# CAPACITY AND LEVEL OF SERVICE CONDITIONS ON DANISH TWO-LANE HIGHWAYS

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In 1969 recordings were carried out on four sections of rural highways in the eastern part of Jutland, Denmark. The purpose of these recordings was to provide Danish data for a decision on whether the particulars provided in the Highway Capacity Manual for two-lane highways were also valid and could be applied to Danish conditions. The recordings were organized as a sample survey of the correlation between operating speed and traffic volume (with different percentages of heavy commercial vehicles) for road sections with different free operating speeds and different gradient and visibility conditions. At each of the four locations, stationary recordings as well as tests by moving test vehicles were carried out. The stationary recordings were carried out by means of a magnetic tape recorder. The test runs were carried out by means of a tachograph and were designed for the recording of overall journey times over distances varying from 3.4 to 6.0 km. All observations show that cars in Denmark, all other factors being equal, are driven faster than is indicated by the Highway Capacity Manual. Based on the Danish observations, a set of curves has been worked out depicting the correlation between operating speed and volume-capacity ratio for free operating speeds ranging from 50 to 100 km/hr and for different sight conditions. Special problems are at last subject to a closer examination, such as the importance of heavy vehicles and measurements of operating speed.

•DURING August 19-24, 1969, systematic recordings were carried out on four sections of rural highways in the eastern part of Jutland, Denmark. The purpose of these recordings was to provide data for a decision on whether the particulars provided in the Highway Capacity Manual (1) for two-lane highways were also valid for Denmark and could be applied under Danish conditions.

In Denmark, new directives for the planning of highways have been worked out for the last few years. For a country like Denmark, it is of decisive importance to determine to what degree recommendations based on foreign data are applicable.

The recordings were organized as a sample survey of the correlation between operating speed and traffic volume (with different percentages of heavy commercial vehicles) for road sections with different free operating speeds and different gradients and visibility conditions. The four locations are given in Table 1.

The width of the pavement at all four locations is 8.0 m (two lanes each 4.0 m including marginal strips). Danish car lengths vary from 3.0 to 5.0 m, the typical length being about 4.0 m.

The results of the survey have been published in a report (2). Apart from the survey results, the report provides some guidance for the calculation of capacity and level of service on Danish two-lane highways. For this purpose, the definitions and notions quoted in the Highway Capacity Manual have been adopted without change; however, to the extent to which it was possible to use the survey for an adjustment to Danish conditions of the values of the input parameters, this was done. The most important results of the survey are discussed below.

## THE SURVEY

At each of the four locations, stationary recordings, as well as tests by moving test vehicles, were carried out.

The stationary recordings were carried out by means of the magnetic tape recorder shown in Figure 1. With the aid of four contact cables, the passage times of all motor cars were recorded separately on each lane. On the Vejle to Kolding road, where the recordings were taken on a 33 per mil gradient, and on the Kolding to Middelfart road, where the gradient was 55 per mil, traffic was recorded at two points about 275 m apart.

The magnetic tape recordings were processed on an IBM 7094 computer at the Technical University.

For each passage of a motor car, the following data were (inter alia) derived: arrival time, headway time, headway space, speed (travel speed over the cable distance of 4.0 m), acceleration, and wheelbase and axle combination.

Mean values were calculated for 5-min intervals (inter alia) for traffic volumes, mean speed, traffic density, and percentage of heavy commercial vehicles.

The results of the stationary recordings obtained at the four locations are shown in Figures 2, 3, 4, and 5 in the form of quarterly figures for both directions together.

The diagrams show correlated values of the operating speed as a function of the volume-capacity ratio. Capacity is defined as

$$c = 2{,}000 \times T_c$$

where $T_c$ is a reduction factor (measured in cars per hour) that decreases with the incidence of heavy vehicles (e.g., trucks) and is calculated from the truck equivalency values given in Table 2. The operating speed is determined from the observed mean speeds by adding a correction value as described later.

The test runs were designed for the recording of overall journey times over distances varying from 3.4 to 6.0 km.

Installed in the test vehicle was a tachograph that, during the run, records the speed of the vehicle as a function of time. During each trip, the passages not only over the fixed starting and finishing points but also over the measuring cables were recorded. A special pen was used for recording driving in queues, the number of overtakings, and the number of cars overtaken. The speed of the test vehicle was closely adapted to the traffic flow, in accordance with the definition of operating speed.

Because the test runs were carried out at the same time as the stationary recordings, it has been possible to compare the results. The individual test run results show, as might be expected, a much greater scatter than the stationary recordings. Allowing for the greater scatter, there is however good agreement between both sets of results.

The observations at the four locations were carried out at different times of the day and on different days of the week so as to obtain data on the distribution of traffic flows and truck percentages. Altogether, the survey comprised about 12 quarterly observations and about 30 test runs at each location.

## DIRECTIVES FOR THE CALCULATION OF CAPACITY AND LEVEL OF SERVICE

### Correlation Between Operating Speed and Volume-Capacity Ratio

If the Danish speed recordings are compared with those quoted in the Highway Capacity Manual (the curves from the Manual corresponding to the geometrical conditions at the survey locations are shown in Figures 2, 3, 4, and 5) it will be seen that, for a given traffic flow, traffic in Denmark moves faster than is indicated by the American data. This difference is equally clear from the results of all the four survey locations and is of an order of magnitude that cannot be simply ignored.

With this observation in mind, curves that take this difference into account have been plotted and are governed by the following conditions.

**Table 1. Study locations and characteristics.**

| Location | Free Operating Speed (km/hr) | Sight Distance (percent) | Terrain |
|---|---|---|---|
| Highway A10 between Christiansfeld and Kolding | 100 | 75 to 100 | Level road |
| Highway A10 between Vejle and Kolding | 100 | 75 to 100 | Moderate gradients |
| Highway A10 between Hasselager and Hørning | 90 | 50 to 75 | Moderate gradients |
| Highway A1 between Kolding and Middelfart | 60 | 0 to 25 | Heavy gradients |

**Figure 1.**

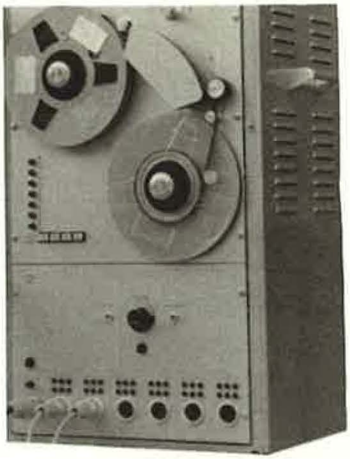


**Figure 2.**

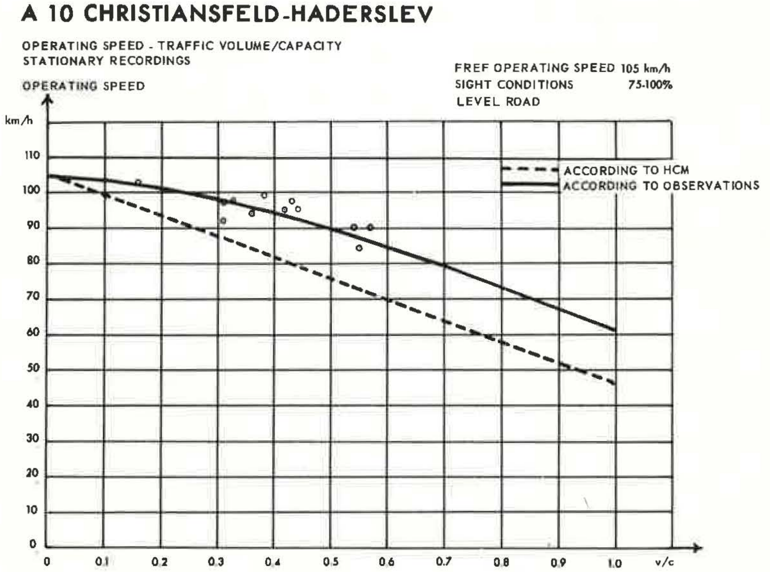



**Figure 3.**

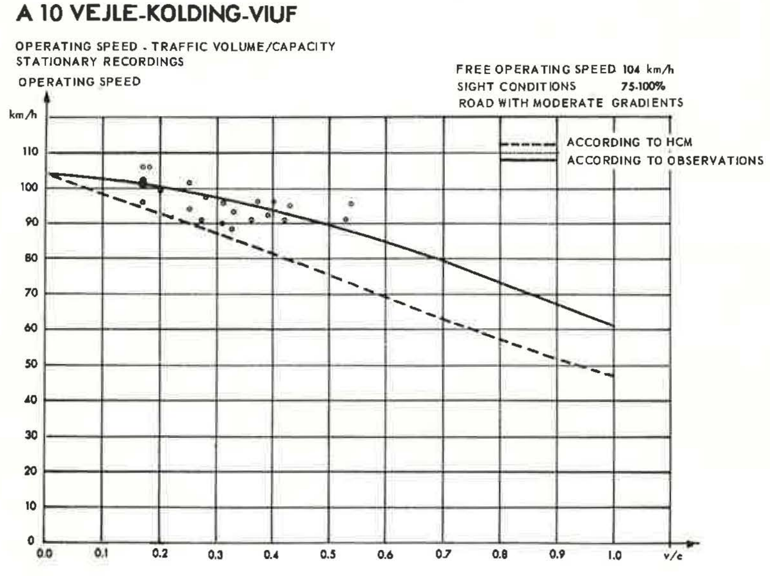


**Figure 4.**

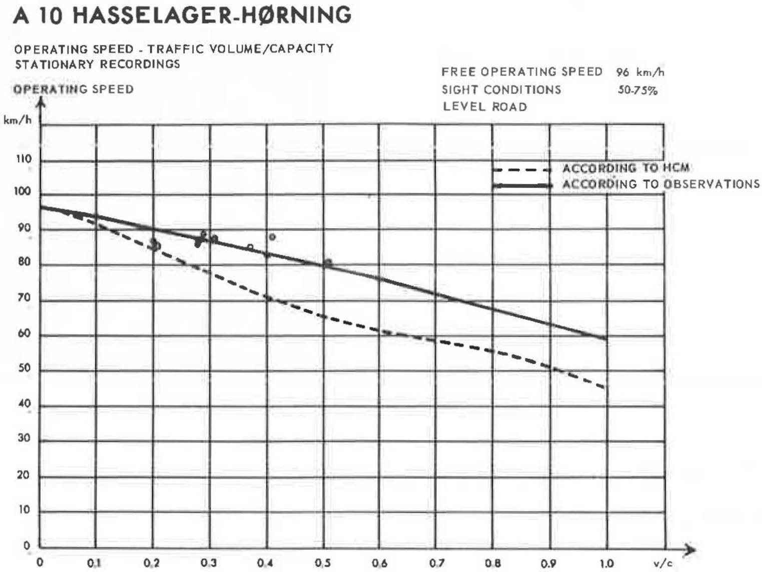



**Figure 5.**

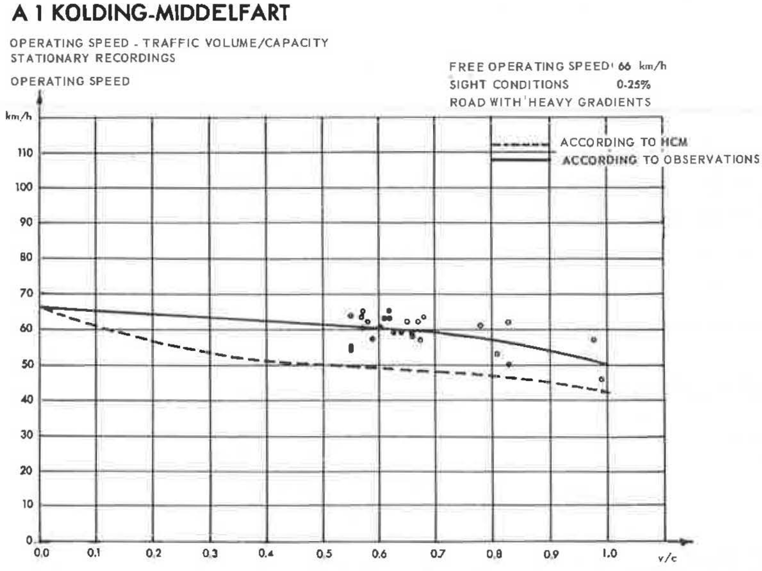



**Table 2. Truck equivalency values for study locations.**

| Highway | Terrain | Truck Equivalency Value |
|---|---|---|
| A10 Christiansfeld to Haderslev | Level road | 2 |
| A10 Vejle to Kolding | 33 per mil gradient at about 500 m | 5 |
| A10 Hasselager to Hørning | 20 per mil gradient at about 125 m | 2 |
| A1 Kolding to Middelfart | 55 per mil gradient at about 400 m | 8 |

1. The curves are intended to form the basis of a set of curves that cover all the free operating speeds and sight conditions encountered in practice and will therefore appear in the cigar-like shape known from the Highway Capacity Manual.

2. The extreme left point of the curve, representing the free operating speed over the section of road, can be separately determined as the 85th percentile of the cumulative frequency curve of the speed of unimpeded passenger cars.

3. The curve for highway A10 between Christiansfeld and Haderslev should be identical with that for highway A10 between Vejle and Kolding where the traffic volumes are fairly low because there is little difference in the free operating speeds (105 and 104 km/hr respectively).

4. For traffic flows close to the capacity limit, the curves should be governed by the results obtained on the Kolding to Middelfart road where traffic volumes close to the capacity limit have been observed.

It was possible to use the curves plotted in Figures 2, 3, 4, and 5 as background information for a set of curves depicting the correlation between operating speed and volume-capacity ratio for free operating speeds ranging from 50 to 100 km/hr and for sight distance percentages of 0 to 25, 25 to 50, 50 to 75, and 75 to 100 percent (Figs. 6 through 11).

The subdivision of the diagrams showing the operating speed as a function of the volume-capacity ratio into the service levels A, B, C, D, and E depends on the observed correlations between operating speed and volume-capacity ratio. In the Highway Capacity Manual, the subdivision is based on the assumption that the intersecting points between the horizontal and vertical limits are located exactly on the curve for a free operating speed of 70 mph with 100 percent sight distance (Fig. 12a). Because the Danish operating speed differs from the American one, a proposal has been worked out for varying the level of service classification on Danish highways (Fig. 12b).

## Influence of Heavy Vehicles

The capacity definition given in the Manual contains the factor $T_c$, which reduces the capacity if the traffic includes heavy vehicles. Because the presence of heavy vehicles has an effect on the capacity and because the traffic load itself is given as the total number of passing cars (without converting the number of trucks into passenger car units), the method of quoting the traffic loads in terms of passenger car units has been formally abandoned. The load is now quoted purely as the volume-capacity ratio during the interval.

In practice, however, this new method is not different from the one based on quoting the traffic load in passenger car units, inasmuch as the reduction factor $T_c$ is based on the determination of the truck equivalency coefficient. All that are vital to the calculations are, therefore, to determine whether it is altogether reasonable to convert heavy vehicles into a corresponding number of passenger cars and, if so, to fix the relevant truck equivalency coefficients.

Although the Danish surveys were not specially designed to provide data concerning these issues, both questions have been investigated with a view to clarifying the many problems associated with the application of the truck equivalency coefficients.

The attempt has been made to use the individual speed recordings in such a way that observations of low truck percentages were compared with observations of high truck percentages, partly to ascertain the difference in the structure of the results and partly to find the most relevant correlation factors (truck equivalency coefficients). It was found that the individual speed recordings had such a great scatter that it was not possible to indicate any clear correlations, and the survey result thus gives rise to doubts of whether it is appropriate to convert heavy vehicles into a corresponding number of passenger cars.

It is however possible, based on the strength of the recordings from highway A1 between Kolding and Middelfart, to check whether the American truck equivalency coefficients could reasonably be applied to Danish highways. For this section of road, the equivalency coefficient amounts to $E_T = 8$, which is in agreement with the Manual.

**Figure 6.**

CORRELATION BETWEEN OPERATING SPEED AND v/c

## FREE OPERATING SPEED 50 KM.P.H.

BASED ON DANISH OBSERVATIONS

OPERATING SPEED

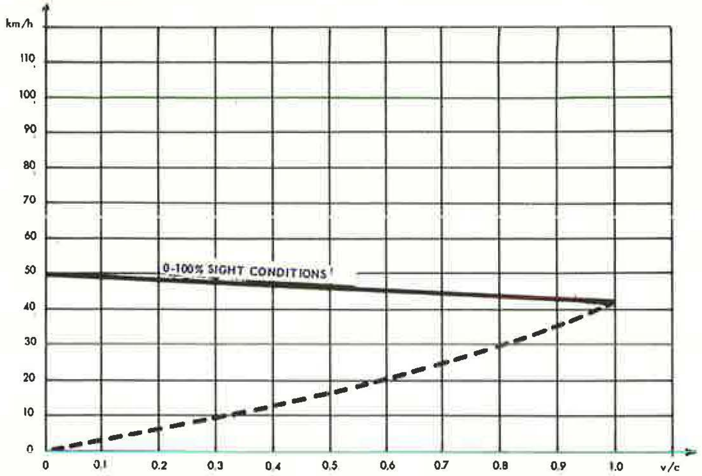



**Figure 7.**

CORRELATION BETWEEN OPERATING SPEED AND V/C

## FREE OPERATING SPEED 60 KM.P.H.

BASED ON DANISH OBSERVATIONS

OPERATING SPEED

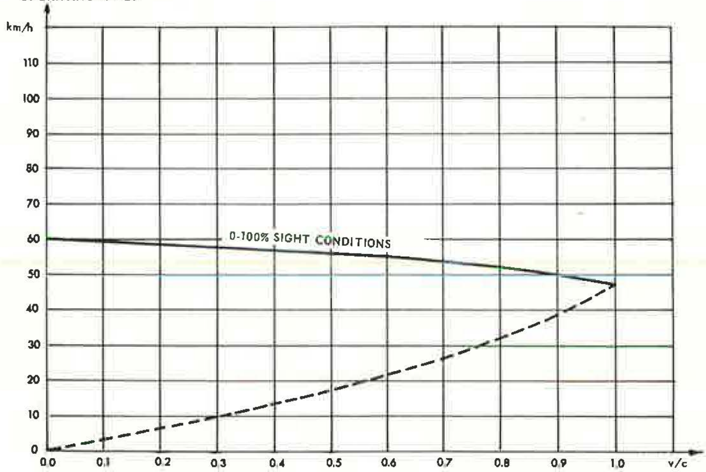



**Figure 8.**

CORRELATION BETWEEN OPERATING SPEED AND V/C

## FREE OPERATING SPEED 70 KM.P.H.

BASED ON DANISH OBSERVATIONS

OPERATING SPEED

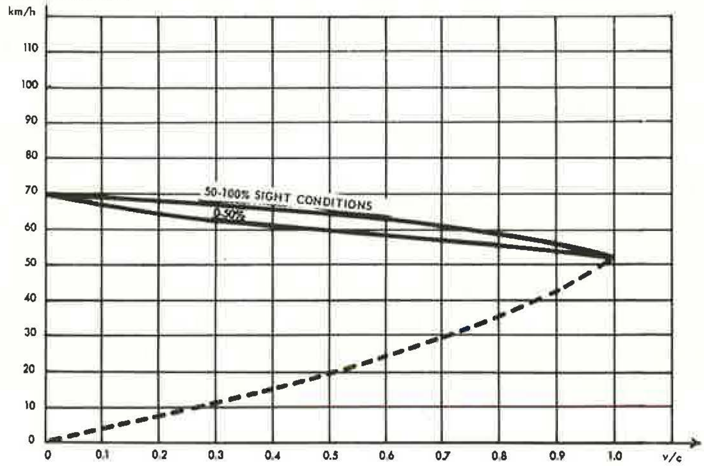


**Figure 9.**

CORRELATION BETWEEN OPERATING SPEED AND V/C

## FREE OPERATING SPEED 80 KM.P.H.

BASED ON DANISH OBSERVATIONS

OPERATING SPEED

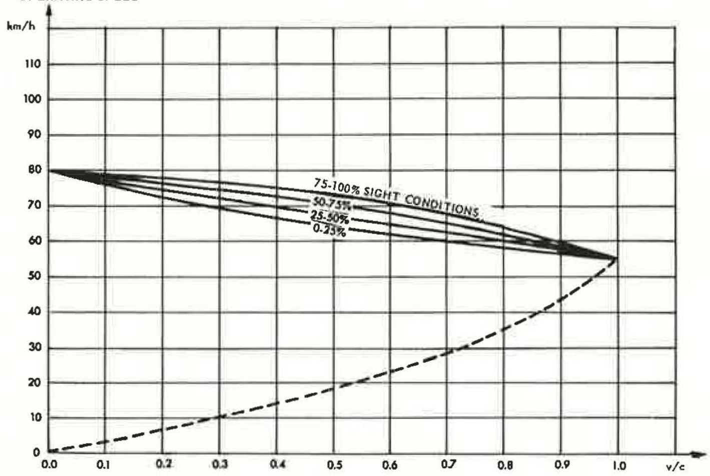



**Figure 10.**

CORRELATION BETWEEN OPERATING STEED AND V/C

## FREE OPERATING SPEED 90 KM.P.H.

BASED ON DANISH OBSERVATIONS

OPERATING SPEED

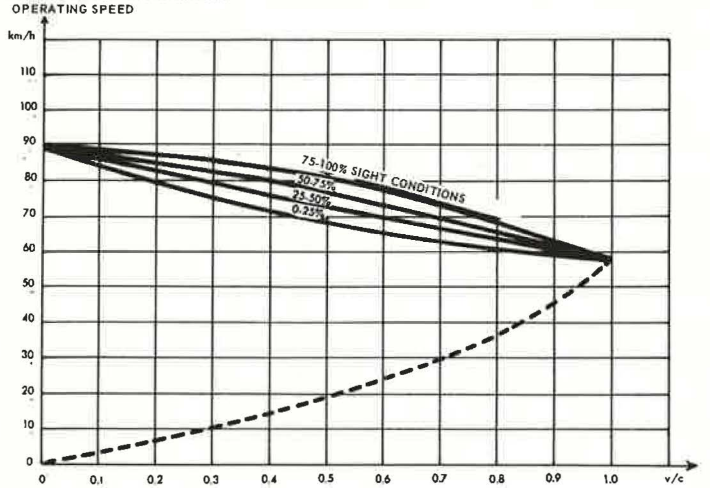



**Figure 11.**

CORRELATION BETWEEN OPERATING SPEED AND V/C

## FREE OPERATING SPEED 100 KM.P.H.

BASED ON DANISH OBSERVATIONS

OPERATING SPEED

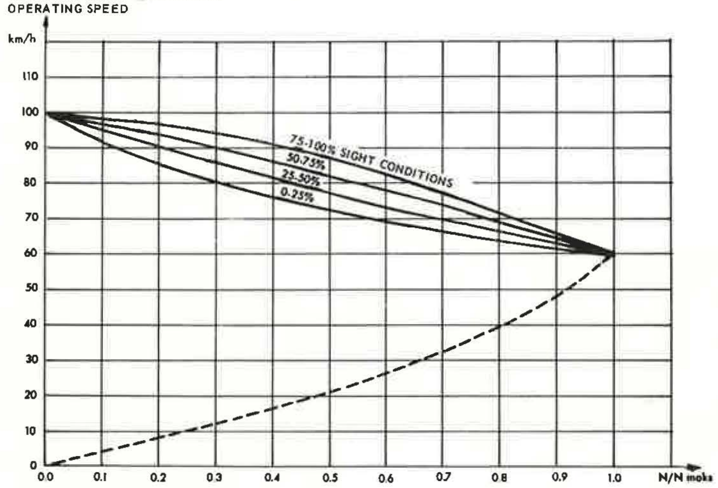


**Figure 12.**

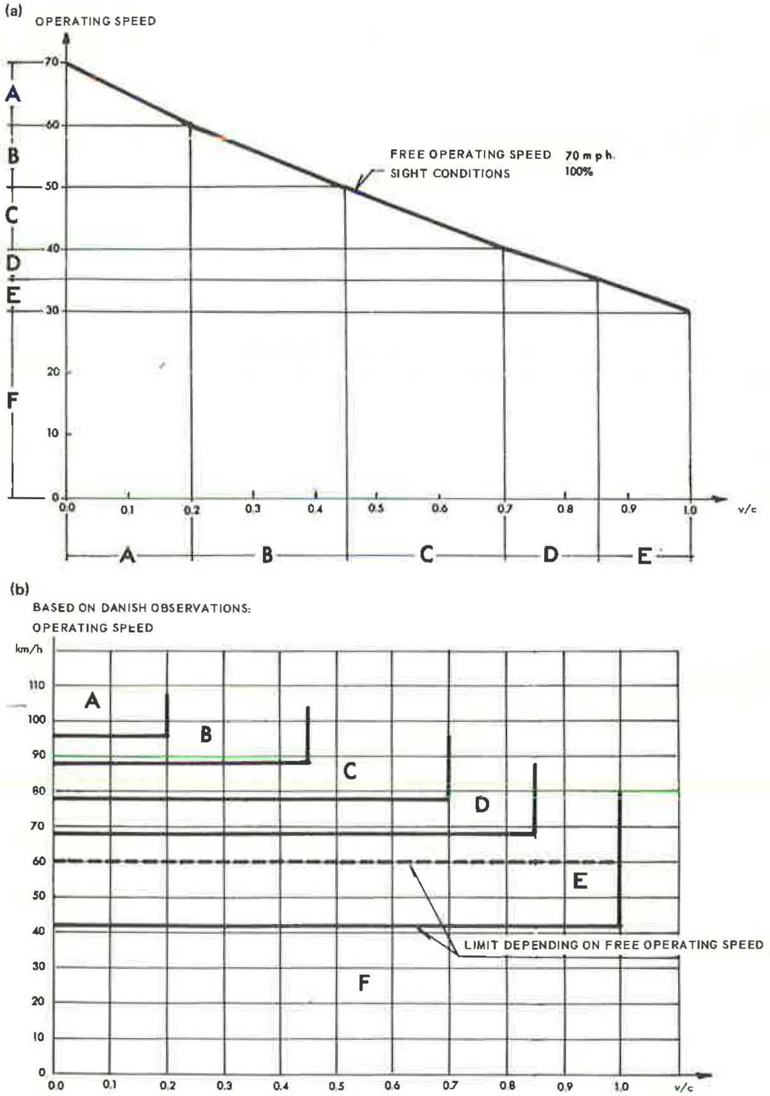
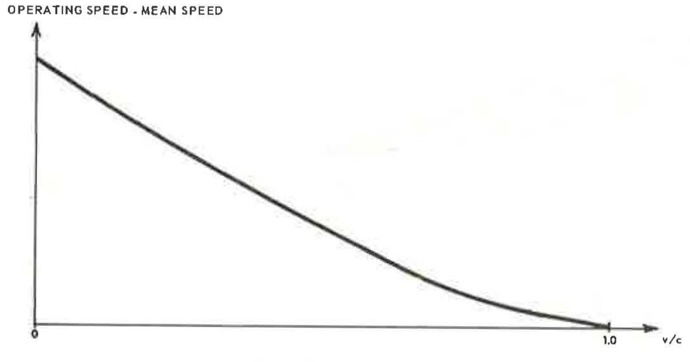



**Figure 13.**



The application of this truck equivalency coefficient means that the traffic load on this road is often around the capacity limit (Fig. 6). If one stands near the road during that period, there is no doubt that the load is close to the capacity limit. This is also corroborated by data obtained from a permanent counting station near the survey point, which shows frequent maximum loads around the capacity based on $E_T = 8$ but no loads much in excess of that figure.

On the two-lane highway A2 between Holbaek and Roskilde on the island of Zealand, which can be classified as a road with moderate gradients (Table 1), similar calculations yield an $E_T$ value of 4 to 5, and the $E_T$ value for roads with moderate gradients is in fact proposed to be taken as $E_T = 4$. The proposal for level roads is $E_T = 2$.

## Measurement of Operating Speeds

In fixing the level of service for a recorded traffic situation, the Manual assumes a knowledge of the operating speed but does not indicate how an observed mean speed can be converted into an operating speed. In the investigation, the following method has been adopted.

It is well known how the speed distribution changes with different traffic volumes; with increasing traffic volume, both the mean speed and its standard deviation are reduced.

The operating speed is the highest speed that a responsible driver will choose in given situations; it has therefore been fixed that the operating speed corresponds to the 85th percentile speed distribution, i.e., 15 percent of the vehicles are driven faster than the operating speed. The 85th percentile figure has been fixed arbitrarily; it is the same figure that has been used in fixing the speed limits. This definition is also supported by a number of laboratories abroad (4, 5).

In this way, the operating speed can be fixed when the momentary speeds of individual vehicles and therefore the speed distribution of the vehicles are known. This would, however, call for a not inconsiderable effort in determining the 85th percentile figure, and a somewhat easier method can also be used: If the operating speed is defined by the 85th percentile, the operating speed will show a greater decrease with increasing traffic volume than the mean speed; i.e., the difference between operating speed and mean speed has the form shown in Figure 13. By comparing the correlations between mean speed and volume-capacity ratio and between operating speed and volume-capacity ratio given in the Manual, one arrives at an almost straight-lined curve. The point of intersection of this curve with the ordinate axis depends on the free operating speed so that the difference increases with the free operating speed (Fig. 14).

A set of curves corresponding to Figure 13 has been prepared for free operating speeds ranging from 50 to 100 km/hr (Fig. 15), based on speed distributions obtained from the four survey locations. Each distribution is plotted for 100 unimpeded passenger cars, and the difference between the 85th percentile and the 50th percentile is read off. Figure 16 shows the result from the highway A10 between Hasselager and Hørning.

## CONCLUSION

The Danish observations have not permitted a check on (a) the basic factor of 2,000 cars per hour in the capacity equation or (b) the effect of the lane width on capacity. As regards the latter, the directives have been adapted to the widths of Danish roads on the basis of the American data alone.

The main finding of the survey is that we in Denmark, other things being equal, drive at higher speeds than those indicated in the Highway Capacity Manual. Similar differences have also been found in other European countries. The question is whether this difference is due to a difference in driving habits between Americans and Europeans or to the fact that the data on which the Highway Capacity Manual is based are now some years old.

For a volume-capacity ratio of 0.5, the difference between the Danish and American observations amounts to about 10 to 15 km/hr. If it is assumed that the basic material of the Highway Capacity Manual is by now about 10 years old, the difference agrees

**Figure 14.**

DIFFERENCE BETWEEN FREE OPERATING SPEED AND OBSERVED MEAN SPEED IN km/h

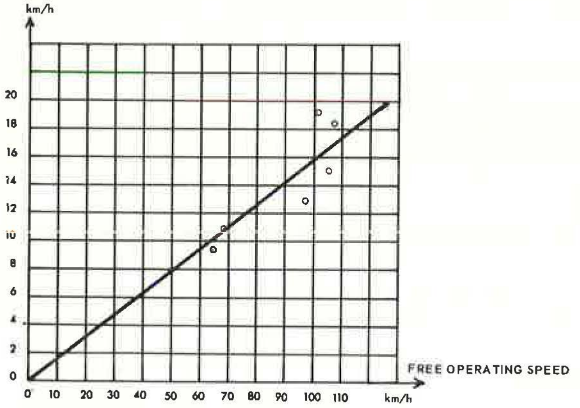



**Figure 15.**

DIFFERENCE BETWEEN:FREE OPERATING SPEED AND MEASURED MEAN SPEED IN KM/H.

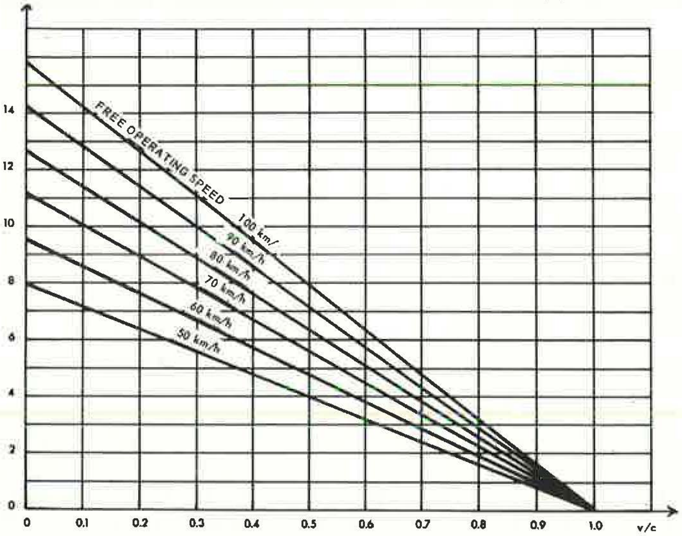
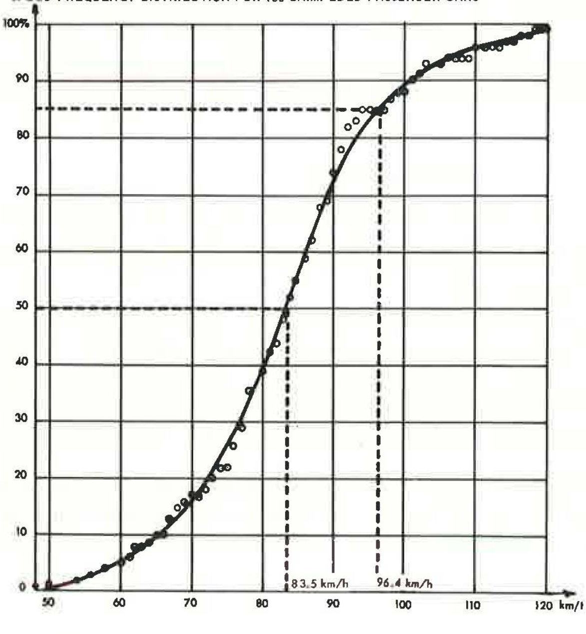



**Figure 16.**

## A 10 HASSELAGER-HØRNING

SPEED FREQUENCY DISTRIBUTION FOR 100 UNIMPEDED PASSENGER CARS



quite well with the general speed increase, experienced in many places, of approximately 1 to 2 km/hr per annum. The Highway Capacity Manual itself refers to observed data showing an increase in the measured mean speeds from 45.2 mph in 1946 to 55.6 mph in 1964, corresponding to 0.9 km/hr per annum. But these speed observations had been carried out during periods of light traffic and thus merely reflect a general desire of being able to increase the free operating speeds. Carrying out the comparisons on Figures 2, 3, 4, and 5 in such a way that the extreme left point of the curve ($v/c = 0$; i.e., the speed corresponds to the free operating speed) is the same for the Danish and American observations should allow for this raised demand for a higher free operating speed.

It thus remains to state that the speed chosen by Danish motorists is less sensitive to increases in traffic volume. Whether this is a specifically Danish or European phenomenon cannot be decided at present, and it is possible that a similar trend could now also be discerned in America. On the other hand, it is not improbable that, because of the rapid increase in the Danish car ownership rates, we have not, to the same degree as in America, learned to drive properly in heavy traffic.

One must be aware that the motorists' speed adaptation to the momentary traffic volume is first and foremost a question of road safety. In fixing the different levels of service, one ought to take into account road safety considerations. As Figure 12 shows, the classification of the levels of service is based on a recording in accordance with the best conditions that can be obtained, without providing any guarantee that a traffic performance corresponding to the curve in Figure 12 does, in fact, take reasonable account of all the factors, including road safety. One should therefore try to determine how the adaptation of the speed takes place so that one may, possibly through the introduction of new explanatory factors, create a better basis for fixing those speeds that would be reasonable to use.

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