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R. Tapio Luttinen and Satu Innamaa

Nordic Highway Capacity

Uninterrupted Flow Facilities in Denmark, Finland, Norway, and Sweden

Finnish National Road Administration
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ABSTRACT

The comparison of Nordic highway capacity calculation methods is part of the Nordic capacity cooperation project NORDKAP. This report presents a comparison of Nordic capacity calculation methods for uninterrupted flow facilities (highway segments).

The Norwegian method follows the 1985 HCM most closely. In Finland the 1985 HCM is followed on freeways and four-lane highways. For two-lane highways the method is modified so that the parameters can be obtained from the Finnra highway database. In Denmark new methods have been documented in draft guidelines. These follow roughly the 1994 HCM, but with a slightly modified logic and locally adjusted parameters. The Swedish method is also under development. The structure of the model is similar to the 1985 HCM, but many adjustment factors are still undefined.

For two-lane highways the ideal capacity is 2,800 pc/h in all Nordic countries. For freeways and multilane highways the ideal capacity 2,000 pc/h/lane of the 1985 HCM is used in Finland and Norway. In Denmark and Sweden higher ideal capacities are used, which reflect more recent results.

The capacities obtained by the Finnish and Norwegian methods are practically the same as the 1985 HCM capacities. The adjustment factors in the Danish method cause a steeper capacity reduction than in the 1985 HCM as the conditions become less ideal. The Swedish method, on the other hand, uses the 1985 HCM adjustment factors for the roadway width, but other adjustments are mostly omitted. Consequently, the Swedish method gives high capacity estimates under unfavorable conditions.

In many countries calculations are performed by special computer software. These software have not been used here, but the calculations and descriptions are based on reported capacity models. The parameters of Finnish IVAR software are, however, briefly discussed.

PREFACE

In 1996 the road administrations in Denmark, Finland, Norway and Sweden started a cooperation project called NORDKAP (NORDiskt KAPacitetssamarbete, Nordic Capacity Cooperation). The project has three objectives:

1. to compare calculation methods for capacity and level of service
2. to coordinate R&D efforts
3. to coordinate the development of national highway capacity manuals.

This report presents a comparison of Nordic capacity calculation methods for uninterrupted flow facilities (highway segments).

There is an extensive development effort going on in all Nordic countries. This fact emphasises the need for a methodological comparison, but also makes it difficult to define the methods to be compared. In Finland and Norway the "handbook" methods have been presented. The Danish and Swedish methods presented are based on current draft guidelines. It is assumed that the reader is familiar with the basic concepts of capacity and level-of-service analysis.

The report has been prepared by Dr. R. Tapio Luttinen from TL Consulting Engineers Ltd. and M.Sc.(Tech) Satu Innamaa from Helsinki University of Technology, Laboratory of Transportation Engineering. This project has been part of the Finnra strategic project S12 (Improvement solutions for main roads). The work has been coordinated by deputy director Pauli Velhonoja from Finnra Traffic and Road Engineering and M.Sc.(Tech) Jukka Ristikartano from Finnra Consulting. M.Sc.(Tech) Åsa Enberg from Helsinki University of Technology, Laboratory of Transportation Engineering has provided very useful comments.

Hopefully, the results presented will be helpful in the development of national guidelines, improve our understanding of highway capacity, and lead to better traffic performance in Nordic highway networks.

Helsinki, June 2000

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Contents

1 INTRODUCTION 6

1.1 Highway Capacity Manual 6
1.2 Nordic capacity methods 7

2 CAPACITY 9

2.1 Capacity models 9
2.1.1 General description 9
2.1.2 Two-lane highways 9
2.1.3 Freeways and multilane highways 9
2.2 Capacity under ideal conditions 10
2.2.1 Ideal conditions 10
2.2.2 Ideal capacity 11

3 ADJUSTMENT FACTORS 13

3.1 Adjustment for terrain type 13
3.2 Adjustment for lane width 14
3.2.1 Freeways and multilane highways 14
3.2.2 Two-lane highways 15
3.3 Adjustment for heavy vehicles 20
3.4 Adjustment for directional distribution 22
3.5 Other adjustment factors 26

4 CONCLUSIONS 28

REFERENCES 29

1 INTRODUCTION

1.1 Highway Capacity Manual

In 1950 the *first edition* of *Highway Capacity Manual* (Bureau of Public Roads 1950), HCM for short, defined three capacity measures for highways:

- *Basic capacity* is “the maximum number of passenger cars that can pass a given point on a lane or roadway during one hour under the most nearly ideal roadway and traffic conditions which can possibly be attained”.
- *Possible capacity* is “the maximum number of vehicles that can pass a given point on a lane or a roadway during one hour, under the prevailing roadway and traffic conditions”.
- *Practical capacity* is “the maximum number of vehicles that can pass a given point on a roadway or in a designated lane during one hour without the traffic density being so great as to cause unreasonable delay, hazard, or restriction to the drivers’ freedom to maneuver under the prevailing roadway and traffic conditions”.

The *second edition* of HCM (Highway Research Board 1965) developed the idea of practical capacity by defining six *levels of service* (A–F). “The maximum number of vehicles which has a reasonable expectation of passing over a given section of a lane or roadway in one direction on multilane highways (or in both directions on a two- or three-lane highway) during a specified time period while operating conditions are maintained corresponding to the selected or specified level of service” was called *service volume*. *Capacity* was defined as “the maximum number of vehicles which has a reasonable expectation of passing over a given section of a lane or a roadway in one direction (or in both directions for a two-lane or a three-lane highway) during a given time period under prevailing roadway and traffic conditions”. The definition was similar to the possible capacity of HCM 1950 (Bureau of Public Roads 1950).

Level of service A described traffic and roadway conditions with “little or no restriction in maneuverability due to the presence of other vehicles, and drivers can maintain their desired speeds with little or no delay”. Levels of service B, C, and D described conditions with increasing restrictions in maneuverability. Level of service E described traffic flow at or near capacity. Level of service F described forced flow operation at low speeds, where volumes were below capacity.

The *third edition* of HCM (Transportation Research Board 1985) was published 20 years later. It extended the scope of the manual to freeway systems, arterial streets, transit, pedestrians and bicycles. The methods were updated to reflect the current research. The third edition has been further updated in 1992 (Transportation Research Board 1992), 1994 (Transportation Research Board 1994), and 1997 (Transportation Research Board 1998).

A slightly revised definition of *capacity* was given in HCM 1985. Capacity is

> the maximum rate of flow at which persons or vehicles can be reasonably expected to traverse a point or uniform segment of a lane or roadway during a specified time period under prevailing roadway, traffic, and control conditions, usually expressed as vehicles per hour or persons per hour.

Capacity was now defined in terms of ‘maximum rate of flow’—not ‘the maximum number of vehicles’ as in the 1965 HCM. Reflecting this change, the ‘service volume’ concept in the 1965 HCM was now replaced with *service flow rate*, which was

> the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given period under prevailing roadway, traffic, and control conditions while maintaining a designated level of service.

Capacity and service flow rates were generally based on 15-minute time periods.

The *fourth edition* (HCM 2000) will be published by the year 2000. The methods for freeways and multilane highways will be very similar to the HCM 1997 (Transportation Research Board 1998), but the two-lane highway methodology will be totally revised (Harwood, May, Anderson, Leiman, & Archilla 1999).

1.2 Nordic capacity methods

All Nordic methods for calculating capacity on highway segments are based on the *Highway Capacity Manual*. Finland, Norway and Sweden have used the 1985 HCM (Transportation Research Board 1985). The current Danish method is based on the 1965 HCM (Highway Research Board 1965), but the new draft guidelines (Vejdirektoratet 1999a) follow more closely the 1994 update of HCM (Transportation Research Board 1994). All these methods have been adjusted to local conditions.

In *Denmark* great attention has been paid to freeways because traffic volumes on the Danish freeway network has increased substantially, and capacity is expected to be reached in several locations (Sørensen & Rysgaard 1997). The present Danish method to calculate the capacity in highway segments is presented in the guidelines *Vejregler* from 1981. Correction factors for freeways were revised in 1996 (Vejdirektoratet 1996). New guidelines for capacity and level of service are under development. The discussion below is based on the draft capacity manual (Vejdirektoratet 1999a). Levels of service are expressed in terms of volume-to-capacity ratios (v/c) and average travel speeds, without any classification, such as A–F used in the HCM.

In *Finland*, capacity is seldom a problem, and it is not considered as important as in other Nordic countries. Capacity problems occur only on certain major highways during summer weekends and on bigger radial highways in the Helsinki metropolitan area. Calculation methods for highway capacity are based on the 1985 HCM (Transportation Research Board 1985) with minor modifications (Pursula & Ristikartano 1987). The Finnish National Road Administration (Finnra) has published guidelines for two-lane highways (Tiensuunnittelutoimisto 1986). Capacity calculations can also be performed with the IVAR (*Investment Impact Analysis Software*) computer software (Tie- ja liikennetekniikka 1998b). IVAR applies the results of HCM (Transportation Research Board 1985), the guidelines for two-lane highways (Tiensuunnittelutoimisto 1986), and an unpublished report for multilane highways (Kehittämiskeskus 1990).

The 1985 HCM level-of-service classification is used in Finland. The adjustment factors for two-lane highways have been adjusted to the Finnish terrain type classification. In the IVAR software (Tie- ja liikennetekniikka 1998a) the level of service is based on speeds and volume-to-capacity ratios specified for 20 facility types.

The *Norwegian* handbook covers one-lane and two-lane highways outside built-up areas, multilane highways, arterials in built-up areas, and weaving sections and ramps. The method does not take into account the correlation of different quality parameters that are included in HCM (level of service, traffic density, speed, and v/c ratio). Levels of service are based on the 1985 HCM. (Giæver 1997)

The *Swedish* capacity manual *Beräkning av kapacitet, kölängd, fördröjning i vägtrafikanläggningar* was published in 1977 (Statens Vägverk 1977). Nowadays capacity calculations are based on the EVA model (Carlsson 1997). It has speed-flow diagrams defined for every highway type and speed limit. The model was updated in the beginning of the 1990's by using data from a traffic monitoring system of 80 fixed measuring points (Carlsson 1992). In addition, simulation was used for two-lane highways. A traffic flow model for four-lane highways is under development. The results of the draft report (Carlsson & Cedersund 1998) have been used below.

In Sweden no methods are presented to evaluate the level of service, but according to the highway design guidelines (Statens Vägverk 1994) new highways should be designed so that the following quality-of-service requirements apply for the design hour:

- Mean travel speed should not be more than 10 km/h lower than the speed limit (20 km/h for lower standard).
- Mean delay should not be larger than five minutes in rural areas.
- The volume-to-capacity ratio should meet the requirements in table 1.1.

Table 1.1: Level-of-service standards in Sweden (Statens Vägverk 1994)

Standard	Suburban	Rural
High	$v/c < 0.7$	$v/c < 0.5$
Medium	$0.7 < v/c < 0.8$	$0.5 < v/c < 0.7$
Low	$v/c > 0.8$	$v/c > 0.7$

2 CAPACITY

2.1 Capacity models

2.1.1 General description

Capacity is the maximum rate of flow at which persons or vehicles can be reasonably expected to traverse a point or uniform segment of a lane or roadway during a specified time period under prevailing roadway, traffic, and control conditions, usually expressed as vehicles per hour or persons per hour (Transportation Research Board 1998). The calculation methods are based on capacity (c_j) at ideal conditions. The prevailing traffic and roadway conditions are considered by multiplying the ideal capacity with adjustment factors for the width of the roadway, the portion of heavy vehicles, the directional distribution of the traffic, etc. Under ideal conditions the adjustment factors are equal to unity.

2.1.2 Two-lane highways

The calculation methods in the 1985 HCM (Transportation Research Board 1985) are based on the level-of-service concept. Capacity is the service flow rate at level of service E. On two-lane highways the capacity (c) is

$$c = c_j (v/c)_E f_w f_{HV} f_d, \qquad (2.1)$$

where c_j is the capacity under ideal conditions, f_w is an adjustment factor for roadway width, f_{HV} is an adjustment factor for the percentage of heavy vehicles, and f_d is an adjustment factor for the directional distribution. The maximum volume-to-capacity ratio at level-of-service E, $(v/c)_E$, is adjusted for terrain type and percent no passing zones. The 1985 HCM model structure is applied in *Finland* (Tiensuunnittelutoimisto 1986) and *Norway* (Giæver 1997).

The *Danish* method (Vejdirektoratet 1999a)

$$c = c_j f_w f_{HV} f_d f_s \qquad (2.2)$$

does not have any adjustment for terrain type. The effect of vertical highway geometry is included in the adjustment factor for heavy vehicles (f_{HV}) only. There is also an additional adjustment factor f_s for slow vehicles, such as tractors or harvesters.

The *Swedish* method (Carlsson 1997) follows the 1985 HCM method (equation (2.1)) but without adjustments for heavy vehicles, terrain type or directional distribution:

$$c = c_j f_w. \qquad (2.3)$$

The capacity is independent of speed limit and sight class. In Sweden sight class is used as a highway classification measure instead of grade and curvature.

2.1.3 Freeways and multilane highways

On *freeways* no adjustment for directional distribution or no-passing zones is needed. The ideal capacity in the 1985 HCM is calculated on a per lane basis and the ideal roadway capacity is obtained by multiplying the lane capacity by the number of lanes (n). A new adjustment factor (f_p) makes a correction for the character of traffic stream (weekday, commuter or other). The freeway capacity according to the 1985 HCM is

$$c = c_j n f_w f_{HV} f_p. \qquad (2.4)$$

For *multilane highways* the 1985 HCM (Transportation Research Board 1985) introduced an additional adjustment factor, f_E, for the type of the highway (divided or undivided) and the development environment (rural or suburban). Accordingly, the capacity equation is:

$$c = c_j n f_w f_{HV} f_p f_E. \tag{2.5}$$

The distance between signalized intersections should be greater than 2 miles (3.2 km), otherwise the method for arterial streets should be applied.

In *Finland* (Pursula & Ristikartano 1987) and *Norway* (Giæver 1997) the equation for freeway capacity (2.4) is used for both freeways and multilane highways. There is, however, no practical difference, because $f_E = 1$ for freeways.

The *Danish* method (Vejdirektoratet 1999a) does not use adjustment factors f_p and f_E. The capacity equation for freeways and multilane highways is

$$c = c_j n f_w f_{HV}. \tag{2.6}$$

The *Swedish* method calculates the capacity separately for each lane. No adjustment factors are used (Carlsson 1997). The draft report for four-lane highways (Carlsson & Cedersund 1998), however, defines adjustment factors for heavy vehicles. The capacity equation is

$$c_i = c_{ji} f_{HV}, \tag{2.7}$$

where c_i and c_{ji} are the capacity and the ideal capacity for lane i, respectively. No adjustment factor for lane width (f_w) could be obtained from the available data. The adjustment factor for terrain type will be analysed later using microscopic models.

2.2 Capacity under ideal conditions

2.2.1 Ideal conditions

The ideal conditions are defined in the 1985 HCM (Transportation Research Board 1985) as follows:

1. Twelve-feet (3.65 m) minimum lane widths.
2. Six-feet (1.8 m) minimum lateral clearance between the edge of the travel lanes and the nearest obstacle or object on the roadside or in the median.
3. Only passenger cars in the traffic stream.
4. Level terrain.
5. The design speed is 70 mi/h (113 km/h) or more on multilane highways and 60 mi/h (97 km/h) or more on two-lane highways.
6. On freeways the driver characteristics are assumed to be typical of weekday commuter streams in urban areas, or regular users in other areas.
7. Multilane highways are divided with no direct access points along the roadway.
8. Two-lane highways have a 50/50 directional split of traffic and no 'no-passing zones'.
9. No impediments to through traffic due to traffic control or turning vehicles.

Under these conditions, the adjustment factors are equal to unity.

2.2.2 Ideal capacity

In the 1985 HCM (Transportation Research Board 1985) the ideal capacity (capacity under ideal conditions) on freeways and multilane highways is 2,000 pc/h/lane. This was the capacity under ideal conditions already in the 1965 HCM (Highway Research Board 1965). If the design speed is 50 mi/h (80 km/h), the ideal capacity is 1,900 pc/h/lane. The ideal capacity of a two-lane highway is 2,800 pc/h in both directions together. These are also the ideal capacities used in Finland and Norway (tables 2.1 and 2.2).

In the 1997 update of the HCM (Transportation Research Board 1998), the ideal capacity on freeways is 2,250–2,400 pc/h/lane, depending on free flow speed. On multilane highways the ideal capacity can reach 2,200 pc/h/lane.

Table 2.1: Ideal capacities on multilane highways

	Ideal capacity (pc/h/lane)			
Highway type	Denmark	Finland	Norway	Sweden
Four-lane freeways	2,300	2,000	2,000	2,500[2)]
Six-lane freeways	2,300	2,000	2,000	2,133[2)]
Four-lane or six-lane highways	2,300	2,000[1)]	2,000[1)]	2,100[2)]

[1)] 1,900 pc/h/lane, if design speed is ≤80 km/h.

[2)] Average lane capacity (Carlsson 1992).

Table 2.2: Ideal capacities on two-lane and three-lane highways, both directions together

	Ideal capacity (pc/h)			
Highway type	Denmark	Finland	Norway	Sweden
Two-lane highway	2,800	2,800[1)]	2,800	2,800
Three-lane highway	2,660			2,600

[1)] 3,080 pc/h on semi-motorways.

All Nordic countries have adopted the 1985 HCM estimate (2,800 pc/h) for ideal capacity on *two-lane highways*. Wide two-lane highways in Denmark and Sweden have, however, higher ideal capacities (see section 3.2.2). A higher ideal capacity for wide two-lane highways is also defined in the Finnish IVAR software (Tie- ja liikennetekniikka 1998a). For Finnish semi-motorways[1] the capacity is estimated as 3,080 pc/h. The HCM 2000 capacity estimate for two-lane highways will be 1,700 pc/h in one direction, but total capacity does not exceed 3,200 pc/h (Harwood, May, Anderson, Leiman, & Archilla 1999). There will be no adjustment for roadway conditions.

In Denmark and Sweden the ideal capacity of *three-lane highways* is lower than the capacity of two-lane highways. In Finland ‘no outstanding increase’ in capacity has been found due to the three-lane design (Enberg 1997).

In Denmark, the ideal capacity of three-lane (2+1) highways is 1,900 pc/h per direction, which gives two-way capacity of 2,660 pc/h, when the effect of directional distribution (section 3.4) is considered. Passing lanes are assumed to be 900–1,400 m long.

For *freeways and multilane highways* Finland and Norway follow the 1985 HCM. The Finnish IVAR software (Tie- ja liikennetekniikka 1998a), however, defines $(v/c)_{\mathrm{E}} = 0.95$ for multilane highways (facility types 13 and 14), which gives a capacity estimate of 1,900 pc/h/lane. (See, however, the discussion about heavy vehicle adjustment in

[1] A semi-motorway is a high-class two-lane rural highway with full access control and motorised traffic only.

IVAR in section 3.3.) Denmark and Sweden use higher ideal capacities, which are more in line with the current HCM update (Transportation Research Board 1998). It is possible that in the final Danish guidelines six-lane freeways will have a higher capacity-per-lane estimate than four-lane freeways (Vejdirektoratet 1999b).

In Sweden (Carlsson 1992) the capacity of four-lane freeways in one direction is 5,000 pc/h (2,100 pc/h on the right lane and 2,900 pc/h on the left lane). The capacity of six-lane freeways is 6,400 pc/h per direction. The estimated speed at capacity on freeways is 76 km/h. On four-lane highways the capacity is 4,200 pc/h per direction, and the speed at capacity is 72 km/h. The draft report for four-lane highways (Carlsson & Cedersund 1998) gives lower and upper limits for capacities on left and right lanes (table 2.3).

Table 2.3: Capacity on Swedish four-lane highways (Carlsson & Cedersund 1998)

Speed limit (km/h)		Left lane (pc/h)	Right lane (pc/h)
70		2,000–2,300	1,700–1,900
90	to CBD	2,300–2,500	1,700–2,000
90	from CBD	2,500–2,800	2,000–2,300
110		2,200–2,700	1,700–2,000

CBD = Central business district.

3 ADJUSTMENT FACTORS

3.1 Adjustment for terrain type

The 1985 HCM defines three terrain types (Transportation Research Board 1985):

1. *Level terrain*—Any combination of grades and horizontal and vertical alignment permitting heavy vehicles to maintain approximately the same speed as passenger cars; this generally includes short grades of no more than 1 to 2 percent.

2. *Rolling terrain*—Any combination of grades and horizontal or vertical alignment causing heavy vehicles to reduce their speeds substantially below those of passenger cars, but *not* causing heavy vehicles to operate at crawl speeds for any significant length of time.

3. *Mountainous terrain*—Any combination of grades and horizontal and vertical alignment causing vehicles to operate at crawl speeds for significant distances or at frequent intervals.

These terrain types are used to determine the passenger-car equivalents for heavy vehicles (see section 3.3). On two-lane highways the terrain types in conjunction with percent no-passing zones are also used to determine the volume-to-capacity ratio (v/c ratio) for each level of service. A *no-passing zone* is a roadway along which sight distance is less than 1500 ft (460 m), or passing is prohibited. This adjustment is considered here.

Table 3.1 displays the adjustment factors $(v/c)_\mathrm{E}$ for terrain type on two-lane highways. This procedure takes into account that capacities vary depending on terrain and the degree of passing restrictions (Transportation Research Board 1985). On level terrain no adjustment is made for passing restrictions. For extended specific grades the 1985 HCM has a separate analysis method.

Table 3.1: Adjustment factors $(v/c)_\mathrm{E}$ for terrain type on two-lane highways in the 1985 HCM (Transportation Research Board 1985)

	Percent no-passing zones					
Terrain	0	20	40	60	80	100
Level	1.00	1.00	1.00	1.00	1.00	1.00
Rolling	0.97	0.94	0.92	0.91	0.90	0.90
Mountainous	0.91	0.87	0.84	0.82	0.80	0.78

The *Danish* guidelines define four (I–IV) grade categories (*stigningskategori*) based on the average gradient and grade length (figure 3.1). The guidelines do not use $(v/c)_\mathrm{E}$, but the grade categories are applied in the estimation of passenger-car equivalents for heavy vehicles.

In *Finland* the adjustment for terrain type is based on hilliness classes (HC) according to table 3.2. HC1 corresponds to level terrain and HC3 to rolling terrain in the 1985 HCM. HC4 does not reduce capacity as much as mountainous terrain. Hilliness classes are based on the hilliness index (table 3.3).

The 1985 HCM adjustment factors (table 3.1) are used in *Norway*. The definitions of terrain types are, however, slightly modified: On level terrain (*flat terreng*) the grades are shorter than one kilometer or not steeper than three percent. Rolling terrain (*kupert terreng*) has 1–2 km long grades of 5–6 percent. Otherwise the definitions are similar to the definitions in 1985 HCM.

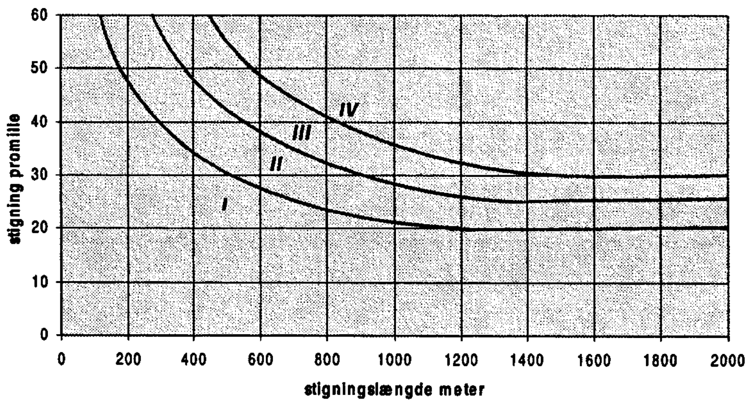

Figure 3.1: Danish grade categories by grade length (meters) and gradient (per mill) (Vejdirektoratet 1999a)

Table 3.2: The adjustment factor $(v/c)_{\mathrm{E}}$ *for terrain type on two lane highways in Finland (Tiensuunnittelutoimisto 1986)*

Hilliness class	Percent no-passing zones 0	20	40	60	80	100
HC1	1.00	1.00	1.00	1.00	1.00	1.00
HC2	0.98	0.97	0.96	0.96	0.95	0.95
HC3	0.97	0.94	0.92	0.91	0.90	0.90
HC4	0.94	0.91	0.88	0.87	0.85	0.84

The *Swedish* method does not use adjustment for terrain type. Neither is terrain type used in heavy vehicle adjustment.

Considering the different criteria for terrain type, the comparison of the methods is problematic. The Swedish method does not have a correction for terrain type. In Norway the definitions are similar to the HCM, but with some quantitative definitions added. These definitions can be used to compare the Norwegian method with the Danish method. The Danish and Norwegian methods are based on grade length and gradient, whereas the Finnish method is based on hilliness classes. In Finland and Denmark there are no mountains and, consequently, no adjustment for mountainous terrain is defined.

The Finnish hilliness class HC3 has the same adjustment factors as the rolling terrain in HCM. The Norwegian method defines rolling terrain as a highway section which has 1–2 km long grades of 5–6 percent. According to figure 3.1 this corresponds to Danish grade category IV. In terms of heavy vehicle adjustment (see section 3.3) the HCM rolling terrain is, however, more like Danish grade category III.

The capacities adjusted for the rolling terrain type are given in table 3.4. It is assumed that the Finnish hilliness class HC3 is equivalent to the Norwegian rolling terrain. The Danish and Swedish methods do not have any terrain type adjustment.

3.2 Adjustment for lane width

3.2.1 Freeways and multilane highways

In *Finland* (Pursula & Ristikartano 1987) the 1985 HCM adjustment factors (f_{w}) for restricted lane width and lateral clearance on freeways and multilane highways are fol-

Table 3.3: Hilliness classes in Finland

Hilliness class	Hilliness index (m/km)
HC1	≤9
HC2	10–16
HC3	17–22
HC4	≥23

Source: Pursula & Ristikartano (1987)

Table 3.4: Capacity on a two-lane highway on rolling terrain in Finland and Norway (other conditions ideal)

Percent no-passing zones	0	20	40	60	80	100
Capacity (pc/h)	2,716	2,632	2,576	2,548	2,520	2,520

Sources: Tiensuunnittelutoimisto (1986), Giæver (1997)

lowed. Table 3.5 displays adjustment factors for 4-lane freeways. The adjustment factors for 6-lane freeways are slightly higher (Pursula & Ristikartano 1987) as presented in the 1985 HCM (Transportation Research Board 1985). For multilane highways the adjustment factors in table 3.5 are supplemented by a further adjustment factor (f_E) as described in section 3.5.

Table 3.5: Adjustment factor for restricted lane width and lateral clearance on four-lane freeways highways in Finland

Lane width (m)	Distance to obstruction on one side (m)				Distance to obstruction on both sides (m)			
	1.8	1.2	0.6	0	1.8	1.2	0.6	0
3.65	1.00	0.99	0.97	0.90	1.00	0.98	0.94	0.81
3.35	0.97	0.96	0.94	0.87	0.97	0.95	0.91	0.79
3.05	0.91	0.90	0.88	0.82	0.91	0.89	0.86	0.74
2.75	0.81	0.80	0.79	0.73	0.91	0.79	0.76	0.66

Source: Pursula & Ristikartano (1987)

In *Norway* (Giæver 1997) the same (HCM) adjustment factors are used as in Finland, but the widths are lower. The Norwegian method also has separate adjustment factors for undivided multilane highways (table 3.6). In addition, a further adjustment factor (f_E) for divided/undivided multilane highways is used as described in section 3.5.

The *Danish* adjustment factors for multilane highways and freeways (tables 3.7 and 3.8) are slightly modified from the 1985 HCM. In *Sweden* f_w is not defined.

Capacities adjusted for distance to obstruction on four-lane freeways and highways are presented in figures 3.2, 3.3, and 3.4. Cubic spline interpolation was used to calculate intermediate values.

3.2.2 Two-lane highways

Table 3.9 displays the adjustment factors for lane and shoulder width (f_w) in the 1985 HCM. These factors are used in Denmark and Norway, but lane widths are 3.50, 3.25, 3.00 and 2.75 meters.

In *Denmark* the shoulder widths are 1.8, 1.2, 0.6 and 0 meters. Wide Danish two-lane highways have a capacity of 3,200 pc/h, but this estimate is not considered accurate

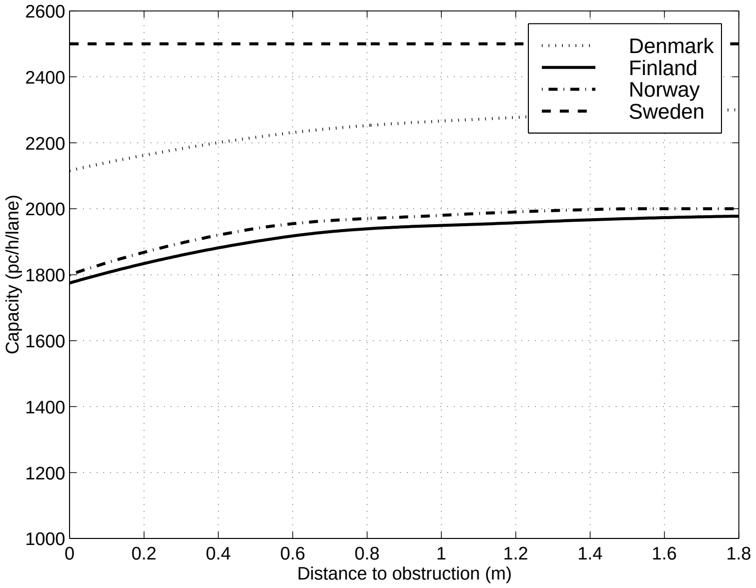

Figure 3.2: Capacity on four-lane freeways as a function of the distance to obstruction on one side of the highway (lane width 3.5 m, other conditions ideal)

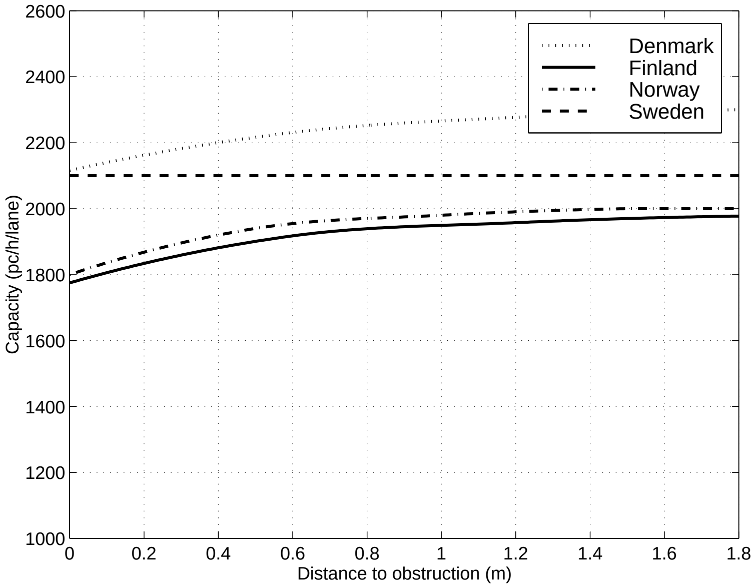

Figure 3.3: Capacity on divided four-lane highways as a function of the distance to obstruction on one side of the highway (lane width 3.5 m, other conditions ideal)

Table 3.6: The adjustment factor for restricted lane width and lateral clearance on freeways and multilane highways in Norway

Type of cross section	Lane width (m)	Distance to obstruction on one side (m)				Distance to obstruction on both sides (m)			
		1.5	1.0	0.5	0	1.5	1.0	0.5	0
Divided	3.50	1.00	0.99	0.97	0.90	1.00	0.98	0.94	0.81
	3.25	0.97	0.96	0.94	0.87	0.97	0.95	0.91	0.79
	3.00	0.91	0.90	0.88	0.82	0.91	0.89	0.86	0.74
	2.75	0.81	0.80	0.79	0.73	0.91	0.79	0.76	0.66
Undivided	3.50	1.00	0.98	0.95	0.88	Not of current interest	Not of current interest	0.94	0.81
	3.25	0.95	0.94	0.92	0.85			0.91	0.79
	3.00	0.89	0.88	0.86	0.80			0.86	0.74
	2.75	0.77	0.76	0.75	0.70				0.66

Source: Giæver (1997)

Table 3.7: Adjustment factor for restricted lane width and lateral clearance on undivided highways in Denmark

Lane width (m)	Distance to obstruction (m)			
	1.8	1.2	0.6	0
$\geq$3.50	1.00	0.97	0.93	0.88
3.25	0.94	0.92	0.88	0.82
3.00	0.87	0.85	0.81	0.75
2.75	0.76	0.74	0.70	0.66

Source: Vejdirektoratet (1999a)

(Vejdirektoratet 1999b). In one direction the maximum flow rate on Danish wide two-lane highways is 2,300 pc/h.

In *Norway* lower values for shoulder widths are used: 1.5, 1.0, 0.5 and 0 meters. These modifications slightly increase the capacity estimates on some highways when compared to the 1985 HCM. This effect can also be observed by comparing the Finnish and Norwegian capacity estimates for multilane highways in figures 3.3, and 3.4.

The adjustment factors in *Finland* (table 3.10) and *Sweden* (table 3.11) are based on the 1985 HCM, but are expressed in terms of standard cross sections. Both tables have adjustment some factors greater than unity, which indicates capacities greater than 2,800 pc/h on some high-class two-lane highways.

In Finland (Tiensuunnittelutoimisto 1986) the ideal capacity for semi-motorways is 3,080 pc/h. The IVAR software (Tie- ja liikennetekniikka 1998a) applies 2,800 pc/h for semi-motorways also, but gives $f_{\mathrm{w}} = 1.30$ for two-lane highways having a wide lanes and pavement wider than 13 meters. The resulting capacity estimate is 3,640 pc/h at ideal conditions. On highways having 6.5–9.5 m wide pavements the Finnish adjustment factors are slightly below the 1985 HCM factors.

In Sweden (Carlsson 1997) the capacity estimate for semi-motorways is 3,000 pc/h, which is also the ideal capacity for 13 meters wide highways. Otherwise, the Swedish adjustment factors follow the 1985 HCM very closely. Table 3.12 displays a comparison of Nordic adjustment factors for roadway width.

Table 3.8: Adjustment factor for restricted lane width and lateral clearance on divided highways and freeways in Denmark

Lane width (m)	Distance to obstruction on one side (m)				Distance to obstruction on both sides (m)			
	1.8	1.2	0.6	0	1.8	1.2	0.6	0
≥3.50 m	1.00	0.99	0.97	0.92	1.00	0.98	0.95	0.86
3.25 m	0.95	0.94	0.92	0.88	0.95	0.93	0.90	0.82
3.00 m	0.90	0.89	0.88	0.84	0.90	0.88	0.86	0.78

Source: Vejdirektoratet (1999a)

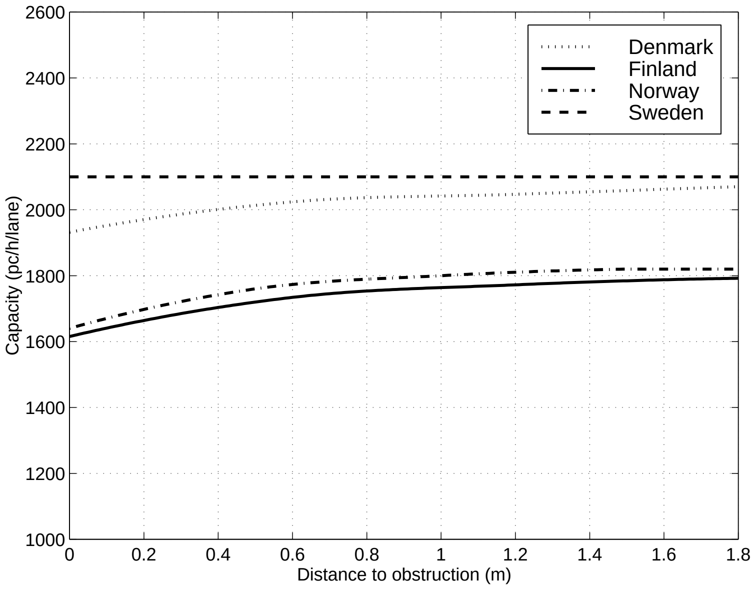

Figure 3.4: Capacity on divided four-lane highways as a function of the distance to obstruction on one side of the highway (lane width 3.0 m, other conditions ideal)

Table 3.9: Adjustment factor for the combined effect of narrow lanes and restricted shoulder width (f_w) at level of service E on two-lane highways in the 1985 HCM (Transportation Research Board 1997)

Lane width	Usable shoulder width 1.8 m	1.5 m	1.2 m	0.9 m	0.6 m	0 m
3.6 m	1.00	0.99	0.97	0.95	0.93	0.88
3.3 m	0.94	0.93	0.92	0.90	0.88	0.82
3.0 m	0.87	0.86	0.85	0.83	0.81	0.75
2.7 m	0.76	0.75	0.74	0.72	0.70	0.66

Table 3.10: Adjustment factor for the width of two-lane highways in Finland

Cross section		
Type	Pavement width (m)	f_W
Semi-motorway	12.0	1.10
12.5/7.5	12.0	1.00
11.5/7.5	11.0	1.00
10.5/7.5	10.0	0.97
10/7	9.5	0.95
9/7	8.5	0.91
8/7	7.5	0.85
7	6.5	0.77
6.5	6.0	0.74
6	5.5	0.66
5.5	5.0	0.58
5	4.5	0.50

Source: Tiensuunnittelutoimisto (1986).

Table 3.11: Adjustment factor for roadway width in Sweden

Roadway width (m)	f_W
Semi-motorway	1.07
13	1.07
11	1.00
8–9	0.93
7–7.5	0.89
6–6.5	0.79
5–5.5	0.64

Source: Carlsson (1997).

Table 3.12: Adjustment factors for the width of two-lane highways

Cross section						
Type	Pavement width (m)	Finland	Denmark	Norway	Sweden	HCM
Semi-motorway	12.0	1.10	1.00	1.00	1.07	1.00
12.5/7.5	12.0	1.00	1.00	1.00	1.04	1.00
11.5/7.5	11.0	1.00	1.00	1.00	1.00	1.00
10.5/7.5	10.0	0.97	0.97	0.99	0.97	0.97
10/7	9.5	0.95	0.97	0.99	0.95	0.96
9/7	8.5	0.91	0.94	0.95	0.93	0.92
8/7	7.5	0.85	0.90	0.91	0.89	0.89
7	6.5	0.77	0.82	0.82	0.79	0.81
6.5	6.0	0.74	0.75	0.75	0.79	0.75
6	5.5	0.66	0.66	0.66	0.64	0.68
5.5	5.0	0.58	—	—	0.64	—
5	4.5	0.50	—	—	—	—

Type: Width of lanes+shoulders / lanes

3.3 Adjustment for heavy vehicles

In the 1985 HCM (Transportation Research Board 1985) the adjustment factor for heavy vehicles (f_{HV}) is obtained from the following equation:

$$f_{HV} = \frac{100}{100 + P_T(E_T - 1) + P_R(E_R - 1) + P_B(E_B - 1)}, \tag{3.1}$$

where P_T, P_R and P_B are the percentages of trucks, recreational vehicles and busses in the traffic. E_T, E_R and E_B (table 3.13) are the corresponding equivalent values for three terrain types described in section 3.1. Adjustment factors are the same for freeways and multilane highways. For specific grades the 1985 HCM has an extended calculation method, which is not discussed here. The 1985 HCM (Transportation Research Board 1985) method is used in *Norway* (Giæver 1997).

Table 3.13: Equivalent values for trucks, recreation vehicles and buses at level of service E on freeways, multilane highways, and two-lane highways in the 1985 HCM (Transportation Research Board 1985)

	Fway & multilane			Two-lane		
Terrain type	E_T	E_R	E_B	E_T	E_R	E_B
Level	1.7	1.6	1.5	2.0	1.6	1.6
Rolling	4.0	3.0	3.0	5.0	3.3	2.9
Mountainous	8.0	4.0	5.0	12.0	5.2	6.5

In *Finland* passenger-car equivalents on both multilane and two-lane highways (table 3.14) are based on hilliness classes (see table 3.3 on page 15). On two-lane highways the equivalence values for hilliness classes HC1 and HC3 are equal to the equivalence values for level and rolling terrains in the 1985 HCM, correspondingly (Tiensuunnittelutoimisto 1986).

Table 3.14: Equivalent values for trucks, recreation vehicles and buses at level of service E in Finland

Hilliness	Multilane[1)]			Two-lane		
class	E_T	E_R	E_B	E_T	E_R	E_B
HC1	1.7	1.6	1.5	2.0	1.6	1.6
HC2	2.0	2.0	1.6	3.5	2.4	2.2
HC3	3.0	2.0	1.6	5.0	3.3	2.9
HC4	5.0	3.0	2.0	8.5	4.2	4.7

[1)] Used in IVAR software.

Sources: Tiensuunnittelutoimisto (1986) and Kehittämiskeskus (1990).

The HCM method is used for Finnish freeways and multilane highways (Pursula & Ristikartano 1987). The IVAR software (Tie- ja liikennetekniikka 1998a), however, uses the passenger-car equivalents presented in an unpublished report of multilane highways (Kehittämiskeskus 1990). Because the effect of heavy vehicles was measured at nonideal conditions, equation (3.1) was modified as follows (Kehittämiskeskus 1990):

$$f_{HV} = \frac{105.2}{100 + P_T(E_T - 1) + P_R(E_R - 1) + P_B(E_B - 1)}. \tag{3.2}$$

In IVAR the base conditions had two percent buses and five percent recreational vehicles. In data input trucks and buses are combined ($P_{HV} = P_T + P_B$). The adjustment is accordingly:

$$f_{\mathrm{HV}} = \frac{100}{100 + 5(E_{\mathrm{R}} - 1) + 2(E_{\mathrm{B}} - 1) + (P_{\mathrm{HV}} - 2)(E_{\mathrm{T}} - 1)}. \tag{3.3}$$

IVAR uses the same modification (3.3) for two-lane highways also. If the assumptions about the percentages of buses and recreational vehicles are not valid, the model has a bias.

The *Danish* guidelines use two categories of heavy vehicles. Category a includes 5.8–12 meters long vehicles. Category b includes vehicles longer than 12 meters. Accordingly, the adjustment factor for heavy vehicles is

$$f_{\mathrm{HV}} = \frac{100}{100 + P_a(E_a - 1) + P_b(E_b - 1)}. \tag{3.4}$$

The passenger-car equivalents (table 3.15) for heavy vehicle categories a and b are defined according to the grade categories in figure 3.1 on page 14.

Table 3.15: Equivalent values for heavy vehicles in Denmark

Grade	Multilane		Two-lane	
category	E_a	E_b	E_a	E_b
I	2.0	2.5	2.5	3.0
II	3.0	4.0	3.5	4.5
III	4.5	6.0	5.0	7.0
IV	6.0	7.5	8.0	10.0

Source: Vejdirektoratet (1999a)

The ideal capacity in the *Swedish* method is expressed in vehicles per hour—not in passenger car units. Consequently, no equivalence values are used. Currently the Swedish method does not have any heavy vehicle adjustment. The draft report for four-lane highways (Carlsson & Cedersund 1998) has, however, proposed adjustment factors, which are presented in table 3.16. For lower (0–5) percentages the adjustment factors are different for left and right lanes. At higher heavy vehicle percentages the adjustment factors are the same for both lanes, because there have not been sufficient field data to define separate values for different lanes.

Table 3.16: Adjustment factors for heavy vehicles on Swedish four-lane highways

Percent heavy vehicles	f_{HV}	
0–5	0.98	left lane
0–5	0.99	right lane
5–10	0.96	
10–15	0.93	
15–20	0.90	

Source: Carlsson & Cedersund (1998)

Figure 3.5 displays the effect of heavy vehicles on the capacity of multilane highways. The HCM methodology is applied for multilane highways in Norway. These curves also describe the Finnish capacity estimates for hilliness classes HC1 and HC3. There are, however, separate curves for the IVAR software. The ideal capacity in IVAR is 1,900 pc/h, whereas the HCM curves are based on ideal capacity 2,000 pc/h. Especially on rolling terrain (HC3) the effect of heavy vehicles is lower in IVAR than in the HCM.

The Danish method is based on different classification of both terrain types and heavy vehicles. Assuming that the Danish grade categories I and III correspond to the level and rolling terrain types in the HCM, the Danish adjustment factors are larger than the HCM factors, but even adjusted capacities is higher than the HCM capacities. The Swedish adjustment factors are those presented in the draft report by Carlsson & Cedersund (1998) and in table 3.16.

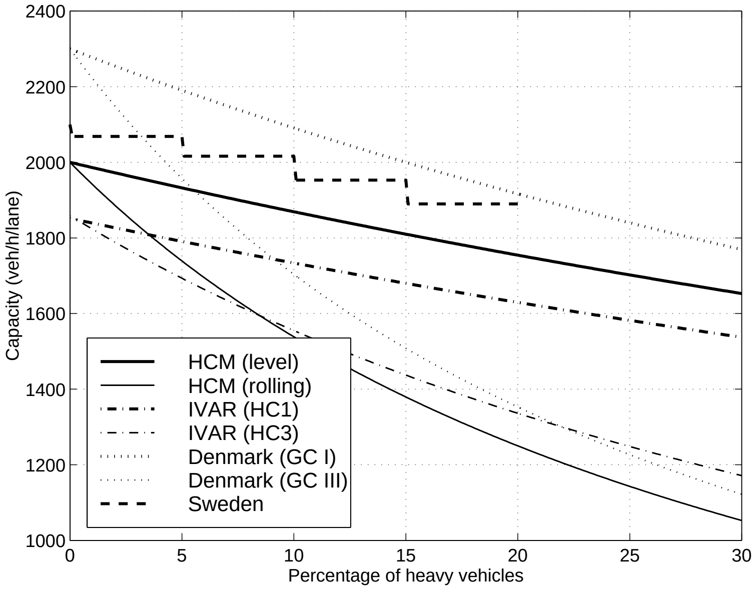

Figure 3.5: The effect of heavy vehicles (trucks = Danish category 'a' vehicles) on capacity on divided four-lane highways (other conditions ideal)

Figure 3.6 shows the effect of heavy vehicles on two-lane highway capacity. The HCM curves for level and rolling terrain describe the results of the Norwegian method and the Finnish method for hilliness classes HC1 and HC3. The curves for IVAR software are also displayed, and they are slightly below the HCM curves. This is caused by the effect of recreational vehicles in IVAR. For level terrain (CG I) the adjustment in Denmark is larger than in the HCM. For grade category III the Danish method has the same passenger car equivalent for trucks as the rolling terrain in HCM ($E_a = E_\mathrm{T} = 5.0$), but the capacity is higher, because the Danish method does not have any terrain type adjustment for passenger cars. The Swedish method does not have any heavy vehicle adjustment.

3.4 Adjustment for directional distribution

The 1985 HCM (Transportation Research Board 1985) adjustment factors, $f_\mathrm{d}(P_\mathrm{d})$, for directional distribution on two-lane highways are displayed in table 3.17. The two-way capacity is

$$C = f_\mathrm{d}(P_\mathrm{d}) 2800\,\mathrm{pc/h}, \qquad (3.5)$$

when the proportion of traffic in major direction is P_d, but other conditions are ideal. There is a slight rounding error: At directional distribution 100/0 the capacity is 1,988 pc/h, not 2,000 pc/h. The adjustment factors of HCM 1985 are used in *Finland* and *Norway*.

The Finnish IVAR software (Tie- ja liikennetekniikka 1998a) is based on directional analysis. The adjustment factors (table 3.17) have been modified accordingly. The

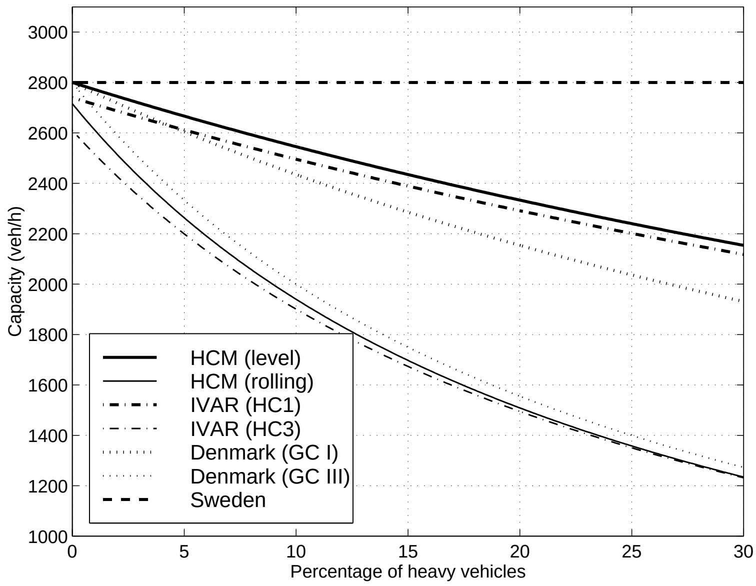

Figure 3.6: The effect of heavy vehicles (trucks = Danish category 'a' vehicles) on capacity on two-lane highways (other conditions ideal)

Table 3.17: Adjustment factors for directional distribution for two-lane highways in HCM 1985 and IVAR

Directional distribution	50/50	60/40	70/30	80/20	90/10	100/0
HCM 1985	1.00	0.94	0.89	0.83	0.75	0.71
IVAR	0.50	0.55	0.62	0.66	0.68	0.71

Sources: Transportation Research Board (1985) and Tie- ja liikennetekniikka (1998a).

capacity adjusted for the effect of opposing flow according to IVAR is

$$C = f_{\mathrm{d}}(P_{\mathrm{d}})\frac{2800}{P_{\mathrm{d}}}\,\mathrm{pc/h}, \tag{3.6}$$

where $f_{\mathrm{d}}(P_{\mathrm{d}})$ is the adjustment factor for directional distribution P_{d}. For an even directional distribution with no passing restrictions the capacity is

$$C = 0.50 \times 2 \times 2800 = 2800\,\mathrm{pc/h}. \tag{3.7}$$

The capacity of unidirectional traffic flow at otherwise ideal conditions is

$$C = 0.71 \times 1 \times 2800 = 1988\,\mathrm{pc/h}. \tag{3.8}$$

The *Danish* adjustment for directional distribution uses the percentage of no-passing zones as an additional parameter (Vejdirektoratet 1999a). The approach will be followed in the HCM 2000, although the adjustment there will also depend on the two-way flow rate (Harwood, May, Anderson, Leiman, & Archilla 1999). In the 1985 HCM the percentage of no-passing zones is included in the volume-to-capacity ratio $(v/c)_{\mathrm{E}}$, which is not used in the Danish method.

The Danish adjustment factors in table 3.18 are applied on a directional basis. For a two-lane highway with no passing restrictions ($P_{\mathrm{np}} = 0$) the adjustment is, within rounding precision, the same as in the 1985 HCM. The adjustment factor is 0.70, if directional distribution is 50/50 ($P_d = 0.5$), or if there are no passing zones on the highway segment being analysed. Other adjustment factors in table 3.18 have been derived by linear interpolation (horizontally).

Table 3.18: Adjustment factors for directional distribution on two-lane highways in Denmark

Directional	Percent no-passing zones, P_{np}					
distribution	0 %	20 %	40 %	60 %	80 %	100 %
100/0 %	1.00	0.94	0.88	0.82	0.76	0.70
90/10 %	0.95	0.90	0.85	0.80	0.75	0.70
80/20 %	0.92	0.88	0.83	0.79	0.74	0.70
70/30 %	0.87	0.84	0.80	0.77	0.73	0.70
60/40 %	0.79	0.77	0.75	0.84	0.72	0.70
50/50 %	0.70	0.70	0.70	0.70	0.70	0.70

Source: Vejdirektoratet (1999a)

Assuming that the opposing flow does not have any effect on capacity, the capacity in one direction is 2,000 pc/h. Without any adverse effect of the opposing flow the two-way capacity would be

$$C = \frac{2000}{P_d}\ \text{pc/h.} \tag{3.9}$$

The capacity adjusted for the effect of opposing flow according to the Danish method is

$$C = f_d(P_d, P_{np})\frac{2000}{P_d}\ \text{pc/h,} \tag{3.10}$$

where $f_d(P_d, P_{np})$ is the adjustment factor for directional distribution P_d and proportion of no-passing zones (P_{np}) as displayed in table 3.18. For an even directional distribution with no passing restrictions the capacity is

$$C = 0.70 \times 2 \times 2000 = 2800\ \text{pc/h.} \tag{3.11}$$

The capacity of unidirectional traffic flow at ideal conditions is 2,000 pc/h. Accordingly, this method avoids the rounding error in the 1985 HCM.

The *Swedish* method does not have any adjustment for directional distribution.

Figure 3.7 displays capacity by directional distribution and percent no-passing zones on Danish two-lane highways. Other conditions are assumed ideal. The upper curve (0 % no-passing zones) is approximately the same as the HCM 1985 curve used in Finland and Norway. HCM does not have any adjustment for percent no-passing zones on level terrain. The capacity estimate for Swedish two-lane highways is constant (2,800 veh/h).

For comparison, the HCM capacities for rolling terrain are displayed in figure 3.8. The curves also represent the capacities on Norwegian two-lane highways with rolling terrain and Finnish two-lane highways with hilliness class HC3.

Figure 3.9 displays rolling terrain capacities with 15 percent heavy vehicles (trucks). The Danish capacities are calculated for grade catagory III and type ‘a’ heavy vehicles. The combined effect of directional distribution and percent no-passing zones is much larger in the Danish method than in the 1985 HCM.

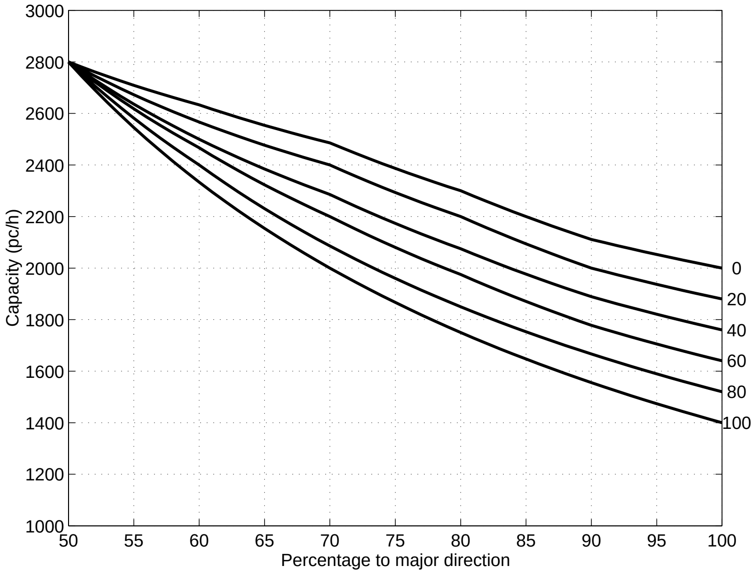

Figure 3.7: Capacity on Danish two-lane highways by directional distribution and percent no-passing zones (percentages on the right, other conditions ideal)

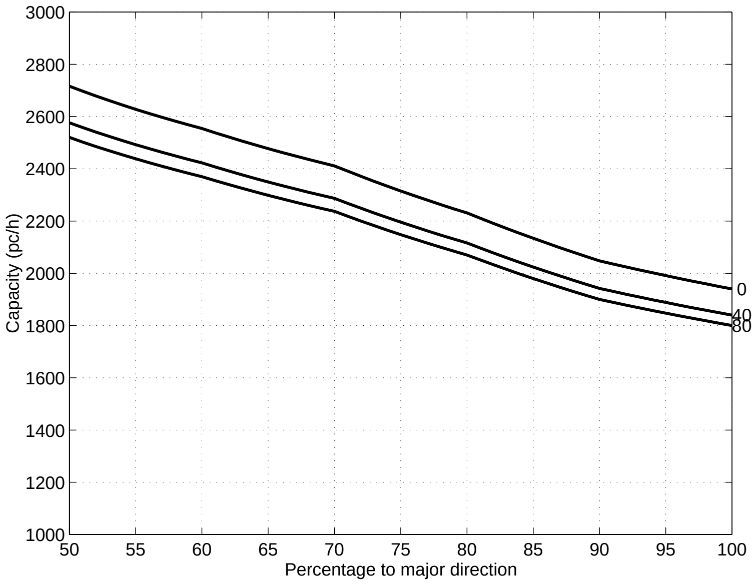

Figure 3.8: HCM 1985 capacity on two-lane highways by directional distribution and percent no-passing zones (percentages on the right, rolling terrain, other conditions ideal)

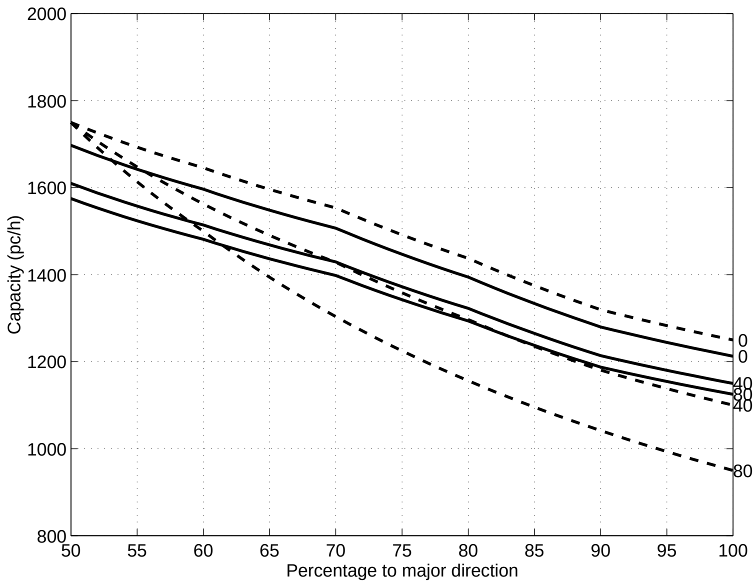

Figure 3.9: HCM 1985 and Danish (dashed line) capacity on two-lane highways by directional distribution and percent no-passing zones (percentages on the right, rolling terrain / grade category III, 15 % trucks, other conditions ideal)

3.5 Other adjustment factors

The 1985 HCM has an adjustment factor (f_p) for *recreational and weekend traffic on freeways and multilane highways*. The adjustment factor for work related and other regular traffic is 1.00. For recreational traffic f_p is 0.75–0.90. This adjustment factor is used in *Finland* (Pursula & Ristikartano 1987) and *Norway* (Giæver 1997).

The 1985 HCM adjustment factor (f_E) for *multilane highway standard and environmental conditions* is presented in table 3.19. This adjustment factor is used in *Finland* (Pursula & Ristikartano 1987) and *Norway* (Giæver 1997).

Table 3.19: Adjustment factor for type of multilane highway and development environment, f_E, in the 1985 HCM(Transportation Research Board 1985)

Environment	Divided	Undivided
Rural	1.00	0.95
Suburban	0.95	0.80

The *Danish* guidelines have an adjustment factor (f_s) for *slow vehicles* with a maximum speed of 25 km/h. These vehicles, such as harvesters, are usually driven as far on the shoulder as possible. Overtaking is thus easier on wide highways. The adjustment factor is based on lane width and the number of slow vehicles per hour in both directions (figure 3.10).

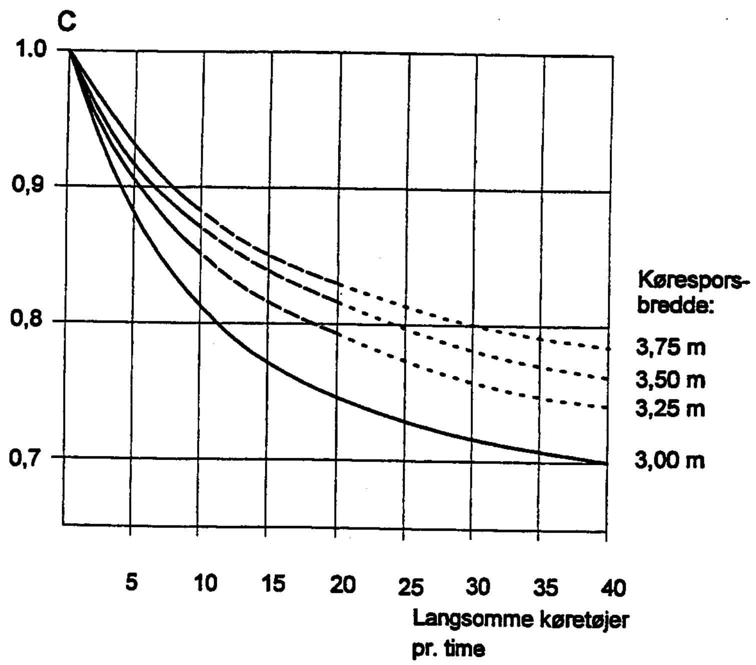

Figure 3.10: Adjustment factor for slow vehicles on Danish two-lane highways (Vejdirektoratet 1999a)

4 CONCLUSIONS

All Nordic capacity calculation methods follow the third edition of the Highway Capacity Manual (Transportation Research Board 1985). The Norwegian guidelines are closest to the 1985 HCM method. The Finnish method is also very close to the HCM. The Swedish method is a simplified version of the 1985 HCM. The draft guidelines in Denmark follow the 1994 update of HCM (Transportation Research Board 1994) and have more originality than the other Nordic methods.

The *Norwegian* method is almost a copy of the 1985 HCM. The only major modification is a distinct adjustment factor (f_w) for restricted lane width and lateral clearance on undivided multilane highways. This makes the capacity estimates for undivided highways lower. Lane and shoulder widths on two-lane and multilane highways are rounded downwards so that the same capacity is reached on narrower highways than in the HCM.

In *Finland* the 1985 HCM method for freeways and multilane highways is used. For two-lane highways the major modifications are in the classification terrain in terms of four hilliness classes (HC1–HC4). This affects the adjustment for terrain type, $(v/c)_E$, and the adjustment for heavy vehicles, f_{HV}. In addition, the roadway width is expressed as standard cross sections. These modifications have been made so that the Finnish road database would be used more easily in capacity calculations. The ideal capacity for a semi-motorway is 3,080 pc/h. The IVAR software gives an ideal capacity of 3,640 pc/h for two-lane highways with wide lanes.

In *Denmark* the ideal capacity on freeways and multilane highways is higher than in the 1985 HCM, and consequently, in Finland and Norway. The Danish guidelines do not have an adjustment factor for terrain type [$(v/c)_E$], for recreational and weekend traffic on freeways and multilane highways (f_p), or for multilane highway standard and environment (f_E). The effect of percent no-passing zones is considered in the context of the adjustment for directional distribution (f_d). The adjustment factors for roadway width (f_w) are slightly modified, and the adjustment factors for heavy vehicles are based on Danish classifications of terrain types and vehicle types. A distinctive feature of the Danish method is the adjustment factor for slow vehicles (f_s). The estimated ideal capacity for wide two-lane highways is 3,200 pc/h.

In *Sweden*, the adjustment factors for two-lane roadway width (f_w) follow the 1985 HCM. No other adjustment factors are used. Consequently, the capacity estimates for rolling or mountainous terrains with a skewed directional distribution, passing restrictions and high heavy vehicle percentages are much higher than in other Nordic methods. For semi-motorways and 13 meters wide two-lane highways the ideal capacity is 3,000 pc/h. On freeways and multilane highways the capacity is higher on inner lane(s) than on outer lane(s). The overall capacity is also higher than in the 1985 HCM. Because the analytical methods are currently under development, simulation studies are suggested for more complicated situations.

The capacity on ideal three-lane highways has been defined in Denmark and Sweden. The capacity estimate for Danish three-lane highways (2,660 pc/h) is a little larger than in Sweden (2,600 pc/h).

In many countries calculations are performed by special computer software. These software have not been used, but the calculations presented above are based on reported capacity models. The Finnish IVAR software was, however, briefly discussed.

REFERENCES

Bureau of Public Roads 1950. *Highway Capacity Manual*. Washington, D.C.: U.S. Department of Commerce.

Carlsson, A. 1992. *Hastighetsflödesdiagram på timnivå*. Väg- och Trafikinstitutet, Trafikavdelningen.

Carlsson, A. 1997. NORDKAP—National översikt, Sverige. In: Vägverket (1997).

Carlsson, A. & Cedersund, H.-Å. 1998. *Modell för fyrfältiga väglänkar: En makro hastighet-flödes-modell för fyrfältig väg*. Royal Institute of Technology. Draft report.

Enberg, Å. 1997. Traffic flow characteristics on a three-lane rural highway in Finland: Results from empirical studies and simulations. In: *Transportation Research Record 1572*. pp. 33–42. Washington, D.C.: Transportation Research Board.

Giæver, T. 1997. Metoder for å bestemme kapasitet og servicenivå på vegstrekninger— en oversikt over allmenn praksis og pågående trafikkavviklings-forskning i Norge. In: Vägverket (1997).

Harwood, D. W., May, A. D., Anderson, I. B., Leiman, L., & Archilla, A. R. 1999. *Capacity and Quality of Service of Two-Lane Highways*. n.a.: Transportation Research Board. (NCHRP Final Report 3-55(3)).

Highway Research Board 1965. *Highway Capacity Manual*. Washington, D.C. Special Report 87.

Kehittämiskeskus 1990. *Monikaistaisten teiden palvelutaso* [Level of service on multilane highways]. Helsinki: Tiehallitus. Unpublished.

Pursula, M. & Ristikartano, J. 1987. Liikennevirta ja liikenteenvälityskyky [traffic flow and capacity]. In: Lyly, S. (ed.) *Liikenne ja väylät I* [Traffic and transportation facilities I]. pp. 131–177. Helsinki: Suomen Rakennusinsinöörien Liitto RIL. RIL 165-1.

Sørensen, H. & Rysgaard, R. 1997. NORDKAP—National oversigt, Danmark. In: Vägverket (1997).

Statens Vägverk 1977. *Beräkning av kapacitet, kölängd, fördröjning i vägtrafikanläggningar*. TV 131.

Statens Vägverk 1994. *Vägutformning 94, Del 5 Sektion*. Borlänge. Publikation 1994:051.

Tie- ja liikennetekniikka 1998a. *IVAR: Investointihankkeiden vaikutusten arviointiohjelmisto* [IVAR: Investment Impact Analysis Software]. Helsinki: Tielaitos. Version 1.2, Unpublished.

Tie- ja liikennetekniikka 1998b. *IVAR-ohjelmiston käyttäjän opas* [User's Manual for IVAR Software]. Helsinki: Tielaitos. Unpublished.

Tiensuunnittelutoimisto 1986. *Kaksikaistaisen tien liikenteellinen palvelutaso: Laskentaohje* [Level of service manual for two-lane highways]. Helsinki: Tie- ja vesirakennushallitus. TVH 723856.

Transportation Research Board 1985. *Highway Capacity Manual*. Washington, D.C. Special Report 209.

Transportation Research Board 1992. *Highway Capacity Manual*. Third ed. Washington, D.C.: National Research Council. (Special Report 209). Revised May 1992.

Transportation Research Board 1994. *Highway Capacity Manual*. Third ed. Washington, D.C.: National Research Council. (Special Report 209). Updated October 1994.

Transportation Research Board 1997. *Metric Analysis Reference Guide: Supplement to 1997 Update of Special Report 209 Highway Capacity Manual*. Washington, D.C. Transportation Research Circular 489.

Transportation Research Board 1998. *Highway Capacity Manual*. Third ed. Washington, D.C.: National Research Council. (Special Report 209). Updated December 1997.

Vägverket 1997. *NORDKAP—NORDiskt KAPacitetssamarbete: Nordiska metoder för beräkning av kapacitet ock servicenivå på vägsträckor*. Dickursby, Finland.

Vejdirektoratet 1996. *Korrektion for trafikkens sammensætning: Motorveje—fri strækning*. Copenhagen. Notat nr. 26.

Vejdirektoratet 1999a. *Kapacitet og serviceniveau*. n.p. Draft.

Vejdirektoratet 1999b. *Kapacitet og serviceniveau: Baggrund og dokumentation*. n.p. Draft.