traffic: Trunk Road 3, Riihimäki.

the measured headways is higher than that of a negative exponential distribution for one-way flows of up to 1,200 vph. This finding is an indication of the nature of the traffic on two-lane roads. A headway distribution with a standard deviation higher than that of the negative exponential distribution indicates that the traffic moves in long platoons with long headways between the platoons. When the standard deviation is smaller than that of the negative exponential distribution, the headways are more evenly distributed (*7*).

PLATOONING OF TRAFFIC

Principles of Analysis

The platoon criterion used was a 5-sec time headway between successive vehicles. The length of a platoon defined in this way is one vehicle shorter than the length of the corresponding vehicle cluster observed on the road. The first vehicle of the cluster is not in the platoon because its headway to the vehicle in front of it is longer than 5 sec.

The basic characteristics analyzed were the percentage of vehicles in platoons and the mean length of the platoons. The mean speeds of vehicles in platoons and those not in platoons were also analyzed, as well as the differences in vehicle composition of platoons compared with that of all traffic.

For the statistical analysis of the platoon percentage and platoon length, the base hypothesis was that the moving queues in one-way traffic follow the geometric distribution (*8*). From that assumption, a simple connection between the platoon percentage and the mean platoon length can be calculated:

$$E(Q) = 100/(100 - p) \tag{1}$$

where $E(Q)$ equals the mean platoon length (veh) and p equals percentage of vehicles in the platoons.

According to the theory, the mean length of the platoons is the same as the mean length of all vehicle clusters (including clusters of only one vehicle) on the road.

If the headway distribution is assumed to be negative exponential, the percentage of vehicles in the platoons and the mean platoon length are

$$p = 100 * [1 - \exp(-q * t)] \tag{2}$$

$$E(Q) = \exp(q * t) \tag{3}$$

where q equals traffic volume (veh/sec) and t equals time headway used as platoon criterion (5 sec in this study).

In logarithmic scale,

$$\ln[(100 - p)/100] = -q * t \tag{4}$$

$$\ln[E(Q)] = q * t \tag{5}$$

Thus, in one-way traffic with negative exponential headway distribution and geometric platoon length distribution, the

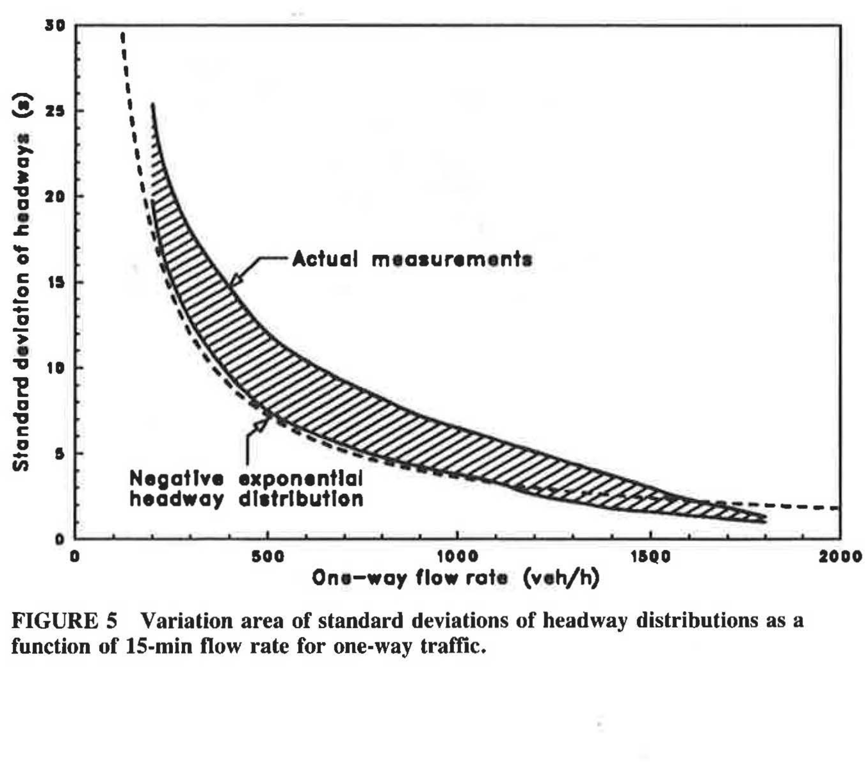

FIGURE 5 Variation area of standard deviations of headway distributions as a function of 15-min flow rate for one-way traffic.

natural logarithm of platoon length and the share of vehicles outside the platoons have the same numerical value but opposite sign. In two-way traffic, the formulas are somewhat more complex because the directional split of traffic must be taken into account.

The analysis of platoon percentages and platoon lengths was carried out in 15-min time intervals. In these time periods, the mean speeds and vehicle composition of traffic in platoons and outside platoons were also registered. Platoons were not cut off at the borders of the time intervals, which means that the length of the interval was not always precisely 15 min.

The data were grouped on the basis of the measuring locations and analyzed in these groups. For some calculations, all of the data were used. The main mathematical tool was multiple linear regression, using logarithmic values of platoon percentage and platoon length. A basic assumption of loglinear relationships was used even though the analysis of headways showed that they do not follow the negative exponential distribution.

Results

The percentage of vehicles in the platoons and the mean platoon length follow a loglinear relationship quite well, as shown in Figure 6. In Figure 7, the actual relationships between traffic volume and platoon percentage are drawn. The figure shows clear differences between the measuring locations. These differences are partly because of road conditions and partly because of traffic composition.

In Figure 8, the corresponding curves of mean platoon length versus traffic volume are shown. Comparison of the measured curves and the curves of traffic with negative exponential headways in Figures 7 and 8 clearly shows that there are more

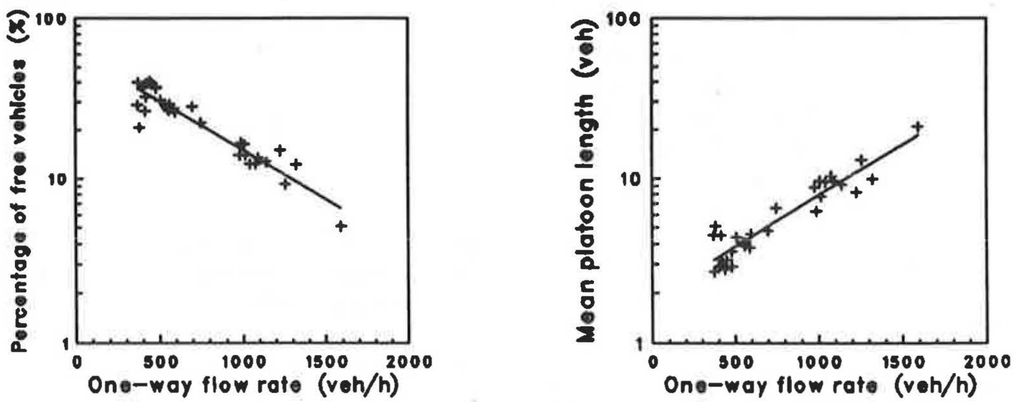

FIGURE 6 Example of loglinear relationship of platoon percentage and mean platoon length with flow rate: Trunk Road 3, Riihimäki.

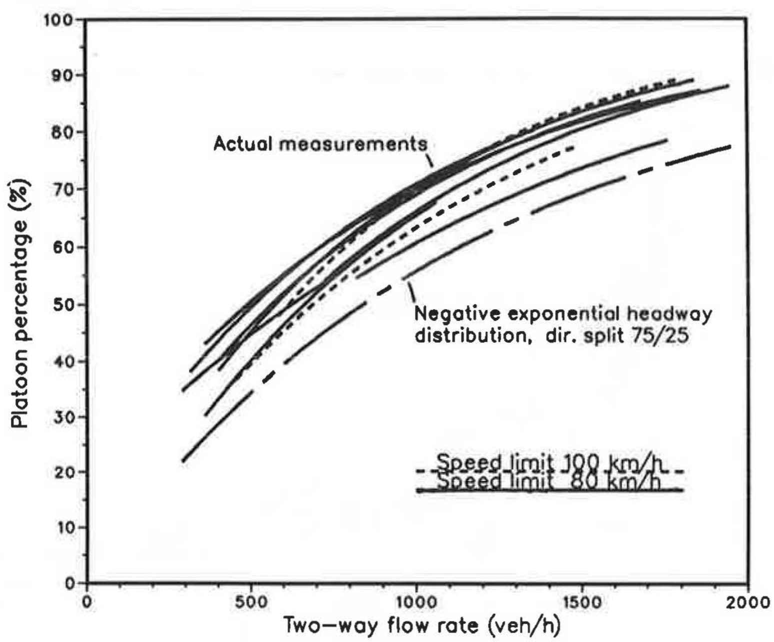

FIGURE 7 Relationship of platoon percentage and flow rate on Finnish two-lane roads.

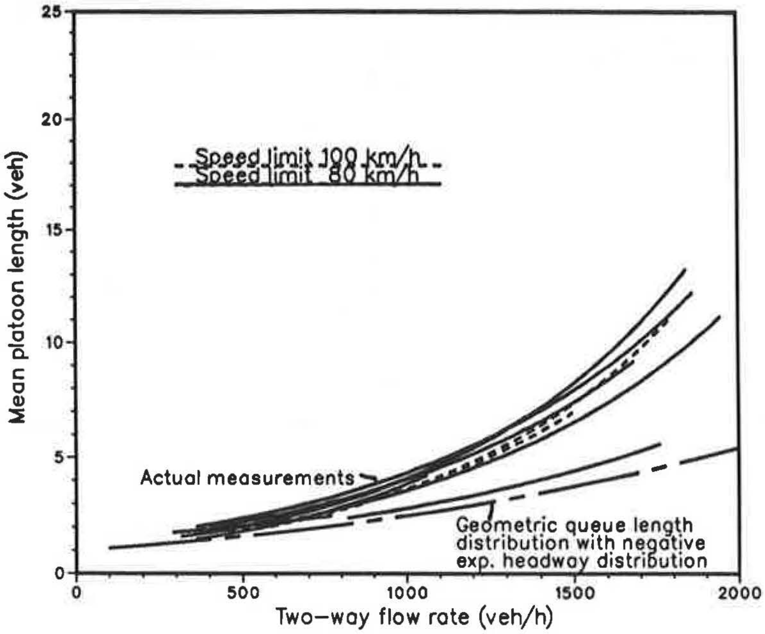

FIGURE 8 Relationship between mean platoon length and flow rate on Finnish two-lane roads.

and longer platoons on Finnish two-lane roads than the simple theory would suggest. According to the theory, a close relationship between platoon percentage and mean platoon length exists. Figure 9 shows the theoretical curve and the basic data of this relationship.

Figure 10 shows a summary of the findings. Using this figure, the average platoon percentage and the mean platoon length on Finnish two-lane roads can be approximated as a function of traffic volume. Two different platoon criteria are shown in the figure, namely, 5- and 3.5-sec time headways.

Figure 10 shows that the relationship between platoon percentage and platoon length is not dependent on the platoon

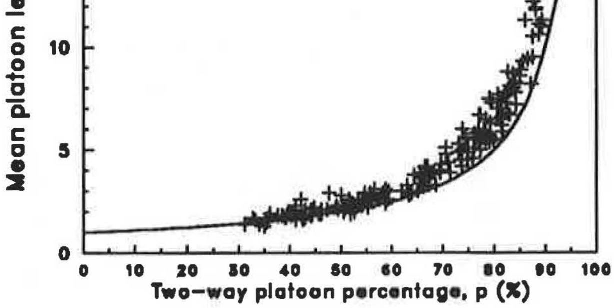

FIGURE 9 Basic data of the relationship of mean platoon length and platoon percentage.

criterion. This finding is in accordance with the theory presented. The simple regression equations of the basic relationships in Figure 10 (two-way traffic, 5-sec platoon criterion) are given in Equations 6–8.

Mean platoon length $E(Q)$ as a function of flow rate q:

$$\ln [E(Q)] = 0.056 + 0.00126 * q \qquad R^2 = 0.894 \tag{6}$$

Platoon percentage as a function of flow rate q:

$$\ln (100 - p) = 4.57 - 0.0011 * q \qquad R^2 = 0.926 \tag{7}$$

Mean platoon length $E(Q)$ as a function of platoon percentage p:

$$E(Q) = -0.57 + 141.8/(100 - p) \qquad R^2 = 0.952 \tag{8}$$

Figure 11 shows an example of the difference between the mean speeds of free and platoon vehicles. In general the difference varied between 1 and 5 km/hr and was found to increase slightly when the traffic flow increased.

Figure 12 shows the result of an analysis of the effect of the opposite flow on the platoon lengths and platoon percentage when the flow in the analyzed direction is constant. The material was so limited that a more general analysis of this phenomenon could not be done. Nevertheless, the figure shows that the level of the opposite flow has a substantial effect on platooning.

The analysis indicated that heavy vehicles (vehicle length more than 6 m) are more often platoon leaders than their

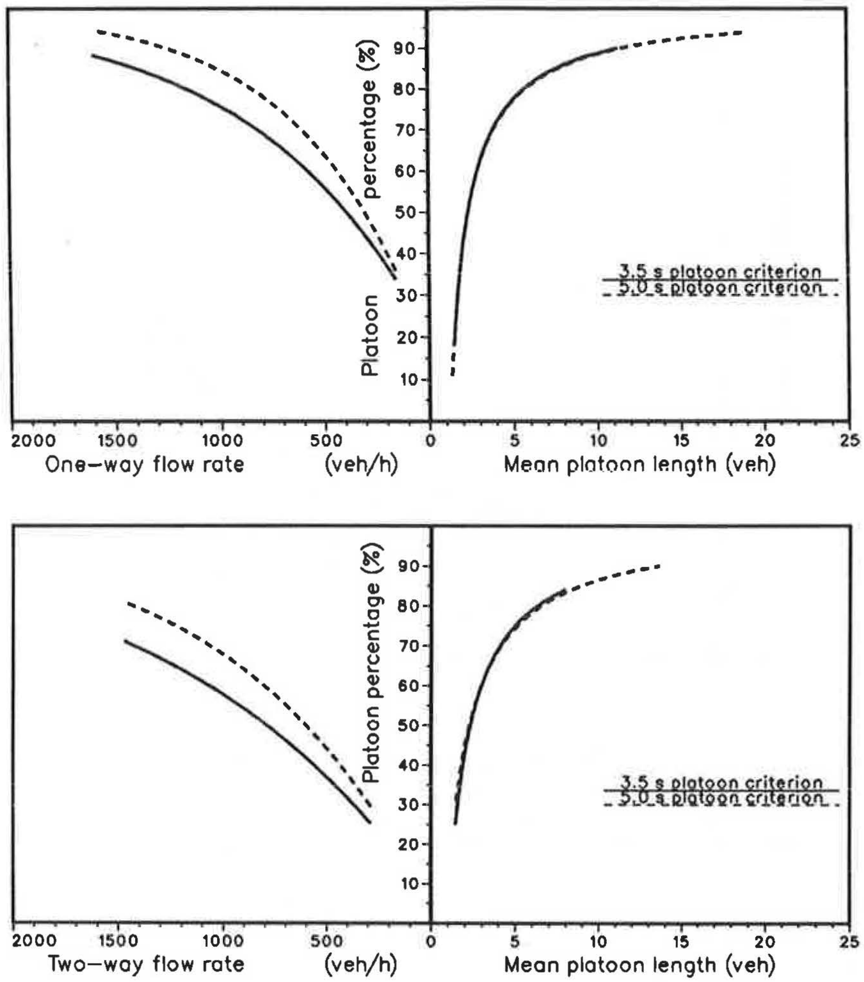

FIGURE 10 Relationship among flow rate, platoon percentage, and mean platoon length on two-lane Finnish roads.

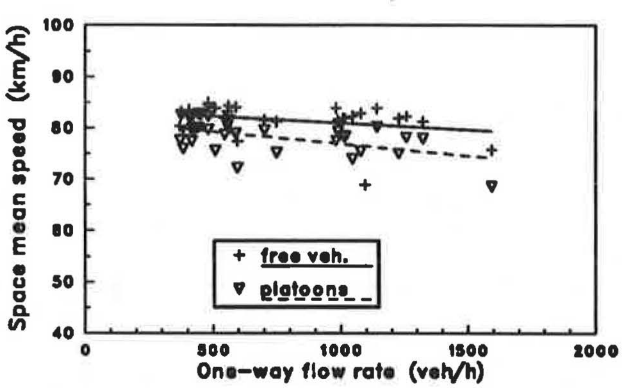

FIGURE 11 Example of speed-flow relationship of platoons and free vehicles: Trunk Road 3, Riihimäki.

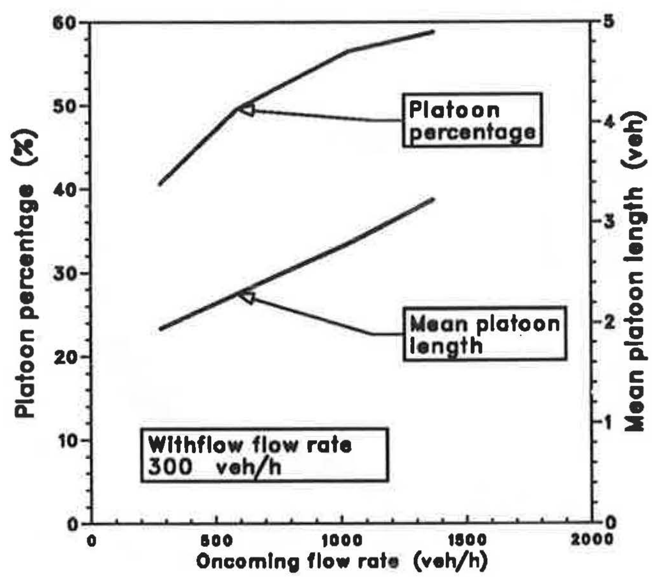

FIGURE 12 Effect of opposite flow rate on platoon percentage and mean platoon length.

share of the traffic would suggest. An example of this finding is shown in Figure 13.

LOS

In the 1985 HCM, the LOS of two-lane rural roads is calculated using the percent time delay (PTD), which, according to the manual, can be approximated with the percentage of vehicles with headways less than 5 sec (*1*). Thus, the platoon percentage of this study can be used as a PTD estimate.

In order to make a comparison between the PTD values and actual traffic volumes on Finnish roads and the 1985 HCM, the following procedure was used. In every measuring location, the maximum service flow rates were calculated using the equation given in the 1985 HCM:

$$SF_i = 2{,}800 * (v/c)_i * f_d * f_w * f_{HV} \quad (9)$$

where

- SF_i = total service flow rate in both directions for prevailing roadway and traffic conditions, for LOS i (vph);
- $(v/c)_i$ = ratio of flow rate to ideal capacity for LOS i;
- f_d = adjustment factor for directional distribution of traffic;
- f_w = adjustment factor for narrow lanes and restricted shoulder width; and
- f_{HV} = adjustment factor for the presence of heavy vehicles in the traffic stream.

The maximum service flow rates were then plotted against the PTD values given in the HCM as LOS criteria. The results are shown with crosses in Figure 14. The variation of service flow rates corresponding to a given PTD value is substantial because of the variations in road and traffic conditions of the measuring locations.

The curves in Figure 14 indicate the mean relationships between flow rate and PTD value at those measuring points where the speed criterion of the LOS was met. The figure shows that the actual measured average service flow rates on Finnish two-lane rural roads are generally higher than those calculated according to the 1985 HCM or, vice versa, the PTD values corresponding to a certain flow level are higher in the HCM. However, in good road conditions, the differences are small.

A different PTD criterion (namely, 3.5-sec headways) with slightly changed v/c ratios has also been suggested in the literature for LOS analysis (*9*). The calculations described previously were also carried out with these criteria. The results (see Figure 14) are about the same even though the differences between the Finnish and the American values are smaller.

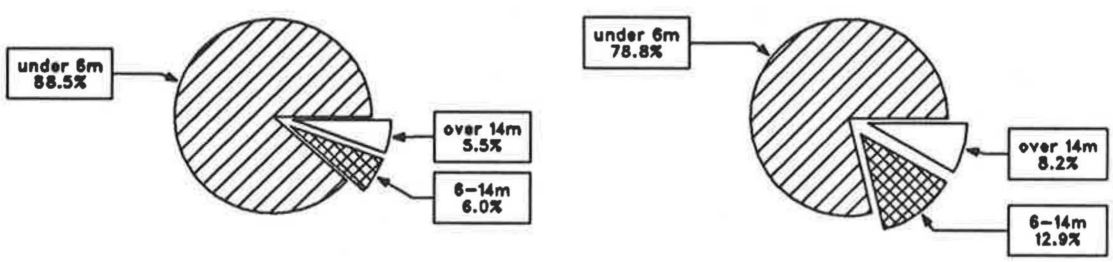

FIGURE 13 Example of vehicle composition of whole traffic (*left*) and that of platoons (*right*).

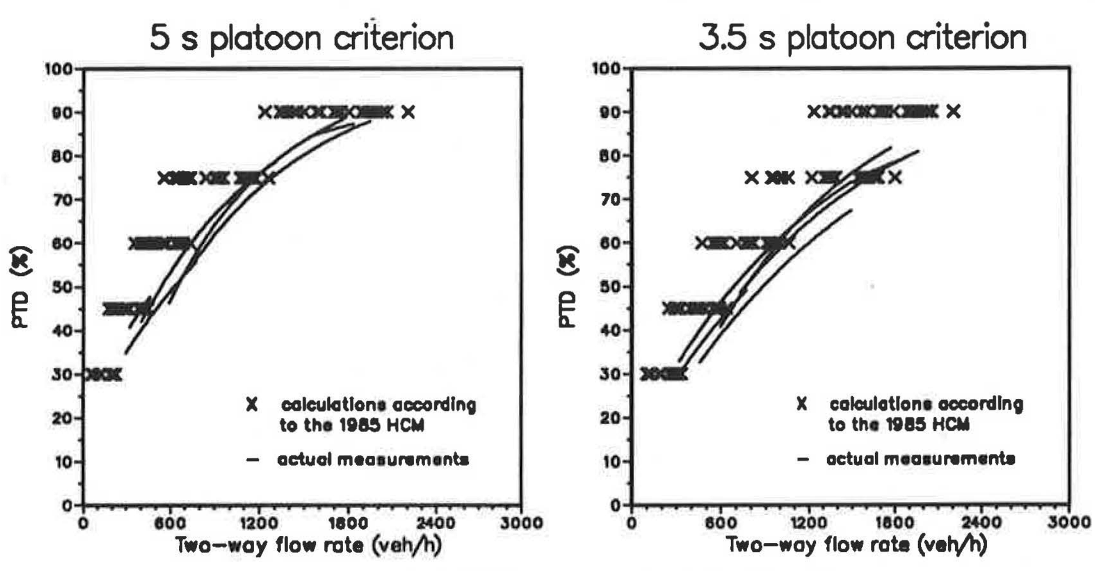

FIGURE 14 Calculated service flow rates (HCM) and measured relationships of flow rate and PTD on two-lane rural roads in Finland.

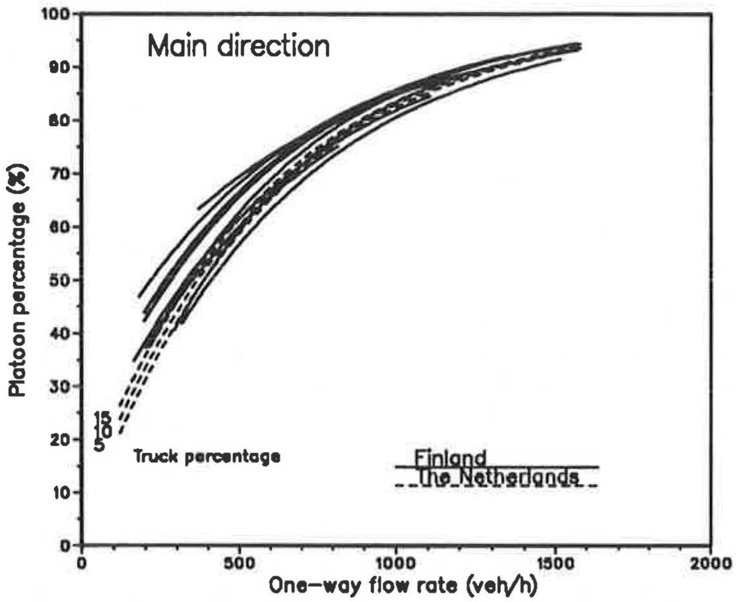

FIGURE 15 Comparison of measured Finnish and Dutch platoon percentages as a function of flow rate.

DISCUSSION OF RESULTS

The studies described are in accordance with U.S. and other international findings on the flatness and linearity of speed-flow curves and on the magnitude of the capacity of two-lane rural roads. The decrease in speed when flow increases seems to be faster in the HCM than in actual traffic on Finnish roads.

In the study, it was assumed that the platoon length and headway distributions were simple and could be represented by geometric and negative exponential distributions. A closer look at the headway distributions and statistical studies on platoon length distributions clearly indicated that the assumptions are not generally valid. Nevertheless, the simple theory provided simple relationships that turned out to be effective in analyzing the basic relationships among the platoon percentage, mean platoon length, and flow rate.

Platooning in Finland seems to be similar to that in the Netherlands. In Figure 15, the Finnish results of platoon percentage are compared with a Dutch model (*10*).

In the analysis of the level of service, the percentage of vehicles with headways less than 5 sec was used as an approximation for the PTD. This procedure is in accordance with the HCM, but it is possible that the differences found between the Finnish traffic and the HCM are an indication of the differences in real PTD values and the approximation used. An analysis of this difference was not possible in this study, and the conclusions drawn are based on the assumption that the approximation is not seriously biased.

Under Finnish road and traffic conditions, the flow levels corresponding to a given PTD value are often considerably higher than those in the HCM. The difference is small on good roads. The Dutch study, as opposed to the Finnish one, concludes that there is a good similarity between the Dutch results and the 1985 HCM (*10*). The reason for the different conclusion may be the different road conditions. The Dutch measurements were carried out in good road conditions, whereas the Finnish results were also near the values given in the HCM.

The similarity of results in good road conditions implies that, in other conditions, the adjustment factors of the HCM calculations may be a reason for the differences. The proper values of the adjustment factors in Finland probably differ from those given in the HCM. So, changing the adjustment factors is one way to adjust the measured service flow rates with the PTD values. Another possible way is to change the critical *v/c* ratios that are closely related to the steepness of the speed-flow curve. So far, no changes to any HCM values have been made. More material is needed to correct the procedure properly for Finnish conditions.

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