Store køretøjers forbrug af motorvejes kapacitet

Determining Passenger Car Equivalents for Freeways

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1. INTRODUCTION

One common measure for the amount of traffic is often appropriate to assess the use of roadway capacity and for planning or design purposes. Normally, passenger car units are used as the measure, and then it is necessary to convert other types of vehicles to passenger car units.

A passenger car equivalent, PCE, is used for this purpose. The PCE is defined as the average number of passenger cars which would consume the same percentage of roadway capacity as one of a given type of vehicles under prevailing roadway and traffic conditions, see Highway Capacity Manual (1994).

As the PCE by the above definition expresses the relative use of capacity which is most critical in situations with heavy traffic, this study has been concentrated on situations with traffic intensity close to road capacity. The PCE does not include the effects on e.g. the speed distribution, the level of comfort or other kinds of service experienced by the drivers.

The objective of the study is to determine the use of road capacity for passenger cars and other typical types of vehicles by estimating the PCEs for the different vehicle types. Only freeway sections are considered and the study has been limited to

- basic freeway sections,
- 4- and 6-lane freeway,
- level terrain,
- "normal" weather conditions which are assumed not influencing the traffic and
- mainly commuter traffic.

2. SELECTION OF SITES

Selection of sites have been based on the following criteria:

1. Frequent situations where traffic intensity is close to capacity
2. Section with less than 2% upgrade and downgrade
3. Lane width is equal to 3.5 m
4. The sites are situated in bottlenecks of the freeway
5. There is at least 1 km distance to an off- or on-ramp

Locating the sites in the freeway bottlenecks is particularly important. Measurements at sites located upstream a bottleneck may not give a true picture of the capacity consumption of the vehicles because the speed and headways measured at the site in this case would be results of the downstream traffic conditions. The bottlenecks found are freeway sections downstream an on-ramp and upstream an off-ramp where the traffic intensity of the freeway section is higher than the traffic intensity of the adjacent freeway sections.

Based on the above criteria, three sites have been selected for measurements. In one site, measurements have covered traffic in one direction, and for the other sites measurements covered both directions. Two sites are on 4-lane freeways and one on a 6-lane freeway. The 4-lane freeway sites are identified as M3 ISL direction north and south, M3 BHG direction north and south, and the 6-lane freeway site as M10 GRC direction north. All sites are located in the vicinity of Copenhagen.

By double inductive loops in the roadway the arrival time, the speed and the length of each vehicle are determined and an estimate on the chassis height of the vehicle is made.

3. VEHICLE TYPES

Based on vehicle lengths and chassis heights the vehicles are divided into the following groups:

	- length -
· Passenger car, length	2.5 - 4.8 m
· Car with trailer, recreational vehicle	7.0 - 10.0 m
· Light goods vehicle	4.8 - 6.0 m
· Small truck	6.0 - 7.0 m
· Single-unit truck (rigid truck)	7.0 - 12.0 m
· Truck and trailer, tractor-trailer truck	12.0 - 22.0 m
· Bus (single)	10.0 - 14.0 m

4. METHODOLOGY

Two methods of calculation could be applied to the task of estimating the consumption of roadway capacity for the different groups of vehicles:

1. A macroscopic method could determine the capacity at different percentages of a certain type of vehicles. It required that all other conditions except the percentage of the actual vehicle type are unchanged. Based on a number of observations of the capacity and the corresponding percentage of the vehicle type, a regression line may

be fitted to the observations. The slope of the regression line determines the PCE for that type of vehicle.

2. A microscopic method could use the relation between flowrate and average headways given by the equation:

$$N = \frac{3600}{h} \cdot l \tag{1}$$

where N is the hourly flow rate in vehicles per direction, h is the average headway in seconds and l the number of lanes per direction. Measuring the headway from the rear bumper of the vehicle in front to the rear bumper of the actual vehicle, the PCE is determined as the ratio between the mean headway for the actual type of vehicle and the mean headway for passenger cars.

Determining the PCE by the macroscopic method appeared to be difficult because the percentage of non-passenger cars only differed slightly in capacity situations on the freeway sections. Furthermore experience has shown that the capacity of a freeway section differs randomly from day-to-day. Thus the macroscopic approach would result in a large variance and an insufficient range of data. The microscopic method makes the study less dependent on the actual percentage of different vehicle types.

By these reasons the microscopic approach is chosen.

The following parameters are recorded:

For passenger cars:	Time gap to the passenger car in front, g_{pp}
	Time for the car to pass a road cross section at the site, p_p
For other types of vehicles:	Time gap to the passenger car in front, g_{vp}
	Time for the vehicle to pass a road cross section at the site, p_v
	Time gap from the passenger car behind to the actual vehicle, g_{pv}

In addition speed, length and chassis height for all the vehicles are measured.

In details the method is described as:

1. For accepted traffic situations with traffic intensity close to capacity of the freeway section (see Section 5), all vehicles are classified based on the vehicle length and the chassis height.
2. The succession of vehicles passing the site are recorded.
3. For each non-passenger car following immediately after a passenger car and for the passenger car following immediately after the same non-passenger car the gaps are observed, and the time for the non-passenger car used to pass the site at actual vehicle length and speed is observed, too.

4. Gaps and time to pass the site for non-passenger cars are compared with gaps between passenger cars and times to pass the site for passenger cars within the same one-minute interval as the arrival of the non-passenger car. The reason for comparing non-passenger cars with passenger cars within the same one-minute interval is that it then is assumed that the intensity, traffic speed and other traffic conditions are similar.
5. The PCE for a vehicle (e.g. truck, bus) is computed by the formula:

$$PCE = \frac{g_{vp} + p_v + g_{pv} - m(g_{pp})}{m(g_{pp}) + m(p_p)} \qquad (2)$$

   where $m(g_{pp})$ and $m(p_p)$ are mean values of gaps between passenger cars and mean values of times to pass the road cross section for passenger cars arriving at the site within the same one-minute interval as the non-passenger car. The equation can be considered as the ratio between the use of capacity of e.g. one truck or bus and the average use of capacity of passenger cars under nearly similar traffic conditions. Both gaps in front and behind the actual vehicle are taken into consideration.
6. Average PCEs are computed. A possible existence of a trend in PCE values as a function of traffic intensity is tested. The traffic situations considered are representing a range of high traffic intensities, and a regression line fitting points of PCEs and actual traffic intensity is determined. If the regression line shows a trend in PCE values, then the PCE representing the actual type of vehicle is determined as the PCE value for traffic intensity approaching capacity.

5. TRAFFIC SITUATIONS

As the study is based on situations where the capacity is the critical factor for the current traffic flow, it is necessary to formulate criteria for selecting traffic situations fulfilling this purpose.

An initial analysis has been carried out to determine traffic intensities for the observations to be included in the study. The ratio of headways observed for vehicles longer than 6 m to headways for passenger cars by different intensities has been plotted, see *Figure 1* which shows one example.

Though some variation it appears that this ratio is close to one or even less than one at low intensities and it is growing to an average of about 2 at high intensities. The ratio is rather constant for intensities above approximately 3500 veh/hour. Similarily, after investigating the other sites, a constant ratio is a general tendency for traffic intensities close to capacity.

Based on the initial study it was decided to use observations for intensities above 3500 veh/hour for 4-lane freeways and above 5000 veh/hour for 6-lane freeways.

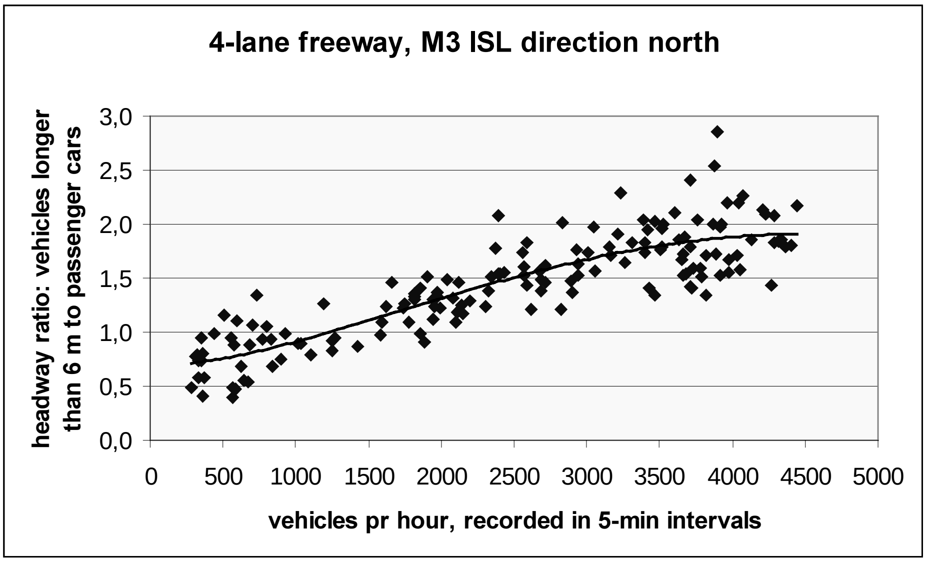

Fig. 1 - Effect of traffic intensity on the relative use of road space by non-passenger cars

Another question to be answered is whether to distinguish between freeway lanes or to combine the lanes in the study. The major part of non-passenger cars are driving in the right lane which is also the case for the more cautious passenger car drivers, while the rest of the passenger cars are driving fast and effectively in the median or middle lane. For that reason the results are influenced on whether all the lanes or e.g. only the right lane is used in estimating the relative use of road space.

Figure 2 shows the percentage of passenger cars in the right lane, the average speed ratio for the right lane to the the median lane and the percentage of non-passenger cars plotted versus the intensity.

Analysing the observations it appears that at high intensities both lanes are used intensively by passenger car drivers, probably because the difference in average speed for the lanes decreases and because all road space is occupied. For this reason and in order not to work with several PCEs representing different freeway lanes, all lanes are included in determining the PCEs. The PCE then represents the use of capacity for vehicles in the traffic flow, regardless of which lanes are being used by the vehicles.

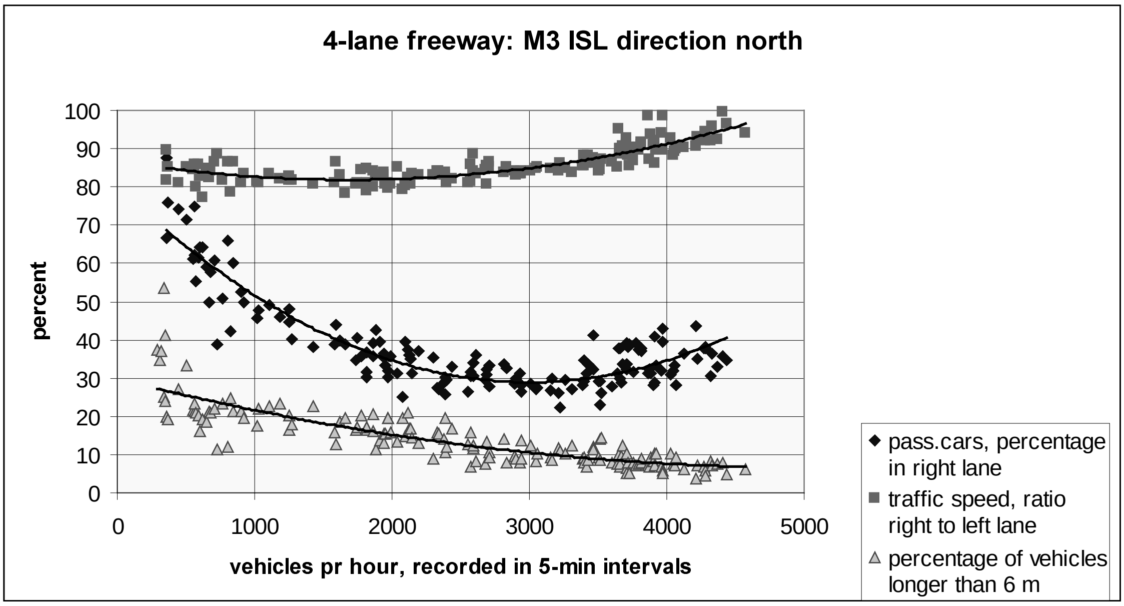

Fig. 2 - Use of lane for passenger cars, percentage of average speed in right to left lane and ratio of vehicles longer than 6 m

6. GAPS

One of the basic parameters in the study is the gap between vehicles. The capacity of the freeway section is highly dependent on the gap that the drivers accept as a safe distance to the vehicle in front. The gap is also considered to characterize the different types of vehicles.

The gap is defined as the time distance between two successive vehicles in the same lane, and the gap is then measured as the time in seconds from the rear bumper of the vehicle in front to the front bumper of the actual vehicle.

One objective of the study is to demonstrate the size of gaps between different types of vehicles on the freeway sections. *Table 1* lists for each location the average gap and the number of observations for different combinations of vehicles following each other. In the table different types of trucks are gathered into one group.

In *Figure 3*, the size of average gaps for the considered types of vehicles relative to average gaps between passenger cars are visualized in diagrams. Average gaps in front of the vehicle types indicated on the horizontal axis following a passenger car are shown in the left diagram and average gaps in front of passenger cars following the indicated vehicle types are shown in the right diagram.

Site → Pairs of vehicles ↓		M3 BHG south 4-lane	M3 BHG north 4-lane	M3 ISL south 4-lane	M3 ISL north 4-lane	M10 GRC north 6-lane
passenger car following passenger car	N obs Avg.gap	1432 1.4	1456 1.5	1415 1.5	1903 1.4	2720 1.5
car + trailer following passenger car	N obs Avg.gap	18 2.5	35 3.0	52 2.6	38 3.3	66 3.3
passenger car following car + trailer	N obs Avg.gap	19 1.2	31 1.6	51 1.6	44 1.6	77 2.1
light goods vehicle following passenger car	N obs Avg.gap	839 1.6	652 1.7	659 1.7	745 1.6	1485 1.7
passenger car following light goods vehicle	N obs Avg.gap	842 1.5	658 1.6	662 1.6	739 1.7	1495 1.8
truck following passenger car	N obs Avg.gap	499 2.8	595 2.8	586 2.7	462 3.1	1132 3.5
passenger car following truck	N obs Avg.gap	495 1.8	595 2.0	580 1.8	452 1.8	1105 2.4
bus following passenger car	N obs Avg.gap	22 2.0	20 3.2	29 2.9	30 2.9	40 3.3
passenger car following bus	N obs Avg.gap	23 2.0	19 2.3	34 1.8	40 1.9	34 2.6
truck or bus following truck or bus	N obs Avg.gap	111 2.4	146 2.5	138 2.4	144 2.8	831 3.3

Table 1 - Number of observations (N obs) and average gap (Avg.gap) in sec

Based on average gaps the vehicles can roughly be divided into two groups, 1) passenger cars and light goods vehicles, and 2) trucks, busses and cars with trailer. This is specially valid for the gap in front of the vehicles in question, but it is also recognised for the gap behind the vehicles. Furthermore, gaps for trucks, busses and cars with trailer generally are larger for the observations at the 6-lane freeway than at 4-lane freeways though the average gap for passenger cars are nearly the same.

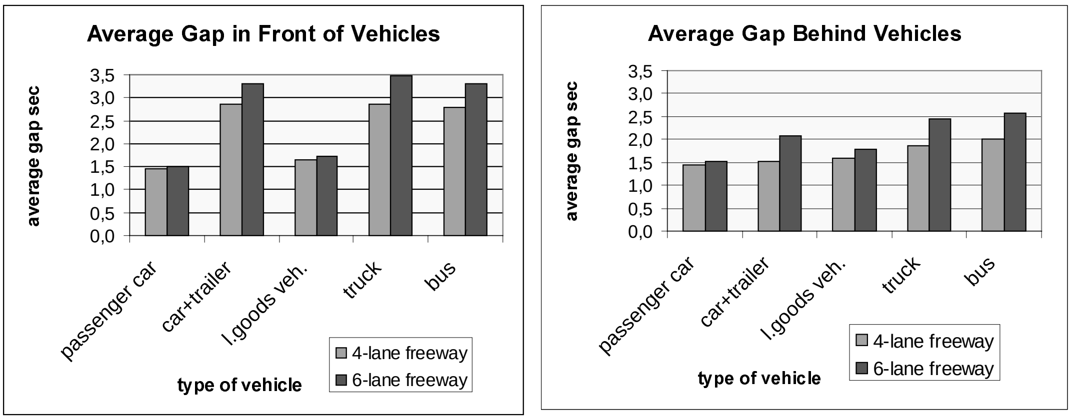

Fig. 3 - Average gaps in front and behind indicated types of vehicles

The time it takes the vehicles to pass a point is dependent of the speed of the traffic flow. The time a vehicle occupies a cross-section becomes significant if the vehicle is long and the speed is low. Another interesting subject is to examine how the gap varies if the speed of the traffic flow differs.

The study showed that the gaps between passenger cars are approximately the same for speeds within the limits 45 and 100 km/h. In contrary to this, the gaps in front of trucks show a slight increase from about 50 km/h to 90 km/h.

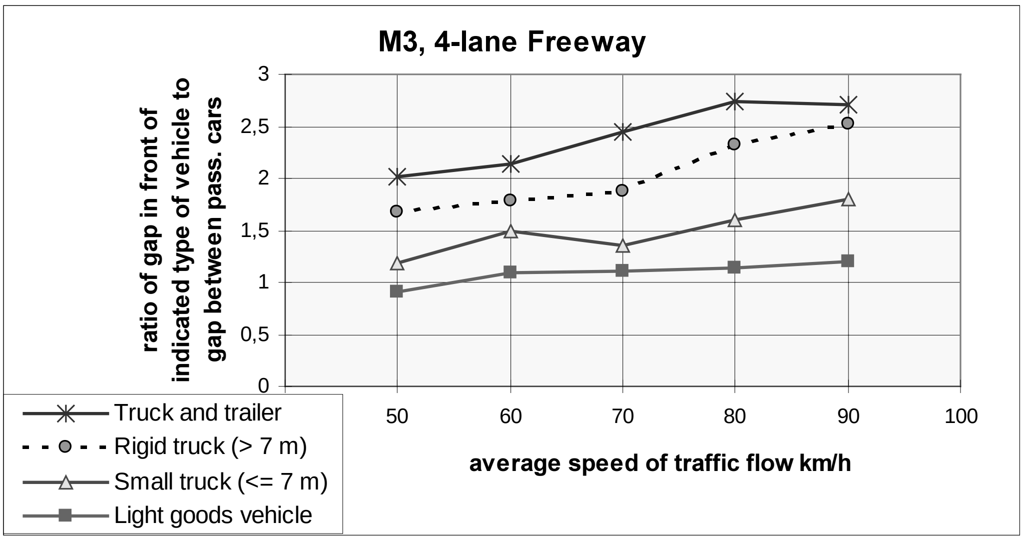

Fig. 4 - Relative gap for non-passenger cars versus average speed

Figure 4 shows the ratio of gap in front of trucks and light goods vehicles to the gap between passenger cars plotted for intervals of the traffic flow speed. The ratio is nearly constant for light goods vehicles but increases with speed of trucks. One can then expect that the PCE for trucks increases with the speed of the traffic flow.

7. PASSENGER CAR EQUIVALENTS

Table 2 shows the results of the analyses. The PCE values in the table are averaged for actual speeds and vehicle lengths for the respective groups of vehicles. The PCEs in the table are mean values representing the distribution of actual speeds observed at the heavy traffic sites. The computation of PCEs are carried out using the methodology explained in Section 4.

The category of light goods vehicles occupies 10 percent - 20 percent more of road capacity than passenger cars. The use of capacity for busses is nearly the same as for single unit trucks longer than 7 m which consume more than twice the capacity than a passenger car. Furthermore a significant difference between the use of capacity from the smallest to the longest trucks is demonstrated. Finally the PCEs are generally larger for the 6-lane freeway than for 4-lane freeways, but it should be kept in mind that the data only covers one section of 6-lane freeways.

Free-way	Type of vehicle → Site ↓	Pass. car + trailer	Light goods vehicle 4.8-6 m	Small truck 6-7 m	Single-unit truck 7-12 m	Truck/ tract.+ trailer >12 m	Bus single 10-14 m
M3 4-lane	BHG south	1.8	1.1	1.4	2.2	2.6	2.2
	BHG north	2.4	1.1	1.7	2.3	2.5	3.0
	ISL south	1.9	1.2	1.7	2.2	2.4	2.3
	ISL north	2.7	1.2	1.6	2.4	3.0	2.7
	Average	2.2	1.2	1.6	2.3	2.6	2.5
M10 6-lane	GRC north	2.3	1.1	1.5	2.9	3.2	2.7
4-/6-lane averaged		2.2	1.2	1.6	2.6	2.9	2.6

Table 2 - Passenger Car Equivalents

In a previous section it was shown that the mean gap for some classes of vehicles depends on the speed of the traffic flow, and as the time to pass a cross-section of the road depends on both the vehicle length and the speed, it is then obvious to plot the PCE for different vehicle lengths and for some intervals of traffic speed, see *Figure 5*.

At first the pattern looks a little confusing but the following seems to appear:

- Vehicles with length below 7 m behave differently from longer vehicles, by havning significant lower PCE, and by the less dependency on the traffic speed.
- For vehicles, which are longer than 7 m, points representing the highest speed level are in most cases situated above points for the middle speed level, which again are situated higher than points for the low speed level.
- An increase in PCE as a function of the vehicle length is observed. However, this is less significant for the highest speed level for which one reason could be that the time for the vehicle to pass the cross-section contributes less for high speeds than for lower speeds.

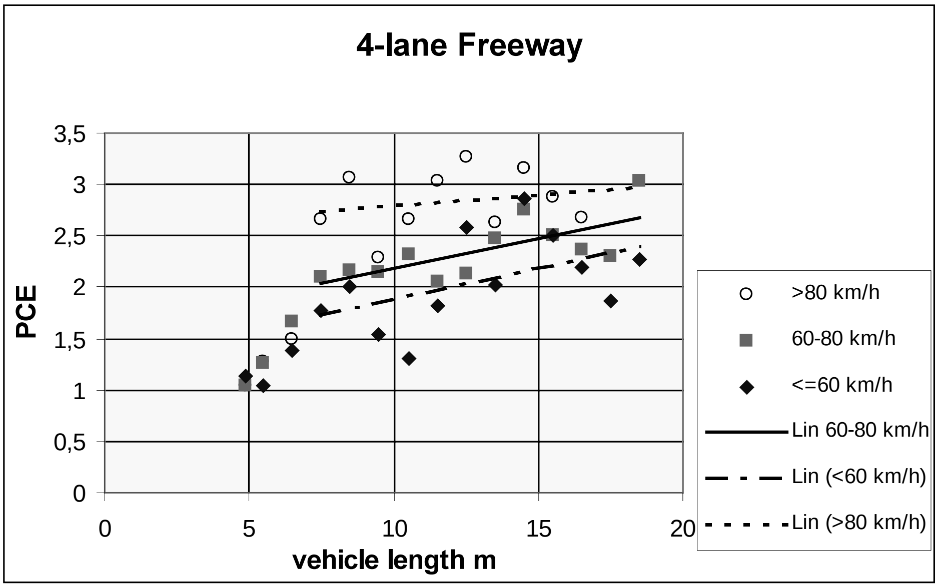

Fig. 5 - Average passenger car equivalents for different speed levels and vehicle length

Concluding on *table 2* and *figure 5* it seems to be reasonable to gather some of the vehicle types and only distinguish between e.g.

a) Single-unit trucks, busses and cars with trailer with a common PCE = 2.0 for 4-lane and 2.5 for 6-lane freeways,

b) Trucks/tractors and trailer with a PCE = 2.5 for 4-lane and 3.0 for 6-lane freeways.

If all vehicles longer than 6 m are gathered into one group, then an average PCE value for all those vehicles passing the sites can be calculated:

- M3 BHG direction south: 2.2 (4-lane freeway)
- M3 BHG direction north: 2.3 (4-lane freeway)
- M3 ISL direction south: 2.2 (4-lane freeway)
- M3 ISL direction north: 2.4 (4-lane freeway)
- M10 GRC direction north: 2.6 (6-lane freeway)

8. CONCLUSION

The investigation covers five freeway sections which represent bottlenecks of the freeway system in the vicinity of Copenhagen.

The analysis shows that in heavy traffic situations on these freeway sections, large vehicles occupy more road space than passenger cars. The time distances in front and behind large vehicles are as an average longer than the time distances between passenger cars. Furthermore, time distances in front of trucks increase with the speed. This increase is contrary to time distances between passenger cars which are much less influenced by the speed.

The PCE equals 2 for a single-unit truck or bus on a 4-lane freeway and equals 3 for a tractor/trailer truck on a 6-lane freeway. These PCEs were estimated for the actual speed distribution in heavy traffic situations. The PCE values obtained are higher than the PCEs stated in Highway Capacity Manual (1994) for level terrain.

REFERENCES

HIGHWAY CAPACITY MANUAL, Special Report 209, Third Edition, Transportation Research Board, National Research Council, Washington, D.C. 1994