Vegdirektoratet
Traffic Safety Enviroment and Technology Department
Traffic Safety Section
April 2013

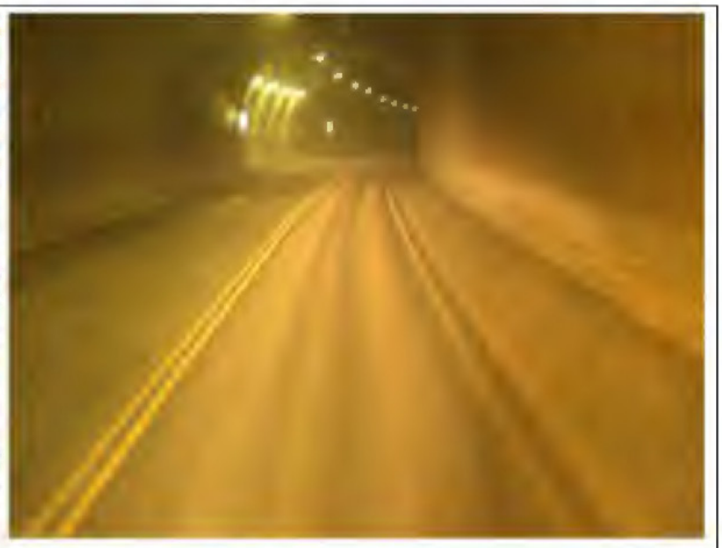
Statens vegvesen

# Automatic Section Speed Control in Tunnels

Effect on speed and accidents

STATENS VEGVESENS RAPPORTER No. 142 E


Statens vegvesen



## Statens vegvesens rapporter

## NPRA reports
Norwegian Public Roads Administration

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|---|---|
| **Tittel** | **Title** Automatic Section Speed Control in tunnels |
| **Undertittel** | **Subtitle** Effect on speed and accidents |
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| **Avdeling** | **Department** Traffic Safety Enviroment and Technology Department |
| **Seksjon** | **Section** Traffic Safety Section |
| **Prosjektnummer** | **Project number** 602710 |
| **Rapportnummer** | **Report number** No. 142 E |
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| **Godkjent av** | **Approved by** Marit Brandtsegg |
| **Emneord** | **Key words** Automatic Section Speed Control in Tunnels, Speed cameras, Effect on speed, Accident reduction |
| **Sammendrag** | **Summary** Trials with Automatic Section Speed Control – ( ASSC) have been carried out in four different tunnels in Norway. The effect on speed has been measured. The reduction is between 3 km/h and 10 km/h. The largest reduction is where the speed is highest before the installation of speed cameras. Accident reduction is between 11% and 20% and is calculated using a new alternative to the power model. |
| **Antall sider** | **Pages** 52 |
| **Dato** | **Date** April 2013 |

# Preface

The National Transport Plan 2014-2023 presents ambitious goals for traffic safety development in Norway, with a maximum of 500 fatalities and serious injuries by 2024. Research shows that to reach this target it is essential to introduce measures that further reduce the speed level on the road network.

Automatic Section Speed Control – (ASSC) is one such measure.

Trials using Automatic Section Speed Control – (ASSC) started in Norway in 2009, initially on three stretches of road in open air. These trials, which are presented in a separate report (VD Report no. 1. January  2011), show very positive results. Significant and permanent speed reductions were achieved over the entire ASSC, with concomitantly large estimated reductions in the number of accidents.

This evaluation report documents the effect of ASSC on driving speed from trials in tunnels. The trials were undertaken in four road tunnels: three subsea road tunnels and one inland, all of which had different technical and trial designs.

Experience indicates that speed levels can be excessive in tunnels in general and in subsea road tunnels in particular. In combination with the considerable potential for disaster from accidents in tunnels, this means that measures targeting driving speeds in excess of the speed limit are necessary and desirable. Concerns for HES issues, as well as the time of the speed limit violations, render traditional police work difficult in tunnels, and this makes ASSC particularly well suited as a measure.

Measurement results have been collected in a cooperation between the Northern Region, Central Region, Eastern Region and the Traffic Safety Section in the Directorate of Public Roads. Bjørn Brændshøi, Head Engineer, and Svenn Fjeld Olsen, Senior Engineer, have participated in the processing of data. The latter has also contributed significantly to the development of a new tool for the estimation of relative risk in speed intervals.

Finn Harald Amundsen, Director of Transport Safety, has provided valuable advice and comments during the project. Arild Ragnøy, Chief Engineer, was responsible for the trials and is the author of this report.

Oslo, April 2013

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# Summary

Automatic Speed Control (ASC) was introduced in Norway in 1988. At the time this took the form of spot speed cameras which involved one or several speed cameras being placed on stretches of road where there were frequent accidents or injuries and where the speed level was high. As of 2013 there are approximately 340 spot speed cameras in Norway.

When Vision Zero was introduced in the late 1990s, further attention was devoted to reducing the number of traffic accidents in Norway. An even stronger instrument based on sanctions against excessive speed was introduced in 2009 in the form of automatic section speed control (ASSC). These are based on the same technology and photographic techniques as spot speed cameras, but to enhance effectiveness the cameras are interlinked in a way that enables the average driving speed between the two cameras to be calcilated. Driving speed is calculated on the basis of the length of the section (km) and measurement of the driving time (h).

The effect of ASSC on driving speed on roads in open air was calculated and reported by the Norwegian Public Roads Administration in 2011, and these cameras were found to be an even stronger instrument for reducing motorists' driving speed. Using knowledge about the correlation between driving speed and accidents/injuries, estimates were made that showed that the effects of ASSC in terms of accident prevention could be as much as three times higher than those of conventional ASC. Since 2011 ASSC have been installed at 14 sites in Norway. The system encompasses 24 individual stretches of road in open air (installing ASSC in both directions is counted as two stretches of road).

This report describes the evaluation conducted on ASSC in tunnels.

Experience indicates that the speed level can be excessive in tunnels in general and in subsea road tunnels in particular. In combination with the considerable potential for disaster from accidents in tunnels, this means that sanctions for driving over the speed limit are necessary and desirable. Concerns for HES issues, as well as the time of the speed violations, render traditional police work difficult in tunnels, and this makes ASSC particularly well suited as a measure.

## Selection of tunnels

In the selection of tunnels for trials of ASSC, emphasis was placed on including different types of tunnels with a focus on various problem areas, in addition to measuring the effect on driving speed. Table S1 shows the selected tunnels, as well as the type of problems we have attempted to elucidate in each.

| Tunnel name | County | Road no. | Tunnel type | Length m | AADT 2010 vhcl/day | Speed limit km/h | Problem to be especially elucidated | Total no. of ASSC (*evaluated*) |
|---|---|---|---|---|---|---|---|---|
| Hell | Sør-/Nord-Trøndelag | E6 | Flat two-way traffic | 3928 | 15000 | 80 | Placement of ASSC cameras outside tunnel openings | 1 *1* |
| Eiksund | Møre og Romsdal | FV653 | Subsea two-way traffic | 7840 | 2030 | 80 | Conversion of ASC at the bottom to full ASSC | 3 *3* |
| Tromsøy-sund | Troms | E8 | Subsea twin-tube one-way traffic | 2021+2016 | 5030/4680 | 80 | Twin-tube tunnel with multiple-lane traffic | 2 *2* |
| Hvaler | Østfold | Fv108 | Subsea two-way traffic | 3887/3874 | 2000 | 80 | Subsea installation with ASSC between the tunnel openings | 3 *1* |

*Table S1: Information on the selected tunnels and the problem areas to be elucidated*

**Effect on driving speed**

Table S2 shows the four selected tunnels, which encompass a total of nine ASSC sections; seven of which are included in our evaluation. The results for each tunnel are presented in separate sections of the report, each of which has an introductory map and a sketch showing key figures for the tunnel as well as the placement of the speed measuring point/counter and cameras.

| Tunnel name | County | Dr. speed km/h Before ASSC | After ASSC | Reduction km/h |
|---|---|---|---|---|
| Hell | Sør-/Nord Trøndelag | 77.9 | 75.3 | 2.6 |
| Eiksund all | Møre og Romsdal | 81.1 | 74.5 | 6.6 |
| S1 | | 84.4 | 75.2 | 9.2 |
| S2 | | 77.9 | 74.3 | 3.6 |
| S3 | | 80.6 | 75.3 | 5.3 |
| Tromsøysund T1 | Troms | 80.3 | 73.6 | 6.7 |
| Tromsøysund T2 | | 79.6 | 73.7 | 5.9 |
| Hvaler dir. 2 | Østfold | 77.8 | 68.8 | 9.0 |

*Table S2: Speed before and after ASSC in the four tunnels included in the trial. Speed reductions in km/h.*

Table S2 shows the results of speed measurements before and after installing ASSC. For Eiksund, a total result from the first to the last measuring point in two subsequent ASSC installations (Eiksund total) is also given. At Eiksund the largest reductions were measured by the ASSC down towards the bottom of the tunnel.

The largest reduction, of 9.2 km/h, was measured in the Eiksund tunnel, road FV653, Møre og Romsdal county. Before the introduction of ASSC, this was also the stretch with the highest driving speed – an average of 84.4 km/h. The results are based on a single-point measurement on the downhill section from Eiksund (km 1580) in the direction from Ørsta in the pre-installation situation, and on system S1 measurements in the same direction at points A1 and M.

The smallest change in driving speed, 2.6 km/h, was measured in the Hell tunnel, E6, Trøndelag county. Here, speed levels before the installation of ASSC were among the lowest recorded. The Hell tunnel had spot speed cameras installed previously.

On the whole, the reductions in speed vary considerably – from 2.6 km/h to 9.2 km/h. Similar to surface roads, there is a correlation between speed before the introduction of ASSC and the speed reduction achieved. The largest reductions are achieved where speed was high before ASSC was installed. The evaluation shows that at least 90% of motorists obey the speed limit after the introduction of ASSC, almost irrespective of the speed before installation.

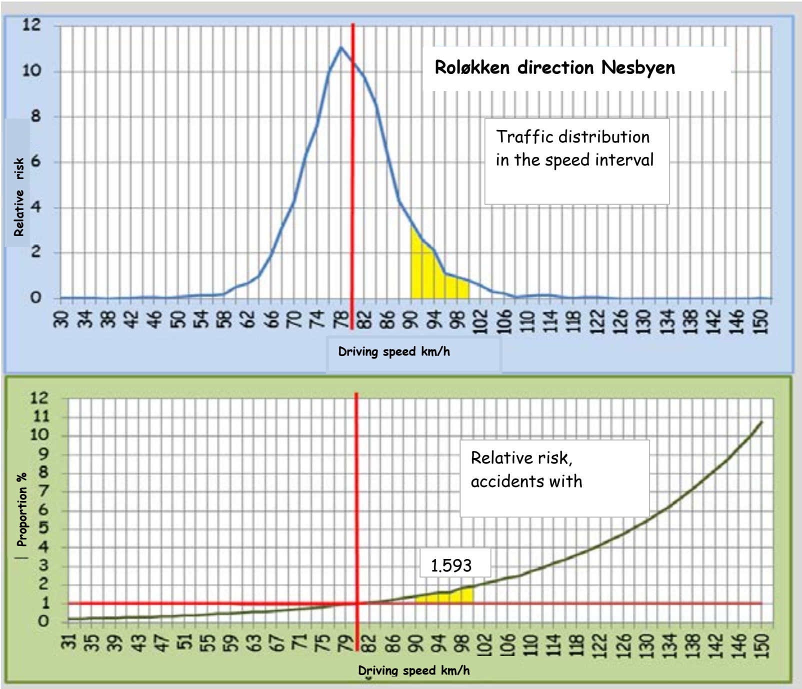
## Correlation between speed and risk

Previously the correlation between driving speed and the risk of accidents was described with the aid of the so-called power model. This model allows for estimates of changes in risk as a function of changes in average speed in a speed distribution.

A scientific article from 2012 re-assessed this model and proposed to replace it with an exponential model. The exponential model gives a better description of data (has higher explanatory ability) than the power model. At the same time, the exponential model predicts that the risk of accidents rises much more steeply than that estimated by the power model. For example, the relative risk (seen in relation to a speed equal to the speed limit (80 km/h with a relative risk = 1)) for a speed v=140 km/h is equal to 3.4 (with the exponent 2.2) when estimated with the power model, whereas the exponential model estimates the risk at 7.7. In other words, if a person drives at 140 km/h, according to the exponential model the risk of an accident is 7.7 times higher than if the driving speed is 80 km/h. The corresponding figure for the Power model is 3.4.

Another feature of the exponential model is that we can estimate the impact of a speed interval on the total risk for the entire population. The only information needed is the average speed and the percentage of vehicles in the relevant interval. This feature is elucidated in an article from 2013, which introduces the multiplicative risk contributions that form the basis for the estimates made here.

The calculation is shown as an example in Figure S1.




| Example: Speed interval <90, 100]km/h | Prop. % | Avg. speed km/h |
|---|---|---|
| | 7.6 | 93.7 |

Risk relative to 80

Rel risk =Exp[0.034(*93.7-80.0)] = 1.593

Contrib. to total relative risk, speed int. <90,100]km/h

$1.593^{0,076}$ = 1.036

*Figure S1: Contribution of speed intervals to total relative risk, estimated using the exponential model*

The average driving speed in the speed interval <90,100] km/h (marked in yellow in the figure) is 93.7 km/h. At this speed, a motorist runs the risk of accidents of 1.593 (=exp 0.034(93.7-80.0)) compared with a motorist driving at 80 km/h. The group with this average speed (93.7 km/h) accounts for 7.6% of the total speed distribution, and the group's contribution to the total risk in the distribution is 1.036(=$1.593^{0.076}$ – see explanatory notes). This can be interpreted as denoting that this group's choice of speed entails an increase in risk of 3.6% for the entire group when compared to an alternative choice of driving speed of 80 km/h. The accident reduction that can be achieved by getting this group to reduce their driving speed to 80 km/h would amount to 3.4% (=1-1/1.036).

### Estimated accident reduction

Using the calculation tool presented above, the expected reduction in the number of accidents can be estimated as change in relative risk. The term "relative risk" means the risk relative to the speed limit (in this case 80 km/h) which is set equal to 1. Changes in relative risk from before to after the installation of ASSC can then be used for calculating changes in the number of accidents (accident reduction).

Table S3 shows an overview of speed distribution, relative risk and total contribution to risk changes before and after ASSC was introduced in the four tunnels the trial encompasses. It is divided into speed intervals lower or equal to the speed limit (<=80 km/h), higher than the speed limit (>80 km/h) and "all" for each of the tunnels.

| Speed interval km/h | BEFORE Prop. % | Avg. speed km/h | Relative risk | Total risk contr. | AFTER Prop. % | Avg. speed km/h | Relative risk | Total risk contr. | CHANGE after/before | Accident reduction % |
|---|---|---|---|---|---|---|---|---|---|---|
| **Hell, E6, Trøndelag** | | | | | | | | | | |
| <=80 | 67.8 | 74.9 | 0.840 | 0.889 | 91.4 | 73.5 | 0.802 | 0.817 | 0.920 | **8.0** |
| >80 | 32.2 | 84.3 | 1.157 | 1.048 | 8.6 | 83.5 | 1.126 | 1.010 | 0.964 | **3.6** |
| Alle (Hell) | 100.0 | 77.9 | 0.931 | 0.931 | 100.0 | 74.3 | 0.825 | 0.825 | 0.886 | **11.4** |
| **Eiksund, FV 653, Møre og Romsdal** | | | | | | | | | | |
| <=80 | 50.2 | 74.2 | 0.821 | 0.906 | 88.7 | 74.3 | 0.824 | 0.842 | 0.930 | **7.0** |
| >80 | 49.8 | 87.0 | 1.269 | 1.126 | 11.3 | 82.9 | 1.104 | 1.011 | 0.898 | **10.2** |
| Alle (Eiksund) | 100 | 80.6 | 1.021 | 1.021 | 100 | 75.3 | 0.852 | 0.852 | 0.835 | **16.5** |
| **Hvaler, FV108, Østfold** | | | | | | | | | | |
| <=80 | 62.9 | 71.4 | 0.748 | 0.833 | 93.8 | 70.6 | 0.727 | 0.741 | 0.890 | **11.0** |
| >80 | 37.1 | 88.6 | 1.338 | 1.114 | 6.2 | 83.5 | 1.128 | 1.007 | 0.904 | **9.6** |
| Alle (Hvaler) | 100.0 | 77.8 | 0.928 | 0.928 | 100.0 | 71.4 | 0.747 | 0.747 | 0.805 | **19.5** |
| **Tromsøysund, E8 Troms** | | | | | | | | | | |
| All T1 | 100.0 | 80.3 | 1.010 | 1.010 | 100.0 | 73.6 | 0.804 | 0.804 | 0.796 | **20.4** |
| All T2 | 100.0 | 79.6 | 0.986 | 0.986 | 100.0 | 73.7 | 0.807 | 0.807 | 0.818 | **18.2** |

*Table S3: Average speed, percentage of motorists, relative and total contribution to risk before and after ASSC distributed among speed intervals (>=80 km/h and >80 km/h) in the four trial tunnels. Estimated risk change after/before ASSC and change in number of accidents in percentages.*

For the Hell tunnel the average speed decreased from 77.9 km/h to 74.3 km/h as a result of ASSC. The relative risk thus declined from 0.931 to 0.825. The change in risk (after/before) is therefore 0.886, and the expected reduction in the number of accidents can be estimated at 11.4% (1-0.886). Divided into the two speed fractions (<=80 km/h and >80 km/h), the table shows that the greatest contribution to total risk reduction, 8.0%, comes from the group with a driving speed of <=80 km/h. Here the average speed dropped from 74.9 km/h to 73.5 km/h while at the same time the group's percentage of motorists increased from 67.8% to 91.4%. The >80 km/h group contribute with an expected accident reduction of 3.6%. This result helps to emphasise and explain how ASSC functions as a measure. Those who drive at a speed in excess of the limit reduce their speed quite considerably. After the installation of ASSC, almost 90% of motorists drive at a speed that is under the limit, while others who in general drive at a speed under the limit also reduce their speed somewhat. This is considered a sort of “bonus” when estimating the expected accident reduction. Strictly speaking, the expected reduction in accidents would have been 4.1% if all those driving at a speed higher than the limit had reduced their speed to exactly the speed limit and if all the other motorists had chosen to drive at the same speed as previously.

The expected reduction in accidents is directly dependent on the size of the reduction in speed. As the table illustrates, the greatest expected accident reduction is in the Tromsøysund tunnel, a total reduction of 20.4%. The reduction in speed is greatest here – 6.7 km/h, from 80.3 km/h to 73.7 km/h.

All the estimated reductions in the number of accidents are large and vary from 11.4% in the Hell tunnel to 20.4% in the T1 section in Tromsøysund. The results from these trials are thus uniformly positive and help to emphasise that ASSC constitute a very strong traffic safety measure in tunnels and produce results that are equivalent to those previously attained for roads in open air.

**Potential for reduction in the number of accidents**

The expected accident reduction estimated above is based on the actual change in speed measured before and after the installation of ASSC. The calculation tool presented can also be used for estimating **the potential for reduction in the number of accidents.** This is exclusively used for measurements of speed **before** the installation of ASSC based on an assumption that all motorists driving at speeds over the speed limit would reduce their speed and adapt it to the speed limit. In practice this means that the relative risk for the group with a speed of >80 km/h is assumed to be reduced to 1.0. Table S3 showed that the relative risk for this group measured after ASSC was installed is very close to 1 (Hell 1.010, Eiksund 1.011 and Hvaler 1.007).

A calculation of this kind has been conducted at the end of the report, and an explanation is also given for how the potential for reduction in the number of accidents depends on whether all speeds (setting the reaction limit for sanctions) over 80 km/h, 90 km/h or 100 km/h respectively are removed.

This calculation can be used in future versions of criteria for the use of ASC or ASSC.

# 1. Introduction

Automatic Speed Control (ASC) was introduced in Norway in 1988. At the time this took the form of spot speed control, called Automatic Speed Control (ASC) which involved one or several speed cameras being placed on stretches of road where there were frequent accidents or injuries and where the speed level was high. As of 2013 there are approximately 340 spot speed cameras in Norway.

Spot speed cameras have been evaluated on several occasions with a view to assessing their effect on accidents and on driving speed. The conclusion was that spot speed cameras constitute a strong and necessary instrument in traffic safety efforts in Norway. The average accident reduction was measured at approximately 16%, and somewhat higher for serious accidents.

When Vision Zero was introduced in the late 1990s, further attention was devoted to reducing the number of traffic accidents in Norway. An even stronger instrument based on sanctions against excessive speed was introduced in 2009 in the form of Automatic section speed control (ASSC). These are based on the same technology and photographic techniques as spot speed cameras, but to enhance effectiveness the camera boxes are interlinked in a way that enables the average driving speed between the two cameras to be calculated. Driving speed is calculated on the basis of the length of the section (km) and measurement of the driving time (h).

The effect of ASSC on driving speed on roads in open air was calculated and reported by the Norwegian Public Roads Administration in 2011, and these cameras were found to be an even stronger instrument for reducing motorists’ driving speed. Using knowledge about the correlation between driving speed and accidents/injuries, estimates were made that showed that the effects of ASSC in terms of accident prevention could be as much as three times higher than those for conventional ASC. Since 2011 ASSC has been installed at 14 sites in Norway. The system encompasses 24 individual stretches of road in open air (installing ASSC in both directions is counted as two stretches of road).

Parallel with this project, under the auspices of the Public Roads Administration, Directorate of Roads, experiments have been made using ASSC in tunnels in Norway. This involves new challenges and problems – both those of a purely technical nature and those concerning motorists’ adaptations to the system.

This report describes the evaluation conducted on ASSC in tunnels.

# 2. Automatic section speed control (ASSC) on roads in open air

The effect of ASSC on driving speed was evaluated in 2011 (Ragnøy 2011). The results of this evaluation are shown in Table 1, supplemented with data from ASSC installed on road RV7 between Bromma and Nesbyen in Hallingdal in summer 2011. The main results are presented in Table 1 as points of reference and comparison.

| Location | County | Road no. | Length m | AADT 2009 vhcl/day | Speed limit km/h | Driving speed km/h Before ASSC | After ASSC | Reduction % |
|---|---|---|---|---|---|---|---|---|
| Bakkevann | Telemark | E18 | 8600 | 6500 | 80 | 76,7 | 74.0 | 2.7 |
| Dovreskogen | Oppland | E6 | 5059 | 3425 | 80 | 89.4 | 80.6 | 8.8 |
| Alvdal | Hedmark | RV3 | 9530 | 2125 | 80 | 88.5 | 78.3 | 10.2 |
| Nesbyen | Buskerud | RV7 | 6700 | 5000 | 80 | 77.5 | 72.6 | 4.9 |

*Table 1: Results from the evaluation of ASSC. Site identity, length, AADT, speed limit and driving speed measured before and after ASSC.*

The table shows that to some extent significant effects were measured on driving speed. The greatest effect is at Alvdal, road RV3, in Hedmark county, where a speed reduction of 10.2 km/h was measured – from 88.5 km/h in the before situation to 78.4 km/h afterwards. A similar reduction was seen on the E6 route in Dovreskogen, measured at 8.8 km/h. On the E18 at Bakkevann the reduction was measured at 2.7 km/h, from 76.7 km/h to 74.0 km/h. It is worth noting that the speed in the before situation here is lower than that at the other sites. The average speed here was 76.7 km/h before the installation of ASSC, which is somewhat lower than the speed limit. With the spread of speed (measured in km/h) found here, this nonetheless means that 36.8% of motorists drive faster than the speed limit.

The reduction in speed achieved shows a clear correlation with the speed measured before the installation of ASSC.

On the introduction of ASSC at Nesbyen on the RV7 in Hallingdal, driving speed is reduced by 4.9 km/h on the 6,700 metre section from A (Bromma) to B (Nesbyen) – from 77.5 km/h in the before situation to 72.6 km/h afterwards. The spread is reduced from 8.7 km/h to 5.4 km/h. The percentage of those with a driving speed over the speed limit of 80 km/h is reduced from 37.7% to 6.0%, and the percentage of those with a driving speed over 90 km/h is reduced from 7.9% to 0.4% after the installation of ASSC.

This is shown in Figure 1.

The figure also shows that the driving speed measured at cameras in point A and B is reduced more than that on the section of road. At point A (Bromma) the speed is reduced by 11.8 km/h, and at point B (Nesbyen) by 12.8 km/h. This is in line with the results from evaluations of other ASSC on roads in open air. On the whole the reduction is greater at point B than at point A, and greater at these points than on the stretch of road.

| Northbound | A Bromma (point) | | | Roløkken | Section | | B Nesbyen (point) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Before | After | Change % | Before | A-B | Change % | Before | After | Change % |
| **Number** | 40730 | 74051 | | 42203 | 74069 | | 43609 | 74030 | |
| **Average km/h** | 76.1 | 64.3 | -11.8 | 77.5 | 72.6 | -4.9 | 77.5 | 64.7 | -12.8 |
| **Spread km/h** | 8.9 | 7.9 | -1.0 | 8.7 | 5.4 | -3.3 | 8.8 | 8.8 | 0.0 |
| **Prop. >80km/h** | 31.2 | 1.0 | -30.2 | 37.5 | 6.0 | -31.5 | 38.3 | 2.0 | -36.3 |
| **Prop. >90km/h** | 6.0 | 0.0 | -6.0 | 7.9 | 0.4 | -7.5 | 7.0 | 0.1 | -6.9 |

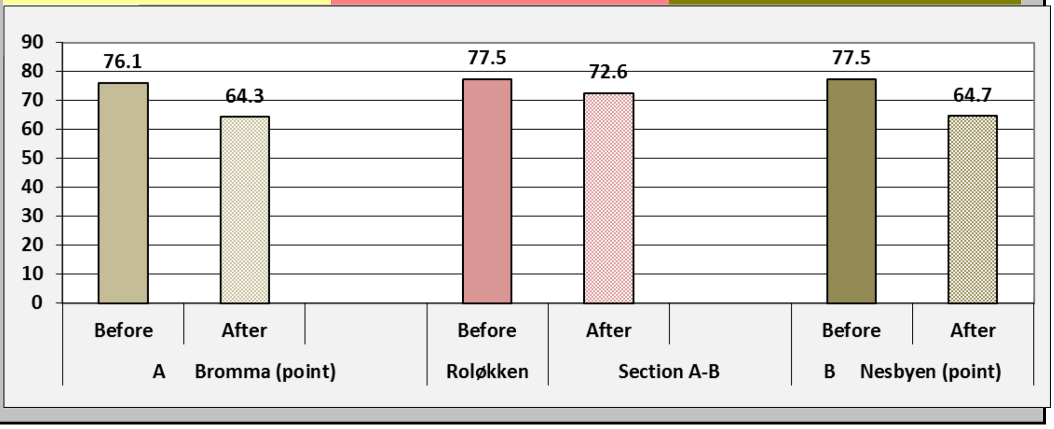



*Figure 1: Before and after ASSC at Nesbyen, RV7, Hallingdal.*
*No. of vehicles, average speed, spread and percentage over 80 and 90 km/h respectively.At camera point A at Bromma, on section AB and at camera point B at Nesbyen.*

The relatively low driving speed at points A and B after the installation of ASSC is worth noting, taking into account that the speed limit is 80 km/h.

More detailed analyses have also been made of measurements of individual vehicles on the stretch of road in Hallingdal to enable motorists' reactions and adaptations to be observed more efficiently.

This is shown in Figure 2.

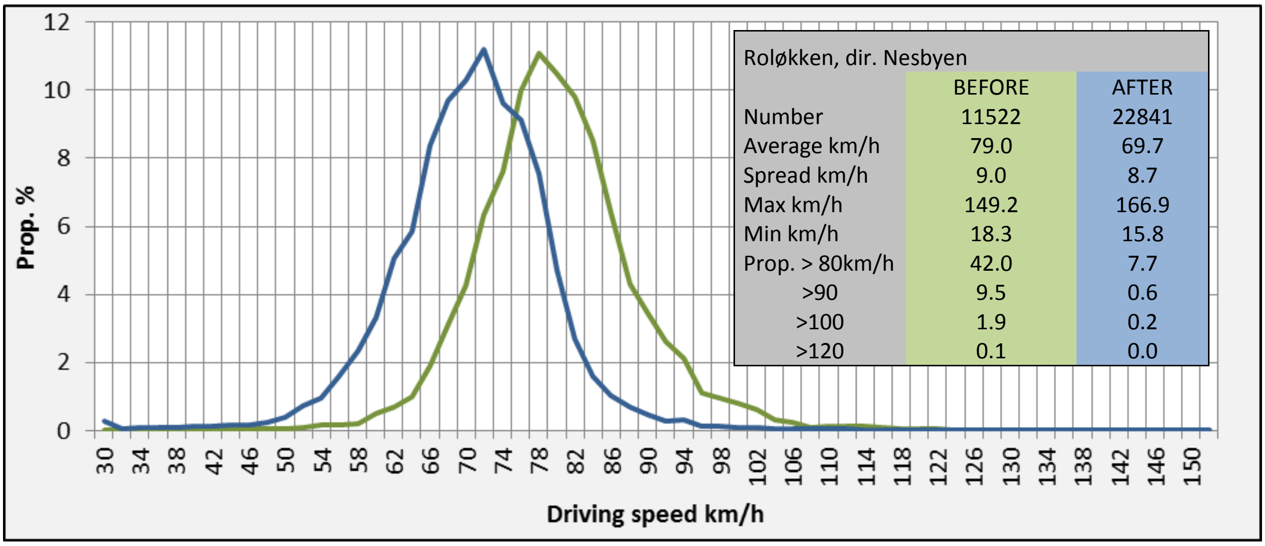



*Figure 2: Speed distribution before and after ASSC at Nesbyen, RV7, Hallingdal. Individual vehicles at Roløkken. No. of vehicles, average and spread (km/h). Percentage of motorists over 80, 90, 100 and 120 km/h respectively.*

The figure was compiled from observations of individual vehicles at the Roløkken measurement point located approximately in the middle of the ASSC section. The figure includes a total of approximately 33,000 vehicles, 11,000 of which were observed in the pre-installation situation in March 2011 and 22,000 in the situation after the installation in July of the same year.

The average speed drops from 79.0 km/h to 69.7 km/h, corresponding to a reduction of 9.3 km/h or 11.8%. (This is the reduction that can be used for estimating the effect on injuries and accidents.)

The spread of speed declines marginally from 9.0 km/h to 8.7 km/h. This indicates that the reduction in speed is fairly even over the entire spread. There will always be a greater spreead at individual points than in section measurements. The percentage of those with a driving speed faster than the speed limit is substantially reduced, from 42.0% to 7.7%, while the percentage with driving speeds over 90 km/h declines from 9.5% in the before situation to 0.6% after the installation of ASSC. The corresponding percentage with driving speeds over 100 km/h declines from 1.9% to 0.2%.

The figure shows that motorists adapt to ASSC in two different ways:

ASSC as an instrument that imposes sanctions means that motorists who drive at a speed over the speed limit reduce their speed quite substantially. The percentage of those with a driving speed over >80 km/h declines from 42.0% to 7.7%.

At the same time, the entire speed distribution is shifted to the left of the figure. This means that those driving at a speed under the speed limit also show a tendency to reduce their driving speed.

Table 2 shows how the two groups (driving speed >80 km/h and <=80 km/h) reduce their driving speed.

| Speed interval km/h | BEFORE Number /prop. veh | BEFORE Speed km/h | AFTER Number/prop. veh | AFTER Speed km/h | Change Speed km/h | Change % |
|---|---|---|---|---|---|---|
| >80 | 4839 | 87.2 | 1766 | 86.1 | 1.1 | 1.3 |
| | 42.0 | | 7.7 | | | |
| <=80 | 6683 | 73.8 | 21074 | 68.8 | 5.0 | 6.8 |
| | 58.0 | | 92.3 | | | |
| ALL | 11522 | 79.4 | 22840 | 69.70 | 9.7 | 12.2 |

*Table 2: Driving speed before and after ASSC measured at Roløkken, RV7, Hallingdal. Motorists with driving speeds >80km/h and <=80km/h respectively. Percentages and average speeds.*

The table shows that the group that in the before situation have a driving speed of >80 km/h reduce their average speed by 1.1 km/h or 1.3% from 87.2 km/h to 86.1 km/h. Similarly those with a driving speed of <=80 km/h in the before situation show a reduction of 5.0 km/h or 6.8%. Even though the change of speed in the group with a driving speed of >80 km/h appears relatively small, this must be understood in the total perspective along with the fact that this group is substantially reduced. The percentage with a driving speed over 80 km/h was reduced from 42.0% in the before situation to 7.7% afterwards.

Figure 1 showed relatively low driving speeds at points A and B after the installation of ASSC – 64.3 km/h and 64.7 km/h respectively. This may indicate that motorists have not completely understood how ASSC work, where no reactions to possible sanctions take place at the measuring points. To demonstrate the possibility of this adaptation changing over time, similar measurements were taken in the situation after the installation of ASSC over a longer period of time.

Later measurements from ASSC – taken in October 2011, December 2011 and March 2012 respectively – do not however indicate that the measured average speed changes substantially over time. At the dates mentioned above the average driving speeds were measured at 73.8 km/h, 73.0 km/h and 74.8 km/h. The measurement from March 2012 is shown in Figure 3.

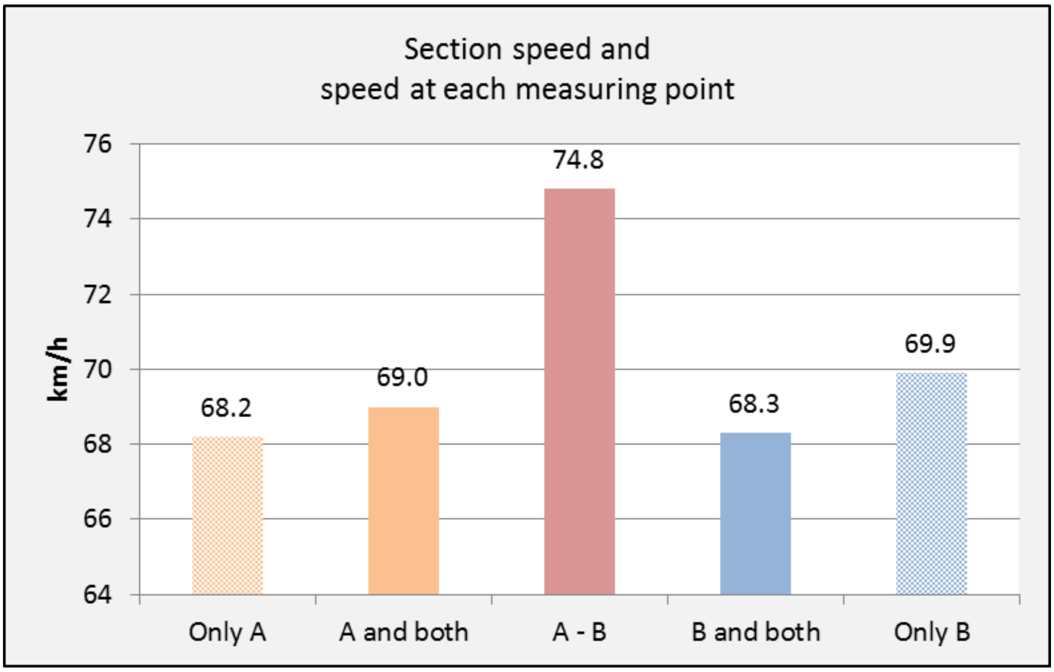



*Figure 3: Measurements after the installation of ASSC, Nesbyen, RV7, Hallingdal, March 2012. Driving speed at points A and B according to whether the motorists were recorded at one point (only A or only B) or both points (A and both, B and both). Speed on section AB (A-B).*

As the figure shows, the speed on the section between points is measured at 74.8 km/h. At each of the measuring points (the camera boxes) the speed is measured at 69.0 km/h at point A and 68.3 km/h at point B. This indicates that the relatively low driving speed at the cameras also continues over time. In addition, the relationship between driving speeds for motorists who are recognised at one or both measuring points has not changed.

# 3 Automatic section speed control (ASSC) in tunnels

## 3.1 General information on the placing of speed cameras in tunnels

A tunnel (the entire tunnel) is to be regarded as a road element where the risk of accidents (accidents/million vehicle kilometres driven) is lower than that for roads in open air, but where the consequences of any accident will normally be more serious than would be the case for roads in open air.

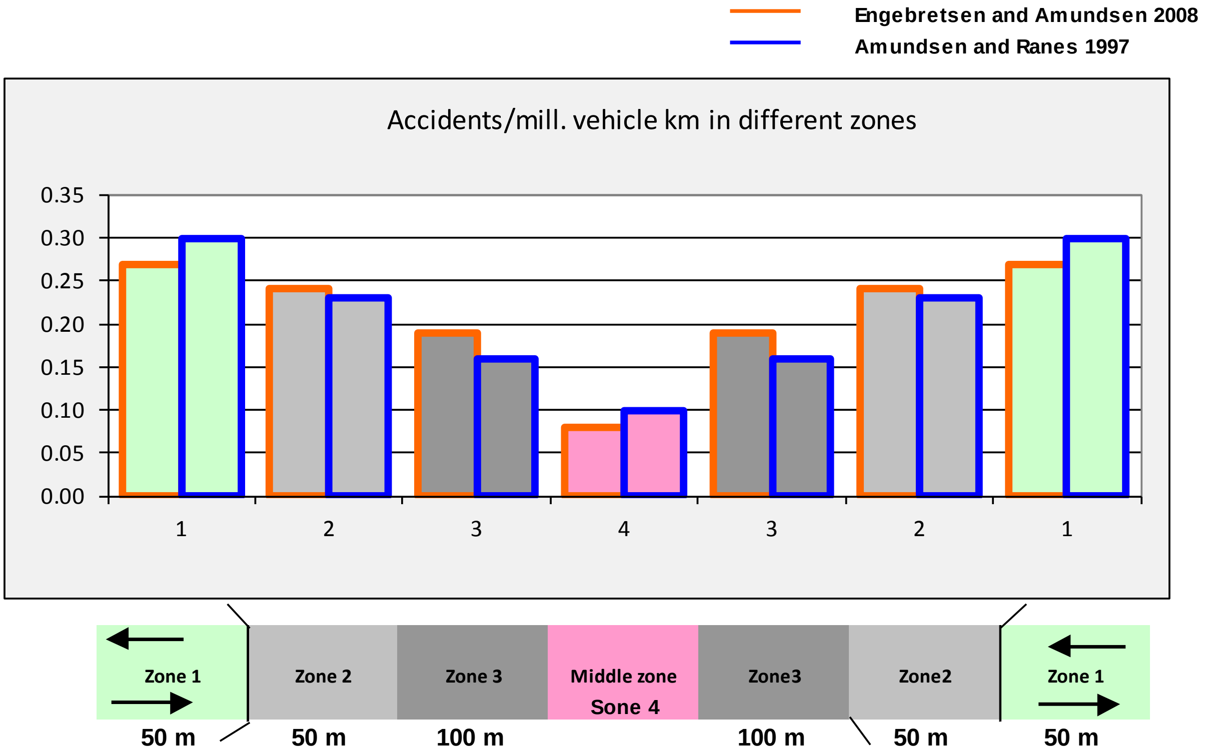



*Figure 4: Risk (acc/mill veh.km) in different tunnel zones according to Engebretsen and Amundsen 2008 and Amundsen and Ranes 1997. Single-tube tunnels with two-way traffic.*

Since the figure shows tunnels with two-way traffic, the zones are symmetrical around the mid-zone. As the figure illustrates, the risk of accidents declines from approximately 0.25-0.30 per million vehicle-kms driven in the entrance zone to roughly 0.07-0.10 per million vehicle-kms driven in the mid-zone. This means that the risk of accidents in zone 1 and zone 2 is higher than the risk of accidents on roads in open air. Considering traffic safety in the light of distractions etc., it will however not be desirable to position speed cameras in these zones.

This entails placing any camera boxes either approximately 50-100 m outside the mouth of the tunnel or a similar distance inside the tunnel (both calculated in the direction of speed). The same increase in risk is not found at the exit of the tunnel, but the risk is also somewhat higher here than that for roads in open air, but the placement of cameras here should also be avoided. This has little impact on tunnels with two-way traffic.

## 3.2 Automatic section speed control in tunnels – new problems and challenges

Even though the total risk is lower for tunnels than for roads in open air, there are constant reports about motorists who choose to drive through tunnels at extremely high speeds. Tunnels are very unusual in such circumstances since the potential for disasters is considerable. Any accident at high speed may have catastrophic consequences for both those in the vehicle in question and other road-users in the tunnel.

At the same time it is difficult for the police to carry out ordinary speed control in tunnels. This is partly due to technical aspects, but also to the fact that it can be difficult or somewhat inappropriate for police officers to conduct such control in tunnels (HES).

There are therefore several reasons for carrying out trials with ASSC in tunnels.

## 3.3 Relevant problems

It was considered desirable to carry out trials in several different types of tunnels that present varying problems.

The following descriptions were submitted to the Public Roads Administration's regions with a view to them proposing suitable tunnels:

**Flat tunnels (with relatively negligible vertical curvature)**
These tunnels do not have great differences in height, and driving speeds will therefore be relatively even and independent of the geometry. Here we want to install ASSC on a stretch of road that starts and stops outside both tunnel mouths, thus covering the entire tunnel, i.e. roughly 100-200 m outside the mouth of the tunnel. Tunnels that have had ASC installed previously are acceptable.

**Subsea single-tube tunnels (with traffic in both directions)**
Experience shows that some motorists drive very fast in such tunnels. There have been accidents with several fatalities where speeds have been very high (over 150 km/h). In our view it will not be relevant to use ASSC from the entrance to the exit due to the difference in height and incline that are normally found in subsea road tunnels. It may also be desirable to try out ASSC only in the downward section (half the tunnel). Today's vehicles have substantial power resources and it is therefore possible to compensate for ASSC downhill with an increase in driving speed uphill. In tunnels where very high speed levels have been experienced we will therefore suggest two consecutive average speed camera systems – one downhill and one uphill. This entails that the cameras at the bottom must function partly as an end point for one of the systems and partly as a starting point for the next.

In subsea road tunnels where ASC cameras are already installed at the bottom we want to try out linking these to an ASSC. This ensures good data on the situation beforehand, and will be able to demonstrate the possibility of linking existing points, as well as giving us the opportunity to see the effect on the driving speed of the change from ASC to ASSC.

**Subsea twin-tube tunnels**
By subsea twin-tube tunnels we mean subsea tunnels where the traffic is so heavy that they consist of two tunnel tubes of one-directional traffic, often with several lanes in each tube.

Here too we have experienced that the driving speed is extremely high, and ASSC should be tried out in tunnels with only one-directional traffic, but with several driving lanes. The placement of the ASSC should be assessed at the individual site.

## 3.4 Sites for trials

Since ASSC in tunnels are to be regarded as a set of trials that are intended to shed light on different problems, the current criteria for automatic speed control are not totally relevant. The working mechanism is the same as that for conventional spot speed cameras and for ASSC on surface roads. Encouraging motorists to decrease their driving speed will reduce both the number of accidents and the severity of the injuries sustained in each accident. A prerequisite for spot speed cameras or ASSC on surface roads is therefore both a high number of accidents and high speeds.

For ASSC in tunnels, the accident requirement particularly can be adjusted somewhat compared with ASC. This is due to the risk of accidents with a considerable potential for disaster, and also to a general wish to be more proactive in the use of ASSC in tunnels.

When selecting sites for trials, however, attempts have nonetheless been made to base the selection on a combination of the accident scenario and the driving speed in a situation before introducing ASSC.

Table 3 shows the sites that have been selected for the trial and evaluation of ASSC in tunnels.

| Tunnel name | County | Road no. | Type of tunnel | Length m | AADT 2010 vhcl/day | Speed limit km/h |
|---|---|---|---|---|---|---|
| Hell | Sør-/Nord-Trøndelag | E6 | Flat two-way traffic | 3928 | 15000 | 80 |
| Eiksund | Møre og Romsdal | FV653 | Subsea two-way traffic | 7840 | 2030 | 80 |
| Tromsøysund | Troms | E8 | Subsea twin-tube One-way traffic (in each tube) | 2021+2016 | 5030/4680 | 80 |
| Hvaler | Østfold | FV108 | Subsea two-way traffic | 3887/3874 | 2000 | 80 |

*Table 3: Information on the tunnels selected for trials of ASSC. Tunnel name, county, road number, type of tunnel, length, AADT 2010 and speed limit.*

The table gives the tunnel's name, county, road number, type of tunnel, tunnel length, AADT (Average Annual Daily Traffic) and speed limit.

# 4 Data collection and methods

The aim of this evaluation is to investigate the effect of ASSC in tunnels, i.e. an aim similar to that of the evaluation previously conducted for ASSC on roads in open air.

The main purpose of ASSC used in general and in tunnels in particular is to achieve a reduction in the number of accidents and the extent of injuries. However, evaluating the effect on accidents requires relatively long time series. Since the correlation between driving speed and accidents/injuries is well known, in this study focus is therefore directed towards the in-between variable of speed.

Several measuring methods for speed are used for evaluating ASSC on roads in open air. By this we mean speed measurements based on inductive loop traffic detectors embedded in the road and on radar. Parts of the measuring system were based on hourly measurements and aggregated speed measurements. Section 2 shows results based on hourly measurements of speed. However, it also shows how more comprehensive analyses require data on individual vehicles, i.e. the storage of speed data from each vehicle. This ensures flexibility and the possibility to “produce” the data material that is required afterwards. The system of concepts that has been developed in Section 6 on the contribution of speed to risk also emphasises this need.

The speed measurements in this project have been exclusively taken with inductive loops. The measurements taken beforehand have been made with specific measuring points/counting points, while in most cases the measurements taken afterwards have been made with the help of inductive loops or cables, but with the loops/cables connected to the actual cameras. In some cases (for example in the Hvaler tunnel) it has been necessary to install separate measuring points independent of the cameras in order to take measurements both before and after.

The effects have been measured using before-and-after analyses based on direct comparisons of driving speed measured before the installation of ASSC with driving speed after the installation. This has been done without any control groups. If the speed in a tunnel like the tunnel where ASSC was installed had changed in the same period as the before-and-after measurements were taken, corrections should have been made for such changes. This is particularly relevant if the before-and-after period extends over a long time or if there are grounds to assume that aspects other than ASSC have contributed to the change in speed between the two periods. Such corrections have not been made.

The fact that this may be a source of error cannot therefore be excluded.

However, based on knowledge about changes in driving speed on the road network over time, we have assessed this to be an extremely limited source of errors. In addition we will give priority to drawing conclusions on speed changes on a conservative basis, even though strictly speaking the changes can be statistically tenable. In practice this means that regardless of the scope of measurements we will not attach importance to changes of less than 1-2 km/h, even though the actual number of measurements is so high that they can be considered significant. This is in line with earlier practice.

All measurements have been taken in close collaboration with the contact persons responsible for automatic speed control in each region.

# 5. Results from before-and-after measurements – change in driving speed

The following is a review of the results from the before-and-after measurements that were conducted in the tunnels shown in Table 3. Attempts have been made to make the presentation as uniform as possible, and each measuring site is discussed in a separate section.

## 5.1 The Hell tunnel

Hell is a single-tube relatively flat tunnel located on the E6 on the county border between Sør-Trøndelag and Nord-Trøndelag on the route between the centre of Trondheim and Værnes airport. ASC had been installed roughly in the middle of the tunnel but was removed some time before ASSC was installed.

Figure 5 shows a sketch map and photography of the Hell tunnel.


*Figure 5: Hell tunnel, E6, Sør/Nord Trøndelag. Map and photography.*

Two speed measuring points were set up based on inductive loops inside the tunnel (level 1 measuring point and using the old ASC-system), and the speed at the average speed camera points was measured before the cameras were installed. The average speed ASSC-system is active in the northward direction from Trondheim towards Stjørdal.

Figure 6 shows a sketch of the tunnel with some key information.

| | | |
|---|---|---|
| Hell | AADT 15000 | ASSC replaces ASC |
| Sør-/Nord Trøndelag E6 | | Dir. 1 Trondhjem → Stjørdal |
| Single-tube flat two-lane | Length 3928m (4232 ASSC) | |

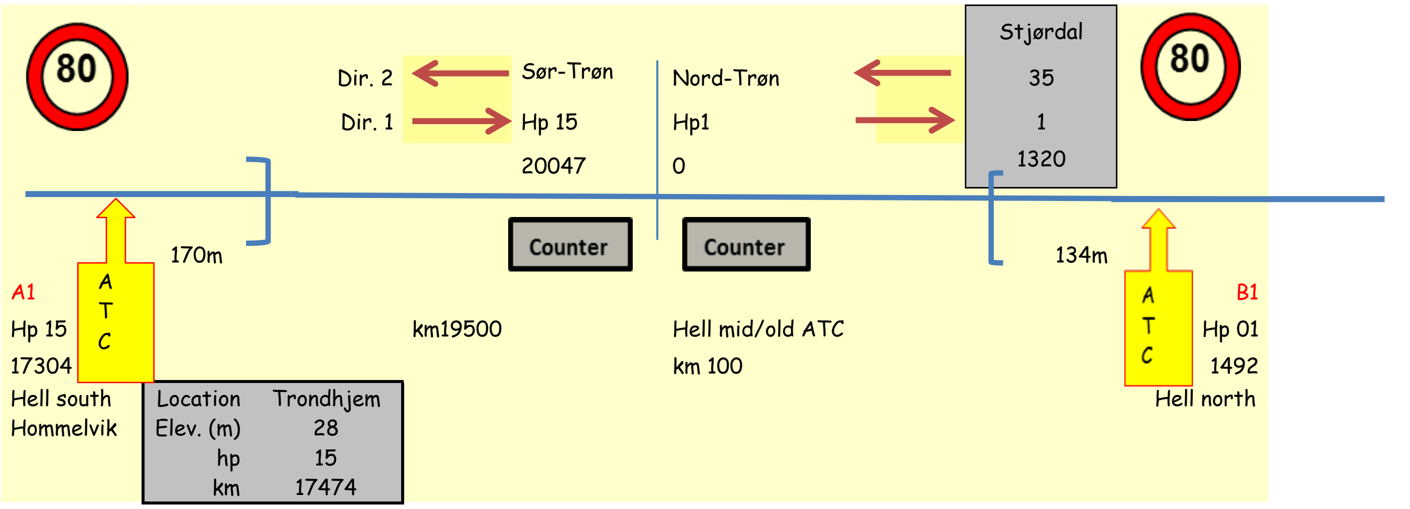



*Figure 6: Hell tunnel, E6, Sør/Nord-Trøndelag. Sketch with key data and positioning of measuring points and ASSC cameras.*

It is worth nothing that both ASSC cameras are positioned outside the tunnel – 170 m before the tunnel and 134 m after respectively. This means that the ASSC section is 304 m longer than the tunnel itself (170 m +134 m). The ASSC section is 4,232 m, while the actual tunnel is 3,928 m. The border between Sør- and Nord-Trøndelag counties is located in the middle of the tunnel.

Measurements before the installation were taken at three points in the tunnel:

South Hell/Hommelvik (Hp15 km17304) – the future ATC point A1.
Mid-Hell (Hp1 km100) – the "old" ASC point that has been removed.
North Hell (Hp1 km1492) – the future ASSC cameras

Results from the before measurements are shown in Figure 7.

| | Hell South | Mid | North |
|---|---|---|---|
| Number | 47637 | 47615 | 47562 |
| Average km/h | 80.2 | 77.9 | 80.6 |
| Spread km/h | 8.4 | 6.0 | 6.7 |
| Max km/h | 149.1 | 171.3 | 150.2 |
| Min km/h | 18.9 | 44.9 | 32.5 |
| Prop. over 80km/h | 49.3 | 32.2 | 52.7 |
| Prop. over 90km/h | 10.0 | 2.7 | 7.0 |
| Prop. over 100km/h | 1.4 | 0.3 | 0.6 |

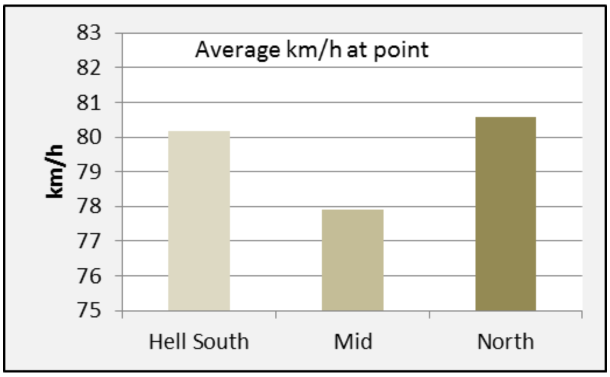



*Figure 7: Before measurements at three points in the Hell tunnel, E6, Sør/Nord Trøndelag. No. of vehicles, average driving speed, spread and percentages over 80, 90 and 100km/h.*

Driving speeds are relatively similar at the two points south and north. The averages are 80.2 km/h and 80.6 km/h. The measurements were taken in week 8 of 2012.

At the mid-Hell tunnel measuring point the speed is somewhat lower than that at the two other points. This may be caused by “inheritance” from the previous spot speed camera point, but it can also be explained by the fact that this point is located inside the tunnel and that the tunnel has so-called Fleximarks marking the centre line, which makes the driving lanes feel somewhat narrower. This can contribute to a reduction in speed.

The percentages of motorists driving over 80 km/h at the three points are 49.3%, 32.2% and 52.7% respectively.

The speed level for the Hell tunnel is slightly higher than the individual vehicle measurements from Roløkken shown in Figure 2 (1-1.5 km/h), while the speed in the middle is slightly lower (1 km/h). The time of year is week 11 for Roløkken and week 8 for Hell. The speed level and speed distribution at the south point, just before the start of the tunnel, are naturally enough most similar to the measurements from Roløkken.

The after measurements in the Hell tunnel were taken in week 16, and the total results before and after the installation of ASSC are shown in Figure 8.

| | A Hell South | | | Mid: Point | Section | | B Hell North | | |
|---|---|---|---|---|---|---|---|---|---|
| | Before | After | Change % | | A-B | Change % | Before | After | Change % |
| Number | 47637 | 36899 | | | 35572 | | 47562 | 36899 | |
| Average km/h | 80.2 | 75.8 | -4.4 | 77.9 | 75.3 | -2.6 | 80.6 | 75.1 | -5.5 |
| Spread km/h | 8.4 | 7.2 | -1.2 | 6.0 | 4.2 | -1.8 | 6.7 | 6.1 | -0.6 |
| Prop. >80km/t | 49.3 | 23.2 | -26.1 | 32.2 | 10.2 | -22.0 | 52.7 | 18.1 | -34.6 |
| Prop. >90km/t | 10.0 | 3.3 | -6.7 | 2.7 | 0.4 | -2.3 | 7.0 | 1.0 | -6.0 |

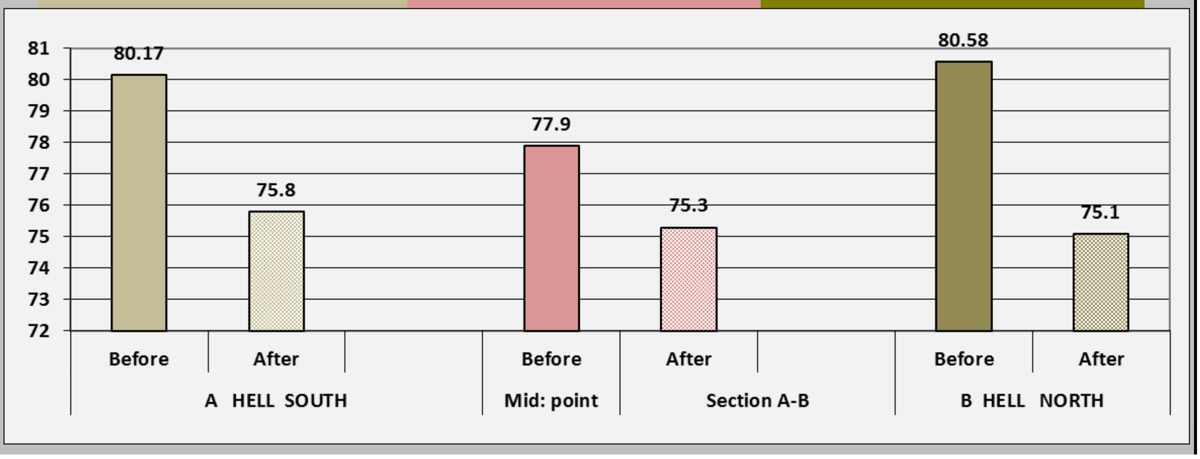



*Figure 8: Before and after ASSC, Hell tunnel, E6, Trøndelag. No. of vehicles, average speed, spread and percentage over 80 and 90 km/h. At camera in point A (south Hell), on the section AB and at cameras in point B (north Hell).*

The before situation at mid-point is here compared with the after situation from ASSC measurements, while points A (south Hell) and B (north Hell) are identical points. The measurements were taken at the actual ASSC points.

The figure shows that the installation of ASSC reduces speed by 2.6 km/h – from 77.9 km/h to 75.3 km/h. The before measurement was taken at the mid-point (HP1 km100) and was compared with a section measurement taken after the installation. Since the speed at different points may vary slightly, a somewhat greater reduction in speed cannot be ruled out.

The results also show a reduction of 4.4 km/h at point A and 5.5 km/h at point B. This pattern is in line with the previous results for ASSC on roads in open air given above. For roads in open air the reduction at point A is also found to be greater than that on the entire section of road, and the reduction is largest at point B.

The percentage of motorists with a driving speed over the speed limit is 32.1% at the mid-point in the before situation. This is reduced to 6.0% after ASSC were introduced. At point A the percentage driving over 80 km/h in the before situation is 49.3%. This is reduced to 23.2%. Similarly, at point B 52.7% in the before situation is reduced to 18.1%. The relatively high percentage of those driving at a speed over the speed limit at points A and B and not on the section may indicate that the motorists in the Hell tunnel have understood better how ASSC work than was the case at Nesbyen in Hallingdal.

It is also worth noting the extremely even driving speed through the entire tunnel in the after situation. The driving speed at points A and B and the average for the entire section of road in practice show no variation. The speeds measured are 75.8 km/h, 75.3 km/h and 75.1 km/h respectively at the three points. One possible explanation of this may be that the volume of traffic during the day (that makes up most of the average) is so heavy that this in itself explains the extremely even speed.

Table 4 shows the speed distribution at the south Hell (Hommelvik) measuring point for night-time (from 0000-0600) and daytime.

| Speed distribution, point Hell South. Night/Day | | |
|---|---|---|
| Proportion, % | Night | Day |
| Total vehicles | 4.9 | 95.1 |
| over 105 km/h | 1.7 | 0.5 |
| <100, 105] | 1.8 | 0.8 |
| <95, 100] | 4.6 | 2.4 |
| <90, 95] | 8.5 | 6.0 |
| <85, 90] | 17.3 | 14.5 |
| <80, 85] | 22.5 | 24.8 |
| over 80 km/h | 56.4 | 49.0 |
| Average km/h | 81.3 | 80.1 |

*Table 4: Speed distribution in the before situation at the measuring point south Hell (Hommelvik), E6, Trøndelag. Divided according to night and day. Total no. of vehicles and percentages at different speed fractions in percentages.*

Altogether 95.1% of the traffic occurs during the daytime. Driving speed is on average 1.2 km/h faster at night compared with that during the day. In addition, at night a somewhat higher percentage of motorists drive at a speed over 85 km/h. However, the differences between night and day are not so great that they alone can explain the "even" speed measurements through the tunnel.

As for roads in open air, estimates have been made that show the average driving speed of motorists who are recognised in one or both camera points (see also Figure 3). This is due to the way ASSC work, i.e. it is the section speed from A to B that is measured and that can cause sanctions to be imposed. In principle point A (or B) can therefore be passed at an arbitrary driving speed without sanctions. For example the motorist can stop in a breakdown lay-by in the tunnel. To study this, the driving speed in the situation after the installation of ASSC has been measured for those who are recognised in both camera point (A and both or B and both) and for those who are only recognised in one of them (A or B).

The results are shown in Figure 9.

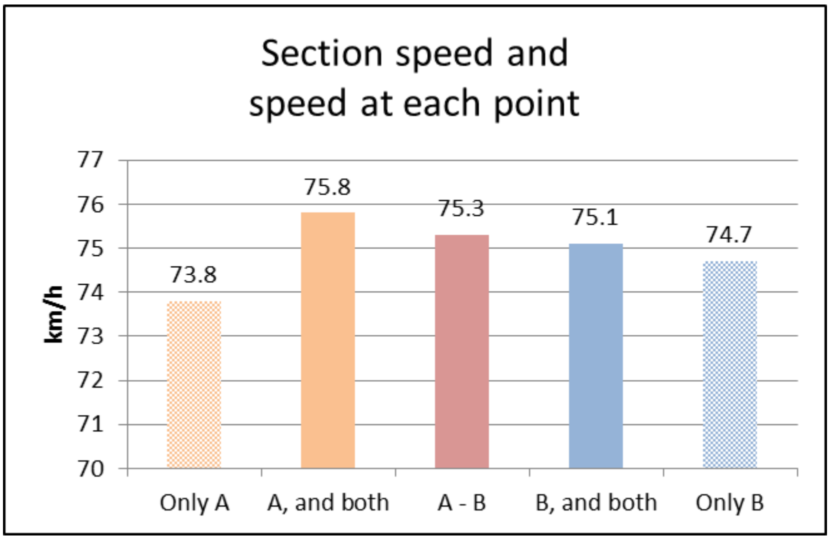



*Figure 9: After measurements in the Hell tunnel, E6, Trøndelag. Driving speed at points A and B according to whether motorists are recorded at one (only A or only B) or both points.*

The figure encompasses approximately 50.000 vehicles. It shows a difference of 2.0 km/h at point A between those who are recorded at both points and those who are only recorded at point A. Similarly at point B there is a difference of 0.4 km/h. These differences are regarded as so modest that they give reason to claim that the problem described is not of great significance.

## 5.2 The Eiksund tunnel

Eiksund is a single-tube subsea tunnel on the FV 653 in Møre og Romsdal county. It links Hareidlandet to the mainland at Ørsta. The total length is 7.840 m and the tunnel is 287 m below sea level at its deepest point. The tunnel was opened in February 2008 and has one through lane in each direction along with an extra lane on the incline in the direction from Ørsta. Figure 10 shows a sketch map and a photography of the tunnel.


*Figure 10: Eiksund tunnel, FV653, Møre og Romsdal. Map and photography.*

In 2009 ASC was installed in both directions at the bottom of the tunnel. Partly due to a serious fatal accident in June 2009, consideration was given to installing further surveillance in the tunnel. Figure 11 gives a sketch of the tunnel with some key information.

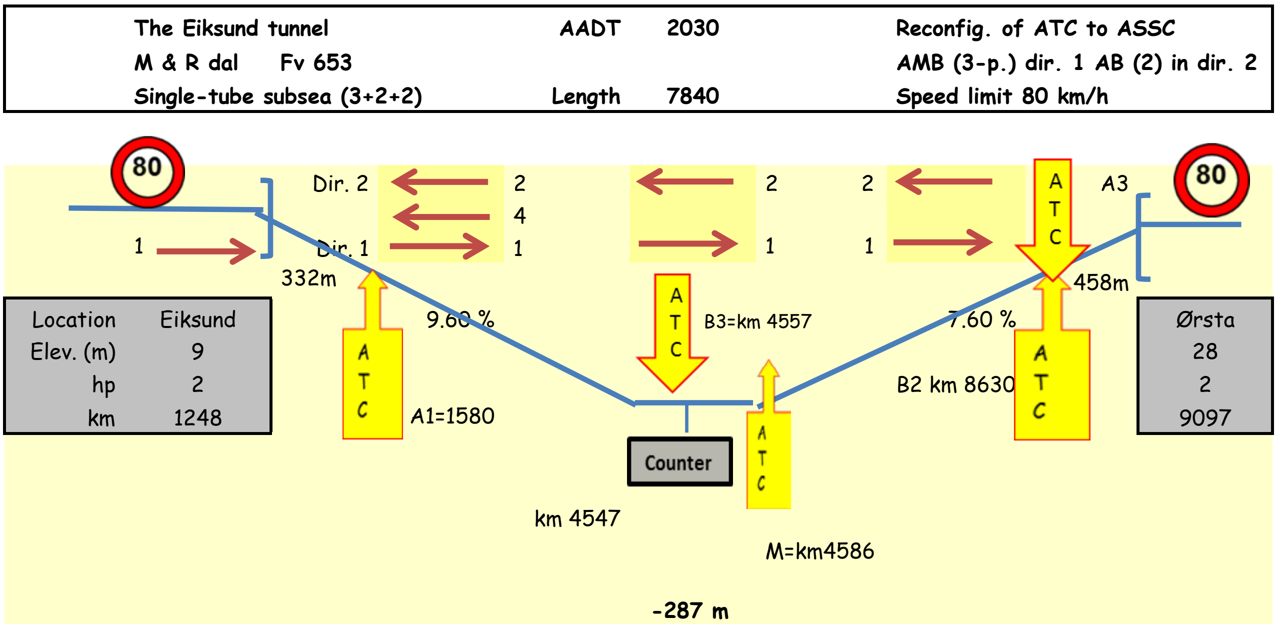



*Figure 11: Eiksund tunnel, FV653, Møre og Romsdal. Sketch with key information and positioning of measuring points and ASSC cameras.*

As is shown in the figure, the geometry in the tunnel is quite demanding with a 9.6% incline in one half and 7.6% in the other. The tunnel has no horizontal curves that could influence or limit driving speed.

A measuring point was set up (km 4547) at the bottom of the tunnel prior to the installation of ASC. Two way ASC was installed in 2009 (km 4557 and km 4586). When ASSC was to be installed, one goal was to retain these points and to install new points on the downward section and link these to the ASSC. There are two cameras in the direction from Ørsta to Eiksund (A3 and B3) that together make up an ASSC system known as S3. The distance between these cameras is 3.997 m.

There are three camera boxes in the direction from Eiksund to Ørsta (A1, M and B2). Together these make up two ASSC systems known as S1 and S2. S1 has a length of 2.917 m and consists of the cameras A1 and M. Point M is also the first point in S2, which has a length of 4.024 m. The last point in S2, known as B2, is located 458 m from the mouth of the tunnel on the Ørsta side. Camera M, one of the “old” bottom points, has thus acquired a challenging dual function.

The evaluation in Eiksund consists of four periods:

1) Before measurements in the period prior to the installation of ASC at the bottom (before 25 November 2009).
2) Measurements of the speed with ASC at the bottom.
3) Before measurements at the “pending” ASSC points in the downhill section.
4) Measurements taken after all three ASSC cameras were installed.

**Period 1 (before 25 November 2009)**
Table 5 shows the results of speed measurements at the measuring point (km 4547) in the period before the installation of ASC at the bottom of the tunnel. The table is based on continuous hourly measurements from 6 March to 3 April 2008, 612 hours one way and 616 hours the other.

| Direction | Number | Average km/h | Spread km/h | > 80 km/h % | > 90km/h % | 85% fractile km/h | 95% fractile km/h |
|---|---|---|---|---|---|---|---|
| tow. Ørsta | 21062 | 81.18 | 11.95 | 55.0 | 18.2 | 92.0 | 101.0 |
| tow. Eiksund | 20993 | 80.08 | 11.63 | 49.0 | 15.4 | 90.0 | 100.0 |

*Table 5: Measurements before ASC in Eiksund tunnel, FV653, Møre og Romsdal. Hourly measurements. No. of vehicles, average speed (km/h), spread and speed intervals. Period 1.*

The average speed is roughly the speed limit. This means that approximately half the motorists drive in excess of the speed limit. The percentage driving over 90 km/h is 15.4% in one direction and 18.2% in the other. The two fractiles, 85% and 95%, are fairly similar in the two directions. The 95% fractile indicates that roughly 5% drive at a speed of >100 km/h. Over the 25 days that the measurements took place, a total of 53 hourly measurements were taken with a 95% fractile over 125 km/h, approximately the same number in each direction.

**Period 2 (26 November 2009-5 October 2011)**
Table 6 shows measurements from the same measuring point at the bottom of the tunnel in the period 9-15 August 2010, i.e. approximately one year after ASSC was introduced at this site. The figures are **combined** for both traffic directions.

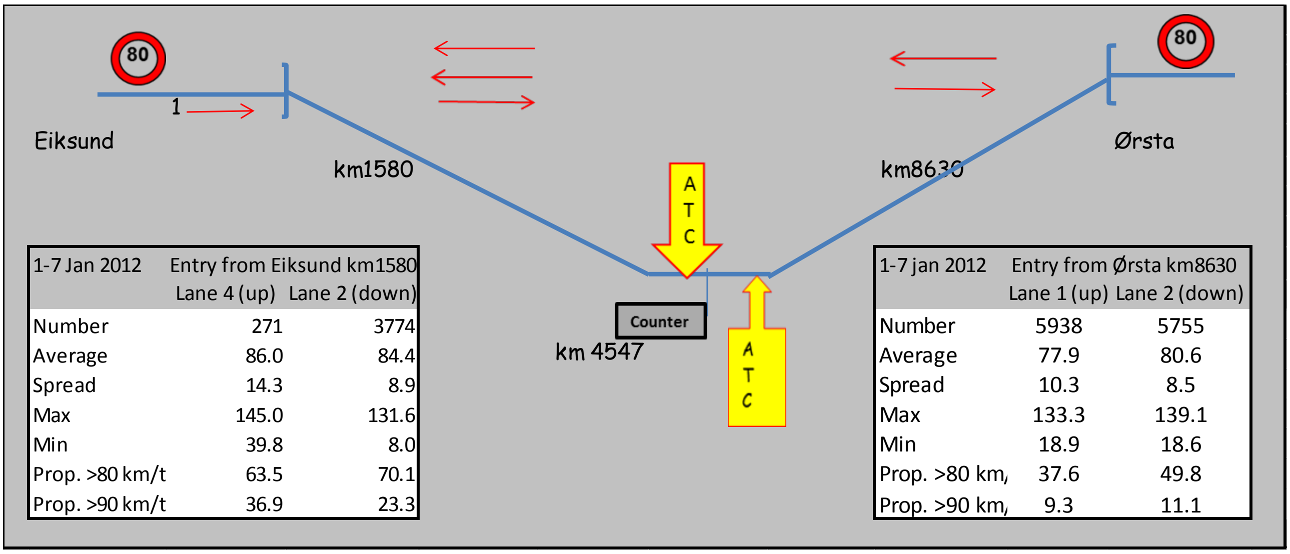
| Eiksund m4547 | |
|---|---|
| ASC period. 9-15 Aug. 2010 | |
| Number | 13425 |
| Average | 71.1 |
| Spread | 7.2 |
| Max | 147.6 |
| Min | 17.3 |
| Prop. > 80 km/h | 5.9 |
| Prop. > 90 km/h | 0 |

*Table 6: Speed measurements after ASC at measuring point at km 4545 in the Eiksund tunnel, FV 653, Møre og Romsdal. No. of vehicles, average speed, spread and percentage with speed over 80 and 90 km/h respectively. Period 2.*

As is shown, the average speed is 71.1 km/h, which is 10.2 km/h lower than the measurements from the before situation. The spread is reduced by approximately 4 km/h, from roughly 11 km/h in the before situation to 7 km/h afterwards. The percentage of those driving at a speed >80 km/h is considerably reduced, from roughly 50% in the before situation to 5.9% on average for both directions. The percentage of those driving at >90 km/h is reduced from 18.2% and 15.4% respectively in each traffic direction to less than 1% in the two directions combined.

**Period 3 (6 October 2011-12 April 2012)**

The next figure (12) shows results from speed measurements in the two downhill sections at km 1580 (from Eiksund) and km 8630 (from Ørsta) in period 3 where there are ASC at the bottom.




| 1-7 Jan 2012 | Entry from Eiksund km1580 | |
|---|---|---|
| | Lane 4 (up) | Lane 2 (down) |
| Number | 271 | 3774 |
| Average | 86.0 | 84.4 |
| Spread | 14.3 | 8.9 |
| Max | 145.0 | 131.6 |
| Min | 39.8 | 8.0 |
| Prop. >80 km/t | 63.5 | 70.1 |
| Prop. >90 km/t | 36.9 | 23.3 |

| 1-7 jan 2012 | Entry from Ørsta km8630 | |
|---|---|---|
| | Lane 1 (up) | Lane 2 (down) |
| Number | 5938 | 5755 |
| Average | 77.9 | 80.6 |
| Spread | 10.3 | 8.5 |
| Max | 133.3 | 139.1 |
| Min | 18.9 | 18.6 |
| Prop. >80 km, | 37.6 | 49.8 |
| Prop. >90 km, | 9.3 | 11.1 |

*Figure 12: Speed measurements on the downhill sections at km1580 and km 8630, with ASC at the bottom. Eiksund tunnel, FV653, Møre og Romsdal. Period 3 with ASC at the bottom.*

On the descent from Ørsta (on the right of the figure), the speed level is higher than at the bottom and in general motorists drive somewhat faster downhill than uphill. The average is 77.9 km/h uphill and 80.6 km/h downhill. The spread is typically much greater at this points than at and near the ASC points at the bottom. The percentage of motorists driving over 80 km/h is 37.6% uphill and

49.8% downhill. The percentages over 105 km/h are 0.9% and 1% in the two directions respectively.

Motorists drive faster on the descent from Eiksund than on the descent from Ørsta. On the 9.6% gradient the speed downhill is 84.4 km/h compared with 80.6 km/h on the 7.6% gradient on the other downhill section.

The percentage driving at more than 80 km/h here is over 70% downhill, while 23.3% drive faster than 90 km/h in lane 2.

Motorists also drive fast in lane 4 (left-hand lane uphill), with an average speed of 86.0 km/h and 63.5% at a speed of more than 80 km/h. A total of 36.9% of motorists drive in excess of 90 km/h. It is worth clarifying that this lane is a passing lane where the traffic constitutes approximately 10% of the total traffic in this direction.

On the whole the spread is higher at these two measuring points (in both directions) than it is at the ASC points at the bottom.

**Period 4 (13 April 2012 onwards)**

Figure 13 shows speed measurements taken after ASSC became operative in the Eiksund tunnel. The two ASSC systems are known as S2 (from the bottom and upwards between points M and B2) and S3 (from the top on the Ørsta side and down to the bottom between points A3 and B3). The figure shows both speeds on the stretch of road and speeds at the points indicated.

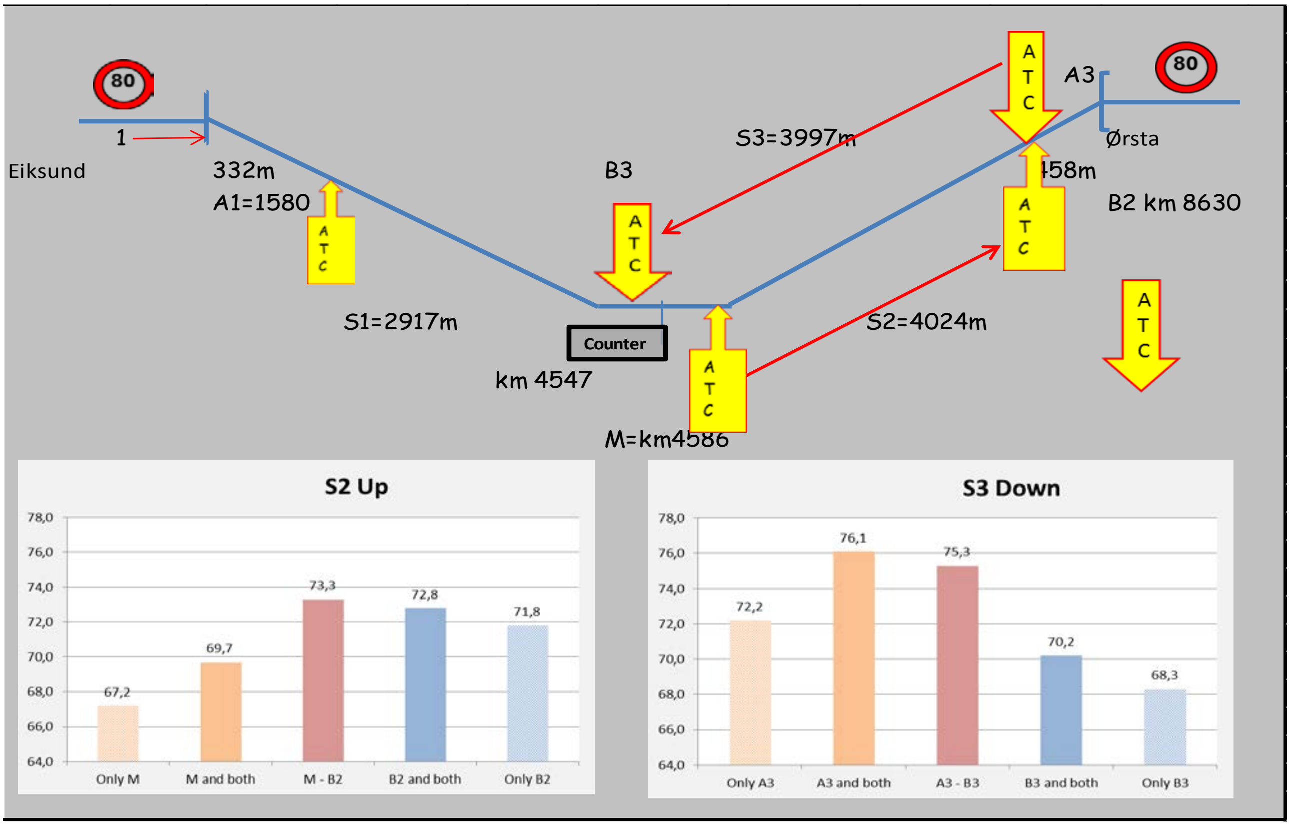



*Figure 13: ASSC systems S2 and S3 in the Eiksund tunnel, FV653, Møre og Romsdal. Speed at the ASC point and on the stretch in km/h. Period 4 with ASSC. Motorists recorded at one or two points.*

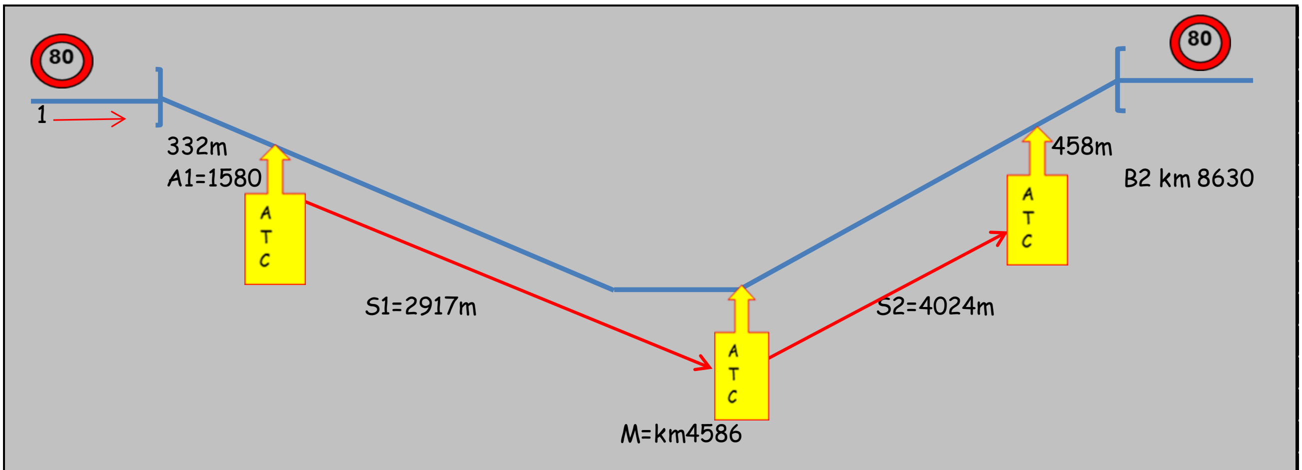
The respective speeds on the stretch of road are 75.3 km/h downhill in S3 and 73.3 km/h uphill in S2. The speed pattern in S3 is the same as that for roads in open air. The highest speed is at the first point, A3, where it is 76.1 km/h, while the lowest speed is at the last point, B3, where it is 70.2 km/h.

The speed pattern in S2 is characterised by the fact the starting point M is also the end point for S1. The speed at M is 69.7 km/h. At B2 it is 72.8 km/h. At both bottom points the speed is thus roughly the same as when these points were used as ASC in periods 2 and 3.

As in Figure 3 from Hallingdal and Figure 9 from Hell, there are no signs in this figure to indicate that those who are recorded at only one of the measuring points on a section drive faster than those who are recorded at both measuring points on the section.

The percentages of those driving faster than 80 km/h are 7.7% at S2 (uphill) and 11.3% at S3 (downhill). The corresponding figures for those driving at more than 90 km/h are 0.2% at S2 and 0.5% at S3.

Figure14 shows simultaneous measurements of 8,125 vehicles that pass S1 and S2 and thereby points A1, M and B2. The figure also shows measured speed on the section from A1 to B2 (top to top). This has been carried out by recognition of licence plate numbers.




| | No. of vhcl. | 8125 | | A1 | M | B2 |
|---|---|---|---|---|---|---|
| | **S1 Section** | **S2 Section** | A1 B2 **Top-Top** | **S1 Start** | **S1 end S2 start** | **S2 end** |
| Average km/h | 75.2 | 74.3 | 74.5 | 77.9 | 70.2 | 73.9 |
| > 80 km/h | 11.1 | 9.9 | 7.9 | 34.1 | 3.1 | 13.9 |
| > 85 km/h | 1.7 | 1.5 | 0.8 | 12.1 | 0.4 | 2.5 |
| > 90 km/h | 0.5 | 0.3 | 0.2 | 3.9 | 0.2 | 0.6 |
| Spread km/h | 4.7 | 6.0 | 4.9 | 6.8 | 6.4 | 7.7 |

*Figure 14: Simultaneous speed measurement on the ASSC sections S1 and S2, the Eiksund tunnel, FV653, Møre og Romsdal.*

The average speed at the starting point A1 is 77.9 km/h, with a percentage of 34.1% driving over the speed limit. The average speed at the end point for S1, point M, is 70.2 km/h, with only 3.1% driving faster than the speed limit. Since we can follow each individual vehicle, we find that 85.1%

have reduced their speed from point A1 to point M, with as many as 59.6% making a reduction of more than 5 km/h. The average speed on the S1 section is 75.2 km/h, which is 2.7 km/h lower than the speed at the entrance. Motorists reduce their speed an unnecessary amount at point M.

On the way up from the bottom, motorists start at an average speed of 70.2 km/h. The average speed at the end point, B2, has increased to 73.9 km/h with 13.9% driving faster than the speed limit. Here too we can follow individual vehicles, and the figures show that 76.0% increase their speed from point M to point B, with 43.1% of the motorists increasing their speed by more than 5 km/h. The average speed on the S2 section is 74.3 km/h, i.e. 0.4 km/h higher than the final speed.

At individual vehicle level exactly half the motorists have a higher speed on the S1 section than on S2. In other words, motorists show no tendency to choose a higher speed at one of the two sections of road. The average speed is 0.9 km/h higher on S1, while the spread is higher on S2.

Measurements from top to top, from A1 to B2, show that the speed on the section of road is 74.5 km/h, which must of necessity lie between the speeds for the S1 and S2 sections.

The next table is intended to present a summary of the main results from the four periods in the Eiksund tunnel.

| | BEFORE | Interim period with ASC at bottom | | | After ASSC | | |
|---|---|---|---|---|---|---|---|
| | Period 1 | Period 2 | Period 3 (Ørsta) | | Period 4 | | |
| | bottom | Bottom | Up | Down | S1 down | S2 up | S3 down |
| Average km/h | 80.5 | 71.1 | 77.9 | 80.5 | 75.2 | 73.3 | 75.3 |
| Spread km/h | 11.9 | 7.2 | 10.3 | 8.5 | 4.7 | 6.3 | 4.9 |
| | | | | | | | |
| Prop. > 80 | 50.0 | 5.9 | 37.6 | 49.8 | 11.1 | 7.7 | 11.3 |
| > 90 | 16.5 | 0.7 | 9.3 | 11.4 | 0.5 | 0.2 | 0.5 |
| >100 | | 0.2 | 2.0 | 1.9 | | | |

*Table 7: Before-and-after analysis of ASC and ASSC in the four periods in the Eiksund tunnel, FV653, Møre og Romsdal. Summary of results.*

In period 1, before the installation of automatic speed control, the average speed is 80.5 km/h in both directions. More than 50% of motorists drive at a speed over 80 km/h, and approximately 16% drive over 90 km/h. The installation of two way ASC at the bottom reduces the driving speed by 9.4 km/h, from 80.5 km/h to 71.1 km/h.

Simultaneous measurements on the downhill sections show that the average speed on the descent from Eiksund is 86.0 km/h uphill and 84.4 km/h downhill. The percentage of those driving at a speed over 80 km/h is 37.6% (uphill) and 49.8% (downhill). Motorists drive considerably faster on this descent than they do on the descent from Ørsta where the averages are 77.9 km/h (uphill) and 80.52 (downhill).

In the measuring period with a full ASSC system (period 4), the three average speeds on S1, S2 and S3 are 75.2 km/h, 73.3 km/h and 75.3 km/h respectively. Although roughly 10% of motorists drive faster than 80 km/h, the spread is very small and fewer than 1% drive over 90 km/h.

## 5.3 The Hvaler tunnel

The Hvaler tunnel is a single-tube subsea tunnel on the FV108 in Østfold county. The tunnel links Asmaløy and Kirkøy together, thus making Skjærhalden part of the mainland. Its total length is 3.775 m.

Figure 15 shows some key figures from the tunnel, as well as the positioning of speed measurement points before and after the installation of ASSC.

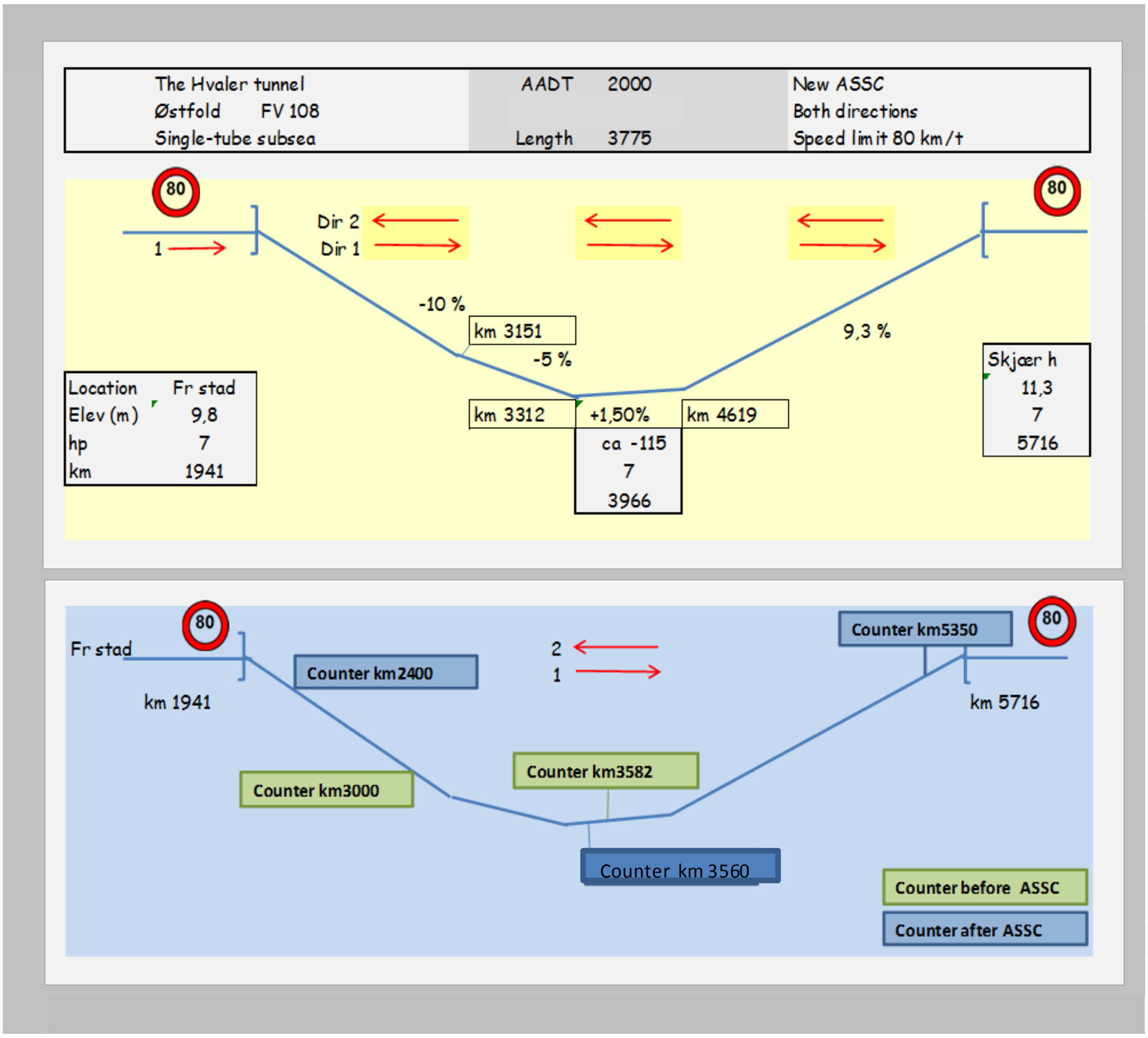



*Figure 15: The Hvaler tunnel, FV108, Østfold. Sketch with key information and measuring points before and after ASSC.*

The geometric sketch shows that the vertical curvature is relatively demanding, with a gradient of approximately 10% down from Asmaløy/Fredrikstad and similarly 9% on the Skjærhalden side. The AADT is approximately 2,000 vehicles, but the traffic is considerably heavier in the summer (approximately 5,000 vehicles). The tunnel has two through lanes, one in each direction, without passing lane. Traffic direction 1, and thereby the kilometer marking, is as it appears in the direction from Fredrikstad to Skjærhalden.

The measuring points are given in green for the before situation. As the figure shows, in the before situation speed is measured at two measuring points, at km 3000 and km 3582. The points given in blue apply for the after situation. Here the three relevant measuring points are at km 2400, km 3560 and km 5350. In addition, speed is measured at all the average speed camera points.

Figure 16 shows the placement of the average speed camera points in three systems – S1, S2 and S3.

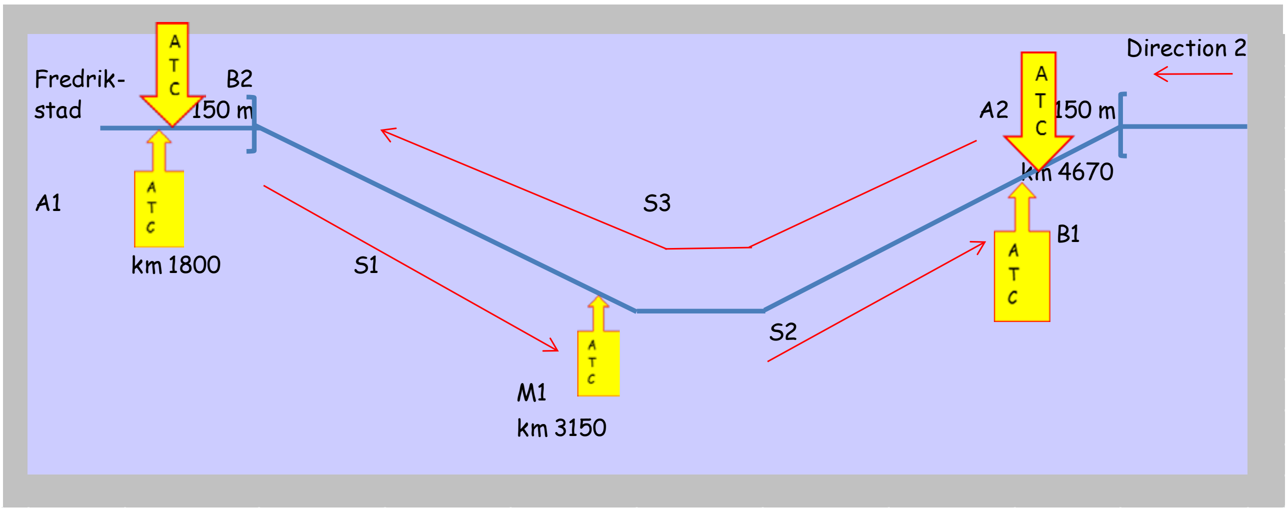



*Figure 16: The Hvaler tunnel, FV108, Østfold. Positioning of cameras in an ASSC-system.*

Focus in this context is on the ASSC system S3 in direction 2 from Skjærhalden towards Fredrikstad. This constellation has been chosen as a supplementary trial to the Eiksund tunnel where it was decided to position three ASSC cameras in direction 1, and two in direction 2. The placement in Eiksund with three ASSC cameras consists of two average speed camera systems, one from top to bottom and one from bottom to top in the same traffic direction. In the opposite direction the cameras are placed at the top and the bottom (S3) in order to prevent fast driving downwards. The reason for this placement is partly the wish to utilise the “old” points at the bottom of the tunnel.

In the Hvaler tunnel it has been possible to choose the positioning freely and, as the figure shows, it was decided to install a camera at each of the two tunnel portals in direction 2. Consideration was given to the wishes to place them in connection with the mouths of the tunnel, and camera A2 was installed approximately 150 m inside the mouth while B2 is placed approximately 150 m outside. This can present a challenge since it can be claimed that the speed downwards is considerably greater than that up such inclines and that this will result in the system not working optimally. The before-and-after measurements shown provide the opportunity to study this. The results can be seen in Table 8.

| BEFORE ASSC direction 2 | | | | | | |
|---|---|---|---|---|---|---|
| Point name | | km 3000 | km 3582 | | | |
| Number | | 7668 | 7582 | | | |
| Average km/h | | 79.3 | 77.8 | | | |
| Spread km/h | | 11.1 | 10.8 | | | |
| Prop. >80km/h | | 43.8 | 37.1 | | | |
| >90km/h | | 13.4 | 11.3 | | Driving dir. | |
| **AFTER ASSC direction 2** | | | | | | |
| | ASSC B2 | West | Mid | ASSC A2 | East | ASSC |
| Point name | km 1800 | km2400 | km3560 | km 4670 | km5350 | A2-B2 |
| Number | 17689 | 5294 | 4980 | 17400 | 5270 | 17400 |
| Average km/h | 64.6 | 65.5 | 71.4 | 63.2 | 70.0 | 68.8 |
| Spread km/h | 9.7 | 9.2 | 6.3 | 7.4 | 7.9 | 5.6 |
| Prop. >80km/h | 0.9 | 1.5 | 6.1 | 0.8 | 7.4 | 1.0 |
| >90km/h | | | | | | |

*Table 8: Results before and after ASSC in the Hvaler tunnel, FV108, Østfold, direction 2 from Skjærhalden towards Fredrikstad. No. of vehicles, average speed km/h, spread km/h and percentages over 80km/h and 90km/h respectively.*

The upper part of the table shows the average speed at the two measuring points before the installation of ASSC. At the bottom, km 3582, the average speed in direction 2 towards Fredrikstad is 77.8 km/h, with 37.1% of motorists driving faster than the speed limit and 11.3% driving over 90 km/h. At point km 3000 on the 10% uphill section the speed is 79.3 km/h, and 43.8% drive over the speed limit. The spread at the two points is approximately 11 km/h, which is relatively high.

The lower part of the table shows the results from the measuring points after the installation of ASSC and from the measurements at the actual cameras. At the measuring point at the bottom of the tunnel (km 3582 in the before situation and 3560 in the after situation) speed has been reduced by 6.4 km/h, from 77.8 km/h to 71.4 km/h. The percentage of motorist driving over 80 km/h is now 6.1%. In the after situation, this bottom point is the point at which the driving speed is highest, but nonetheless considerably lower than the speed limit. The driving speed is lowest at the cameras: 63.2 km/h at A2 (km 4670) and 64.6 km/h at B2 (km 1800). The spread is somewhat reduced compared with the before situation. At the east point (km 5350) and the west point (km 2400) the driving speeds are 70.0 km/h and 65.5 km/h respectively.

The part furthest to the right in the lower section of the table shows that the average driving speed on the ASSC section A2-B2, (the entire stretch), is 68.8 km/h. The percentage of those driving at a speed over 80 km/h is 1.0%, and the spread is 5.6 km/h.

The results from Hvaler in direction 2 show that, as is the case with a flat tunnel, it is possible in a subsea road tunnel to use two average speed camera boxes in one direction placed by the tunnel portals in order to regulate the driving speed to a level under the speed limit. It is worth noting that at Hvaler there are three cameras in the opposite direction, one of which is placed at the bottom. It may well be the case that the back of this camera helps to reduce the speed at the bottom in direction 2 as well. However, it is not very likely that this effect is particularly significant.

## 5.4 The Tromsøysund tunnel

The Tromsøysund tunnel is a subsea road tunnel with two separate parallel tubes – T1 and T2. Both of these have two driving lanes. T1, the southbound tunnel from Tromsøya to the mainland, consists of lane 2 (right) and lane 4 (left). T2 is the northbound tube with lane 1 (left) and lane 3 (right).

Figure 17 shows the constellation of the lanes and the tunnel tubes and gives a simple geometrical sketch of the horizontal and vertical geometry in the tunnel and the positioning of the speed cameras.

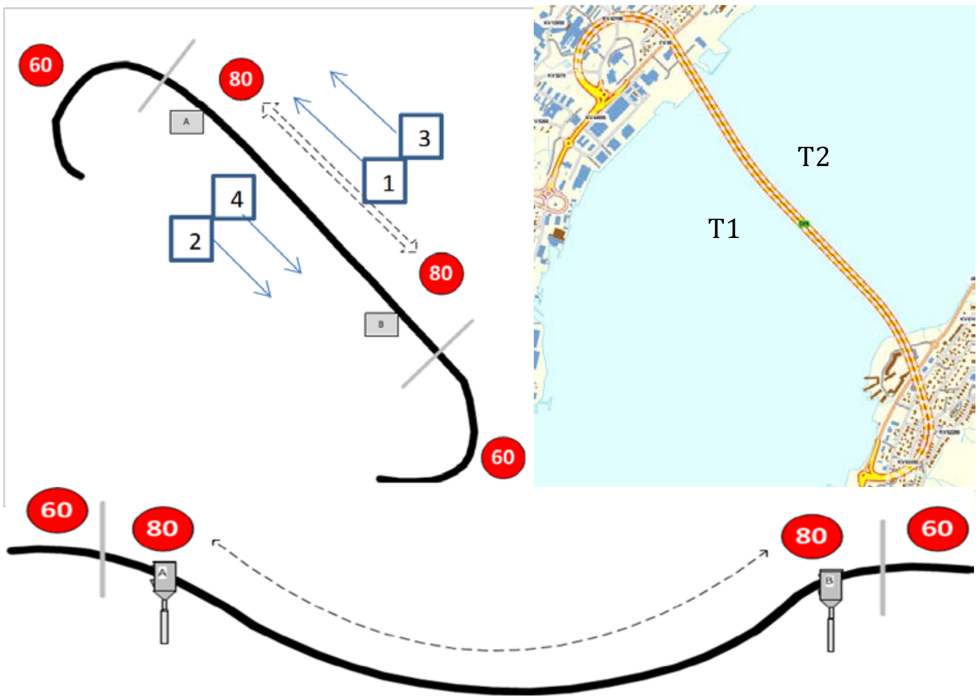



*Figure 17: The Tromsøysund tunnel, E8, Troms. Geometry, lane constellation and speed limits.*

The geometry is relatively demanding. The horizontal curves in both tracks are so sharp at the entrance as well as the exit that a speed limit of 60 km/h has been imposed on these sections. In the straight part (horizontally) the speed limit is 80 km/h. ASSC was installed in this part of the tunnel in February 2012. The AADT is 5,030 and 4,860 vehicles.

The speed measuring points in both tubes are placed at the bottom of the tunnel at roughly the deepest point. The results for the before measurements are shown in Table 9.

| Before ASSC | No. of vhcl. | Speed av. km/h | Spread km/h | Proportion in per cent over 80 km/t | over 90 km/t | over 100 km/l | over 110 km/h | over 120 km/h |
|---|---|---|---|---|---|---|---|---|
| Lane 1 | 12724 | 89.1 | 8.0 | 91.0 | 36.4 | 7.3 | 1.8 | 0.5 |
| Lane 3 | 128701 | 78.7 | 6.5 | 37.7 | 4.4 | 0.5 | 0.1 | 0.0 |
| **Total T2** | **141425** | **79.6** | **6.7** | **42.5** | **7.2** | **1.1** | **0.3** | **0.1** |
| Lane 2 | 128738 | 79.7 | 7.5 | 46.5 | 6.8 | 1.1 | 0.2 | 0.06 |
| Lane 4 | 16700 | 85.3 | 8.9 | 75.6 | 23.7 | 4.4 | 0.9 | 0.24 |
| **Total T1** | **145438** | **80.3** | **7.7** | **49.8** | **8.8** | **1.4** | **0.3** | **0.08** |

*Table 9: Tromsøysund, E8, Troms. Measurements before ASSC. No. of vehicles, average speed and spread (km/h). Percentage over the indicated speed.*

The speed in the two directions combines is 79.6 km/h in T2 and 80.3 km/h in T1. The spread is approximately 7 km/h. More than 1% of motorists drive faster than 100 km/h. High speeds are particularly prevalent in the two left-hand lanes, with 91% driving at >80 km/h in T1 and a corresponding 76% in T2. Here 4.4% of motorists drive at a speed >100 km/h (T1) and 7.3% in T2. The traffic in these lanes makes up roughly 8% of the total traffic in each direction.

The speed measurements are presented together for the two lanes in each of the tunnel tubes for the situation after the installation of ASSC. This is shown in Table 10.

| | | Speed average km/h | Spread km/h | Prop. in per cent > 80 km/h | > 90 km/h |
|---|---|---|---|---|---|
| T2 | BEFORE | 79.6 | 6.7 | 42.5 | 7.2 |
| | AFTER | 73.7 | 4.2 | 4.4 | 0.1 |
| | Change | 5.9 | 2.5 | | |
| T1 | BEFORE | 80.3 | 7.7 | 49.8 | 8.8 |
| | AFTER | 73.6 | 3.9 | 3.4 | 0.1 |
| | Change | 6.7 | 3.8 | | |

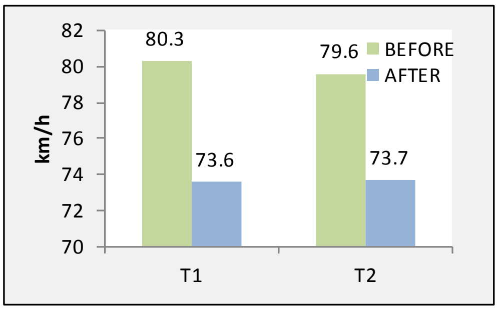



*Table 10: The Tromsøysund tunnel, E8, Troms. Measurements before and after ASSC in the tunnel tubes T1 and T2.*

The average speed was reduced in both tunnel tubes – by 6.7 km/h in T1, from 80.3 km/h to 73.6 km/h. In tube T2 the corresponding driving speeds are 79.6 km/h before the installation of ASSC and 73.7 km/h afterwards, i.e. a reduction of 5.9 km/h. The percentage of motorists driving at a speed of >80 km/h has been substantially reduced in both tunnel tubes, from 49.8% in T1 and 42.5% in T2 to 3.4% in T1 and 4.4% in T2.

As is the case with the other ASSC systems that have been evaluated, both in tunnels and on roads in open air, driving speeds are somewhat lower when motorists pass the actual camera boxes than they are between the cameras on the ASSC-section. The reduction in speed is greater at point B than at point A in both tunnel tubes. There is nothing to indicate that those who are recorded at only one of the measuring points (A or B) are driving at a speed that is different from those recorded at both measuring points. This corresponds with the results from Hallingdal (Figure 3) and Hell (Figure 9).

# 6. The contribution of speed to risk

## 6.1 The exponential model – an appropriate system of concepts

(The exponential model has been presented and discussed in more detail by Olsen (Olsen 2013).)

The correlation between driving speed and the risk of accidents has previously been described using the so-called power model (Elvik 2010). This makes it possible to calculate changes in risk as a function of changes in average speed in a speed distribution.

In 2012 a scientific article (Elvik 2013) re-assessed this model and proposed that it be replaced by an exponential model. The exponential model has three main features compared with the power model:

1. The exponential model gives a better description of data (has a higher explanatory ability) than the power model. This particularly applies at higher speeds.
2. The risk of accidents rises much more steeply with the exponential model than with the power model.
3. The mathematics in the exponential model make it possible to calculate the total risk contribution to an interval in the speed distribution.

Figure 18 shows a comparison of the two models (the power model and the exponential model) that describes the relative risk of accidents as a function of driving speed.

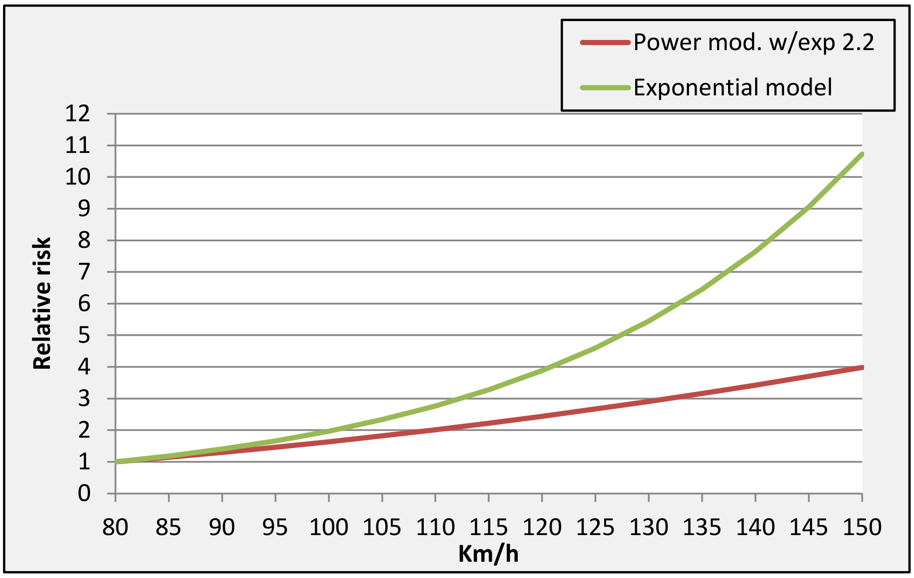



*Figure 18: The power model and the exponential model. Relative risk as a function of driving speed.*

The exponential model is based on the formula

$$Y = \exp(0.034*\text{Vafter}-\text{Vbefore})$$

Where Y represents the risk of accidents and V is the driving speed in km/h before and after a measure has been implemented, here presented relatively as 80 km/h, i.e. Vetter=80 km/h. The coefficient 0.034 appears on calibration shown in Elvik (Elvik 2013).

As can be seen, the risk rises much more steeply with the exponential model than it does with the power model. For example the relative risk for v=140 km/h calculated with the power model is 3.4 (with the exponent 2.2), while with the exponent model it is 7.7.

The relative risk presented in the figure is related to the individual vehicle with the given driving speed, i.e. according to the exponential model, if a motorist drives at a speed of 140 km/h the risk of accidents is 7.7 times higher than if he or she drives at 80 km/h. The corresponding figure in the power model is 3.4.

The third feature of the exponential model means that it is also possible to calculate the importance of a speed interval (a fraction) for the total risk for the entire population, taking into account how large a part of the entire speed distribution and the average speed the speed interval constitutes.

This is shown in the calculation example in Figure 19.

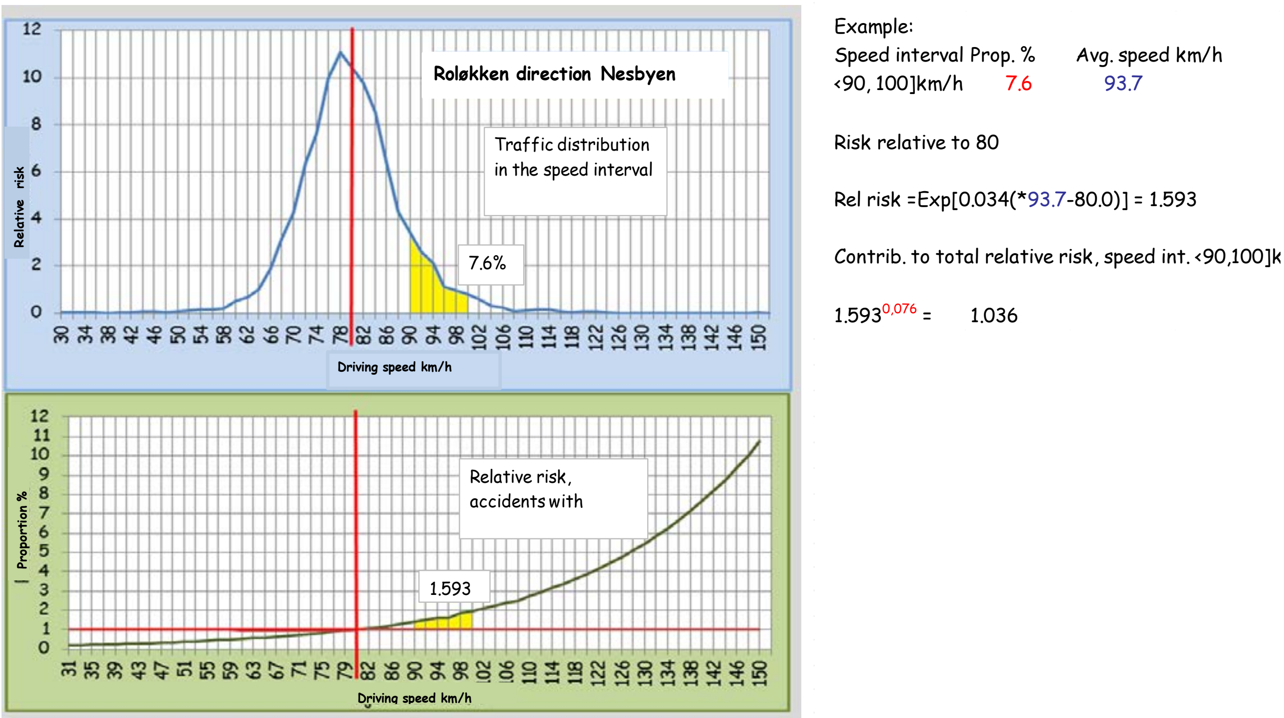



*Figure 19: Contribution of speed intervals to total relative risk estimated with the exponential model. Figures from Roløkken, RV7 in Hallingdal.*

The average driving speed in the speed interval <90,100] km/h (marked in yellow in the figure) is 93.7 km/h. At this speed, a motorist runs the risk of accidents of 1.593 compared with a motorist driving at 80 km/h. The group with this average speed (93.7 km/h) accounts for 7.6% of the total speed distribution, and the group's contribution to the total risk in the distribution is 1.036(=$1.593^{0.076}$ – see explanatory notes). This can be interpreted as denoting that this group's choice of speed entails an increase in risk of 3.6% for the entire group when compared to an alternative choice of driving speed of 80 km/h. The accident reduction that can be achieved by getting this group to reduce their driving speed to 80 km/h would amount to 3.4% (=1-1/1.036).

## 6.2 Reduced risk and reduced number of accidents in speed intervals

If a speed distribution is split up into different intervals, using the exponential model the total risk can be calculated as a multiple of the contributions to risk in each interval. By doing this before and after an installation of ASSC, the risk change and an expected change in the number of accidents can be estimated and related to changes in each speed interval.

This is shown in Table 11. The example is from Roløkken, RV7 in Hallingdal, and the data correspond to Figure 2.

| BEFORE ASSC<br>Speed interval | Prop.<br>% | Av. speed<br>km/h | Relative<br>risk | Total<br>contrib. to risk |
|---|---|---|---|---|
| <= 80 | 58.0 | 73.3 | 0.796 | 0.876 |
| <80,90] | 32.5 | 84.0 | 1.146 | 1.045 |
| <90,100] | 7.6 | 93.7 | 1.593 | 1.036 |
| >100 | 1.9 | 106.9 | 2.496 | 1.018 |
| >80 control | | =1,045*1,036*1,018= | | 1.102 |
| >80 | 42.0 | 86.8 | 1.260 | 1.102 |
| All control | | =0,876*1,102 = | | 0.967 |
| ALL | 100.0 | 79.0 | 0.967 | 0.967 |

| AFTER ASSC<br>Speed interval | Prop.<br>% | Av. speed<br>km/h | Relative<br>risk | Total<br>contrib. to risk |
|---|---|---|---|---|
| <= 80 | 92.3 | 68.3 | 0.672 | 0.693 |
| <80,90] | 6.4 | 83.3 | 1.119 | 1.007 |
| <90,100] | 0.9 | 93.8 | 1.599 | 1.004 |
| >100 | 0.4 | 107.8 | 2.573 | 1.004 |
| >80 | 7.7 | 85.7 | 1.214 | 1.015 |
| All | 100 | 69.7 | 0.705 | 0.705 |

*Table 11: Relative and total risk in the speed distribution before and after ASSC, RV 7 in Hallingdal. Percentages, average speed in km/h.*

The upper part of the table describes the situation before the installation of ASSC. The total average speed is 79.0 km/h with a risk relative to 80 km/h of 0.967.

58.0% of motorists have a driving speed of <=80 km/h. The average speed in this group is 73.3 km/h and the relative risk for this group will be 0.796 (=exp(0.034*(80-73.3)). This group's contribution to the total relative risk is 0.876(=$0.796^{0.58}$).

42.0% of motorists have a driving speed of >80 km/h. The average speed in this group is 86.8 km/h and the relative risk for the group is 1.260. This group's contribution to the total risk for all motorists is 1.102.

To check this, the total relative risk for the entire speed distribution can then also be calculated (=0.967) by multiplying the relative risk for the two intervals (0.876*1.102=0.967).

Similarly the total relative risk for all those driving at a speed of >80 km/h (= 1.102) is calculated by multiplying together the risk contributions from each of the three speed intervals <80-90],<90-100] and <100 km/h (1.045*1.036*1.018=1.102).

The lower part of the table shows the corresponding position after the installation of ASSC. The average driving speed in the entire speed distribution is reduced by 9.3 km/h, from 79.0 km/h to 69.7 km/h. The total relative risk is reduced from 0.967 to 0.705. All speed intervals contribute to the reduction in the total risk. The relative risk may of course increase in some intervals with a high driving speed (in the >100 km/h group the average speed increases from 106.9 km/h to 107.8 km/h), but since the number in the same group drops (from 1.9% in the before situation to 0.4% in the after situation), the contribution to the total risk will nonetheless decline.

The results in the table indicate that the total risk is reduced from 0.967 in the before situation to 0.705 after the installation of ASSC. This is a relative change (after/before) of 0.729 (=0.705/0.967), corresponding to an expected reduction in the number of accidents of 27.1% (=1-0.729).

This is shown in Table 12, which also illustrates changes in relative risk and expected accident reduction from each speed interval.

| Speed interval | BEFORE Tot. contr. to risk | AFTER Tot. contr. to risk | Change after/before | Acc. red. % |
|---|---|---|---|---|
| <= 80 | 0.876 | 0.693 | 0.791 | **20.9** |
| <80,90] | 1.045 | 1.007 | 0.963 | **3.7** |
| <90,100] | 1.036 | 1.004 | 0.969 | **3.1** |
| >100 | 1.018 | 1.004 | 0.987 | **1.3** |
| >80 | 1.102 | 1.015 | 0.921 | **7.9** |
| ALL | 0.967 | 0.705 | 0.729 | **27.1** |

*Table12: Contribution of speed intervals to total relative risk before and after ASSC, Roløkken, RV7 in Hallingdal. Change in relative risk and associated expected reduction in number of accidents (%).*

The table shows that the total estimated expected reduction in the number of accidents is 27.1%. When split up into the various speed intervals, it can be seen that the greatest reduction is found in the group with a driving speed of <=80 km/h where the reduction is estimated to be 20.9%.

In the whole group with a driving speed of >80 km/h, where the speed is reduced from 86.8 km/h to 85.5 km/h from before until after the installation of ASSC and the corresponding percentages are reduced from 42.0% to 7.7%, the change in relative risk is estimated to be 0.921, i.e. a reduction in accidents of 7.9% (=1-0.921).

In this example, where the driving speed in the <=80 km/h group is reduced quite considerably; it appears that this group makes the greatest contribution to total risk reduction. There are many possible explanations of why this is the case, but based on how we want the regulating ASSC to work, it is mainly the effects of speed changes for the group that at the outset drive faster than the speed limit that is to be ascribed importance. Possible effects in other groups must only be considered a bonus.

The next figure shows the contribution of speed intervals to risk reduction **that is related to** the installation of ASSC at Roløkken, RV7 in Hallingdal.

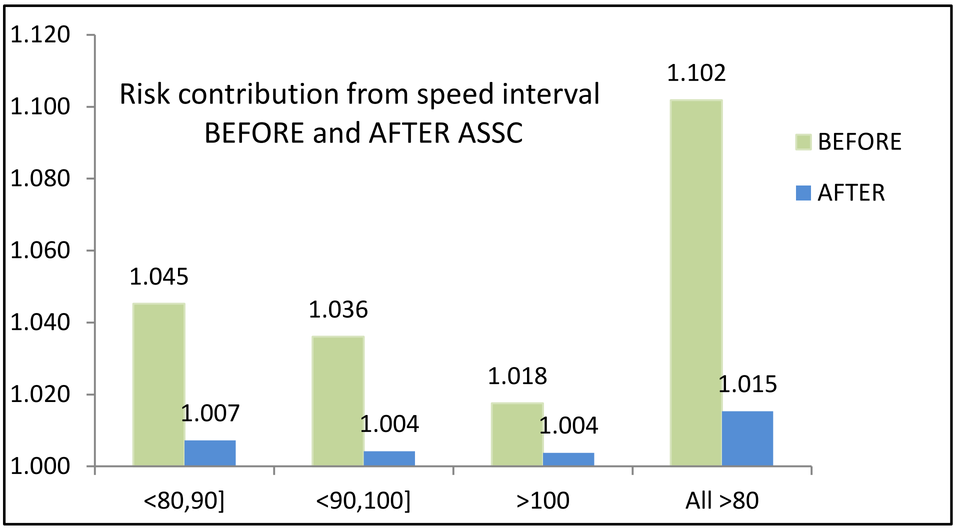



*Figure 20: Total contribution to risk of speed interval >80km/h before and after ASSC at Roløkken, RV7 in Hallingdal*

The figure shows how the total risk of accidents is reduced as a result of the installation of ASSC, from 1.102 in the before situation to 1.015 afterwards. This corresponds to an expected reduction of 7.9%. The largest part of the reduction, 3.7%, can be ascribed to the speed interval <80,90] km/h, but the interval <90,100] also makes a significant contribution of 3.1%. The changes in the interval >100 km/h show the smallest significance, 1.3%, which is due to the fact that the number in this group is somewhat small before the installation of ASSC.

## 6.3 Change in risk profile – accident reduction potential

Further processing of the data enables us to present a risk profile for the relevant speed distribution. This shows how the total risk depends on the contributions from each speed interval.

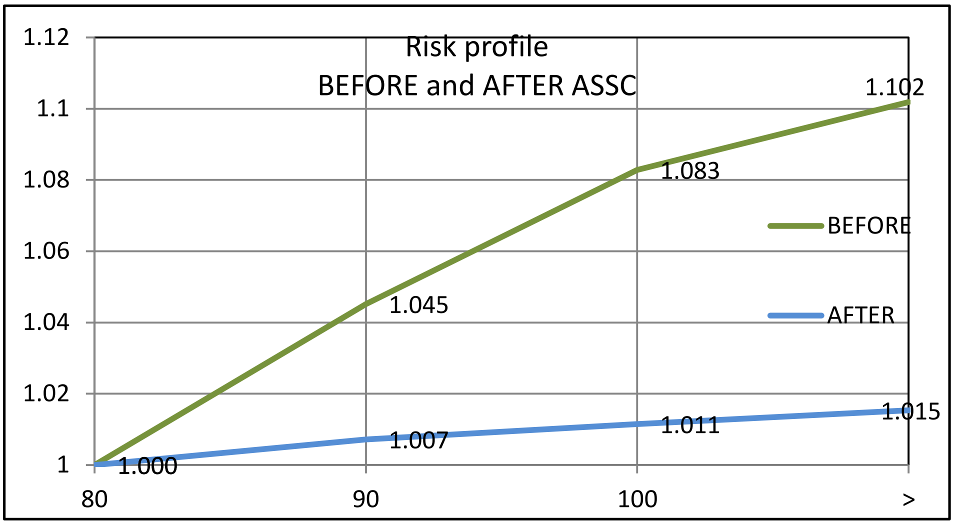



*Figure 21: Risk profile before and after ASSC at Roløkken, RV7 in Hallingdal*

The green line in the graph shows the risk profile before ASSC. In the interval with the speed <=80 km/h (the speed limit), the relative risk is set equal to 1.
The <80,90] km/h interval contributes a risk of 1.045 (see Table 11). The total contribution for the <=90 km/h interval is thus 1.045 (=1.0*1.045). The next interval of <90,100] km/h makes a contribution of 1.036 to the total risk (see Table 11), which means that the total risk for the <=100 km/h interval is 1.083 (=1,045*1,036). The last interval of >100 km/h alone contributes a risk of 1.018 (see Table 11), and the total risk for all >80 km/h intervals is 1.012(=1.083*1.018= 1*1.045*1.36*1.018).

The blue line on the graph in the figure presents the speed distribution in the same way after the installation of ASSC, and the area between the lines expresses the risk reduction the installation represents.

In total the change in the risk profile represents a change in relative risk from 1.102 in the situation before the installation of ASSC to a risk of 1.015 afterwards. This corresponds to a relative change (after/before) of 0.921 or an expected reduction in accidents of 7.9%.

The figure shows an estimated accident reduction based on a before-and-after consideration related to ASSC. If we had not had measurements from the situation after the installation of ASSC, we could estimate an accident reduction potential based on the assumption that all motorists change their speed in the after situation so that none of them drive at a speed >80 km/h. This indicates that the relative risk in the after situation would be 1.0, which corresponds to the X axis in the figure. In this way the absolute accident reduction potential can be estimated to be 9.3%. (1-1/1.102). This potential can be an important entrance parameter in the evaluation when criteria for the installation of an ASSC system are to be compiled.

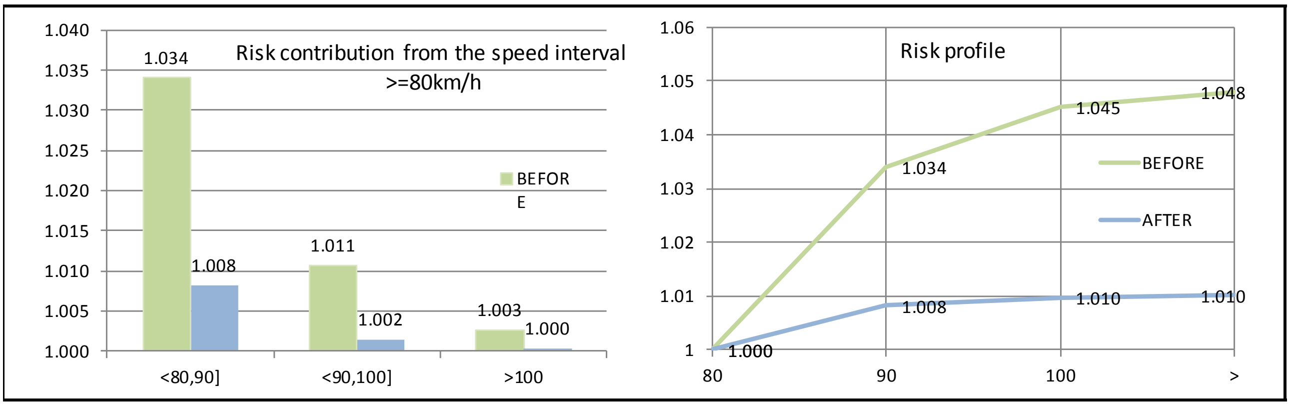
# 7. Estimated accident reduction resulting from automatic section speed control

Using the system of concepts developed in Section 6, we can now estimate an expected reduction in the number of accidents resulting from the installations of ASSC in the different tunnels.

## 7.1 The Hell tunnel

The calculations have been based on figures from the measuring point in the middle of the tunnel, shown in Figure 7, where the speed before ASSC is 77.9 km/h on average. The risk calculation can be seen in Figure 22.

**Hell, E6, Trøndelag County      Accident reduction after ASSC**




| Speed interva km/h | BEFORE Prop. % | \vg. speec km/h | Relative risk | Total risk contrib. | AFTER Prop. % | Avg. speed km/h | Relative risk | Total risk contrib. | Change after/before | Accident reduction % |
|---|---|---|---|---|---|---|---|---|---|---|
| <=80 | 67.8 | 74.9 | 0.840 | 0.889 | 91.4 | 73.5 | 0.801 | 0.817 | 0.919 | **8.1** |
| >80 | 32.2 | 84.3 | 1.157 | 1.048 | 8.6 | 83.5 | 1.125 | 1.010 | 0.964 | **3.6** |
| | | | | | | | | | | |
| <80,90] | 29.5 | 83.3 | 1.120 | 1.034 | 8.2 | 82.9 | 1.105 | 1.008 | 0.975 | **2.5** |
| <90,100] | 2.4 | 93.1 | 1.562 | 1.011 | 0.3 | 93.2 | 1.565 | 1.002 | 0.991 | **0.9** |
| >100 | 0.3 | 106.9 | 2.496 | 1.003 | 0.0 | 109.3 | 2.706 | 1.000 | 0.998 | **0.2** |
| | | | | | | | | | | |
| All | 100.0 | 77.9 | 0.931 | 0.931 | 100.0 | 74.3 | 0.825 | 0.825 | 0.886 | **11.4** |

*Figure 22: Estimated reduction in risk and accidents after ASSC in the Hell tunnel, E6, Trøndelag*

The average speed in the >80 km/h group is 84.3 km/h in the before situation. With a percentage of the total traffic of 32.2%, this group's contribution to total relative risk in the before situation is 1.048. In the after situation the risk contribution from this group is reduced to 1.010, which corresponds to a relative figure (after/before) of 0.964 or an expected reduction in accidents of 3.6% (1-1.010/1.048). The biggest contribution to risk reduction is from the <80,90] km/h group, which alone contributes with a reduction of 2.5%. The total accident reduction potential (if no motorists drove at a speed of >80 km/h in the after situation) is estimated to be 4.6%. The achieved result of 3.6% shows that the driving speed is significantly reduced after the installation of ASSC, which is also reflected in the fact that the relative risk in the >80 km/h group in the after situation is 1.010.

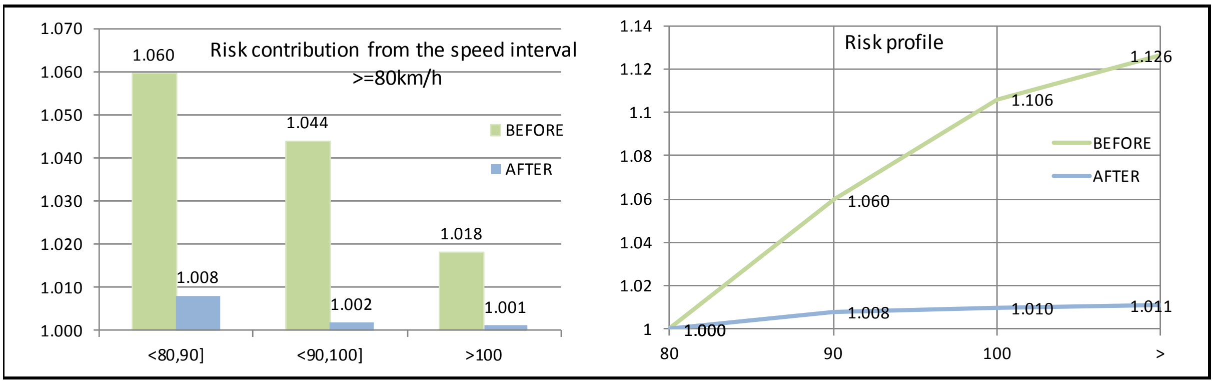
The total reduction in accidents resulting from ASSC is estimated to be 11.4%. The largest part of the total reduction can be ascribed to the group with a driving speed of <=80 km/h. This group reduces their speed from 74.9 km/h in the before situation to 73.5 km/h in the after situation, at the same time as the size of the group increases from 67.8% to 91.4%. In the situation after the installation of ASSC, 8.6% drive at a speed of >80 km/h, and 0.3% at a speed of >90 km/h.

In general the risk profile in this flat tunnel is similar to the risk profile estimated at Roløkken, RV7, Hallingdal (shown in Figure 20). The total contribution to risk reduction is greatest in the group with a speed of <=80 km/h. In the >80 km/h group the contribution constitutes approximately one-third of the total, and of the three speed fractions the contribution is greatest from the <80,90] km/h group.

## 7.2 The Eiksund tunnel

Calculations in the before situation are based on the measuring point at km 8630 (downhill lane) on the descent from Ørsta, shown in Figure 12. Here the average speed is measured at 80.6 km/h. In the after situation, the result from ASSC section S3 (shown in Figure 13) is used. The average speed here is measured at 75.3 km/h.

**Eiksund, FV 653, Møre og Romsdal County** **Accident reduction after ASSC**




| Speed interval km/h | BEFORE Prop. % | Avg. speed km/h | Relative risk | Total risk contrib. | AFTER Prop. % | Avg. speed km/h | Relative risk | Total risk contrib. | CHANGE after/before | Accident reduction % |
|---|---|---|---|---|---|---|---|---|---|---|
| <=80 | 50.2 | 74.2 | 0.821 | 0.906 | 88.7 | 74.3 | 0.824 | 0.842 | 0.930 | **7.0** |
| >80 | 49.8 | 87.0 | 1.269 | 1.126 | 11.3 | 82.9 | 1.104 | 1.011 | 0.898 | **10.2** |
| <80,90] | 38.7 | 84.4 | 1.161 | 1.060 | 10.8 | 82.2 | 1.078 | 1.008 | 0.951 | **4.9** |
| <90,100] | 9.3 | 93.6 | 1.588 | 1.044 | 0.4 | 93.0 | 1.556 | 1.002 | 0.960 | **4.0** |
| >100 | 1.9 | 107.9 | 2.582 | 1.018 | 0.1 | 113.0 | 3.071 | 1.001 | 0.983 | **1.7** |
| All | 100 | 80.6 | 1.021 | 1.021 | 100 | 75.3 | 0.852 | 0.852 | 0.835 | **16.5** |

*Figure 23: Estimated reduction in risk and accidents after ASSC in the Eiksund tunnel, FV653, Møre og Romsdal*

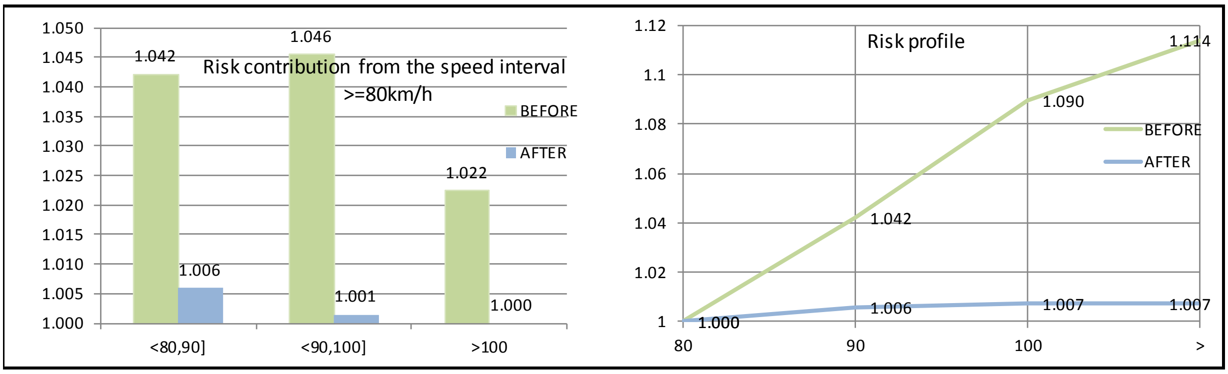
Here, too, there is some contribution from the two groups with a speed of <=80 km/h and <80 km/h respectively. The largest contribution is from the >80 km/h group where the relative risk is reduced from 1.126 before the ASSC to 1.011 afterwards. The relative figure is therefore 0.898, corresponding to an estimated risk reduction of 10.2%. The <=80 km/h group contributes a total reduction of 7.0%.

There is roughly the same contribution from both groups with a speed of <80,100] km/h, a contribution of approximately 4.5% from each, but the >100 km/h group also contributes. The average speed in this group rises steeply, from 107.9 km/h to113 km/h. However, since the size of the group is reduced from 1.9% in the before situation to 0.1% in the after situation, this group alone nonetheless contributes a reduction in accidents corresponding to 1.7%.  This reduction is larger than that of the corresponding group at Hell where the reduction was 0.2%. The total accident reduction potential for those with a speed of >80 km/h is estimated at 11.2%. Compared with the estimated result of 10.2%, this means that the speed in the after situation is significantly reduced, with a relative risk of 1.011 after the installation of ASSC.

## 7.3 The Hvaler tunnel

The estimates from Hvaler – from both before and after the installation of ASSC – are based on data from the measuring point at km 3582 placed at the “bottom” of the tunnel as shown in Figure 15. The speed measurements are also given in Table 7. Figure 24 shows the result of the estimated risk reduction.

**Hvaler, FV108, Østfold County     Accident reduction after ASSC**




| Speed interval km/h | BEFORE Prop. % | Avg. speed km/h | Relative risk | Total risk contrib. | AFTER Prop. % | Avg. speed km/h | Relative risk | Total risk contrib. | CHANGE after/before | Accident reduction % |
|---|---|---|---|---|---|---|---|---|---|---|
| <=80 | 62.9 | 71.4 | 0.748 | 0.833 | 93.8 | 70.6 | 0.727 | 0.741 | 0.890 | **11.0** |
| >80 | 37.1 | 88.6 | 1.338 | 1.114 | 6.2 | 83.5 | 1.128 | 1.007 | 0.904 | **9.6** |
| <80,90] | 25.8 | 84.7 | 1.174 | 1.042 | 5.8 | 83.0 | 1.107 | 1.006 | 0.965 | **3.5** |
| <90,100] | 8.9 | 94.8 | 1.652 | 1.046 | 0.3 | 92.9 | 1.551 | 1.001 | 0.958 | **4.2** |
| >100 | 2.4 | 106.7 | 2.480 | 1.022 | 0.0 | 0.0 | 0.066 | 1.000 | 0.978 | **2.2** |
| All | 100.0 | 77.8 | 0.928 | 0.928 | 100.0 | 71.4 | 0.747 | 0.747 | 0.805 | **19.5** |

*Figure 24: Estimated reduction in risk and accidents after ASSC in the Hvaler tunnel, FV108, Østfold*

Here, too, the figure shows significant reductions in risk from before until after ASSC. The reduction is 9.6% in the group with a speed of >80 km/h. The speed is reduced in this group from 88.6 km/h before to 83.5 km/h after, at the same time as the size of the group is reduced from 37.1% to 6.2%. Here the <90,100] km/h group contributes a somewhat greater reduction in risk than the <80,90] km/h group.

When the achieved reduction in accidents for the >80 km/h group corresponds to 9.6% and the total reduction potential can be estimated at 11.4%, this means that the speed after the installation of ASSC is considerably reduced. The driving speed of 0.3% of motorists is >90 km/h, and the total risk contribution in the after situation is 1.001.

## 7.4 The Tromsøysund tunnel

No data material is available for Tromsøysund in a form that allows individual groups' contribution to risk change to be calculated in detail. However, with the exponential model the results given in Table 9 can be used to estimate the total contribution to accident reduction in the two tunnel tubes separately. In T1 (southbound) the risk is reduced from 1.010 in the situation before the installation of ASSC to 0.804 afterwards. This corresponds to a relative figure of 0.796 or a reduction in accidents of 20.4%. Similarly, the accident reduction for tunnel tube T2 is 18.2%. The percentage of motorists with a driving speed of >80 km/h is here reduced from 42.5% to 4.4%, and the risk is reduced correspondingly from 0.986 to 0.807.

# 8. Estimates of the total accident reduction potential

As shown above, it is possible to calculate an accident reduction potential for an ASSC installation on the basis of the before measurements. This is based on the assumption that all those who at the outset drive at a speed higher than the speed limit reduce their driving speed to the speed limit. Comments on such estimates are given in Section 7 to indicate what is actually achieved regarding speed reductions by measurements before and after the installation of ASSC. These estimates showed that the group driving at a speed of >80 km/h (the speed limit) in the before situation largely reduce their driving speed. This is partly verified by the fact that the relative risk after ASSC is installed is small, i.e. close to 1.0. This supports previous knowledge, indicating that the effect of speed cameras in general is a function of the speed before speed cameras are is installed.

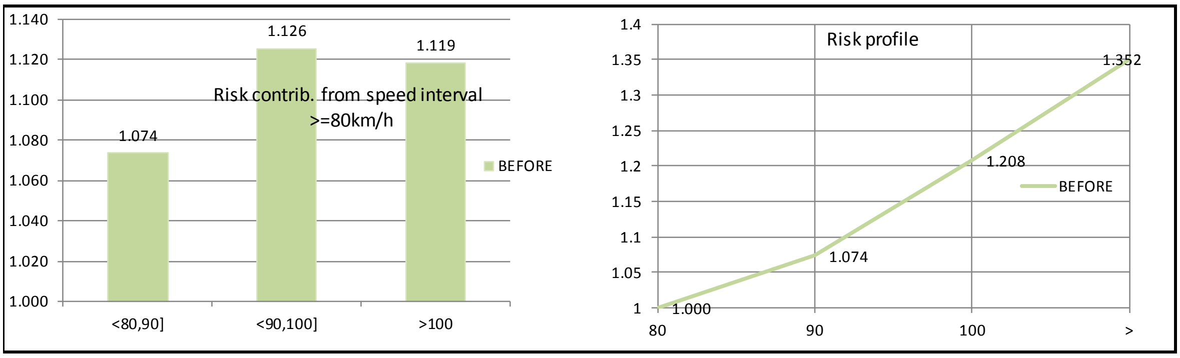
The advantage of calculating potentials is that these estimates are made on the basis of measurements taken **before** the installation of ASSC and represent an expectation of the results that can be achieved.

Such estimates can be relevant for the compilation of criteria for the use of speed cameras in general and for Automatic Section Speed Control (ASSC) in particular.

## 8.1 The Valderøy tunnel

Figure 25 shows an example of a potential calculation from the Valderøy tunnel, FV653, Møre og Romsdal. Speed measurements were taken in a section at the bottom of the tunnel.

**Valderøy, FV653, Møre og Romsdal County**




| Speed interval km/h | BEFORE Prop. % | Avg. speed km/h | Relative risk | Total risk contrib. |
|---|---|---|---|---|
| <= 80 | 23.3 | 68.7 | 0.680 | 0.914 |
| >80 | 76.7 | 91.6 | 1.482 | 1.352 |
| <80,90] | 40.8 | 85.1 | 1.190 | 1.074 |
| <90,100] | 24.4 | 94.3 | 1.624 | 1.126 |
| >100 | 11.5 | 108.7 | 2.657 | 1.119 |
| All | 100.0 | 86.2 | 1.235 | 1.235 |

| Cutoff km/h | Rel. risk BEFORE | AFTER | Change after/before | Accident red. % |
|---|---|---|---|---|
| 80 | 1.352 | 1.000 | 0.740 | **26.0** |
| 90 | 1.259 | 1.000 | 0.794 | **20.6** |
| 100 | 1.119 | 1.000 | 0.894 | **10.6** |

*Figure 25: Estimated potential for the reduction of risk and accidents with ASSC, Valderøy tunnel, FV653, Møre og Romsdal.*

The results are based on measurements of individual vehicles in a section of the tunnel.

Experience from the Hvaler tunnel described in Section 5.3 shows that this can often be a point located at the “bottom” of a subsea road tunnel, or in the middle of a flat tunnel as that shown from Hell.

Figure 25 from Valderøy shows that the average speed for all motorists where no ASSC is installed is 86.2 km/h. In the group driving at a speed of >80 km/h (which is the speed limit) the average speed is 91.6 km/h. If these motorists adapt their speed to the speed limit, the relative risk is reduced from 1.352 in the situation without ASSC to 1.0 if such cameras are installed. This represents a reduction of 26.0%. It is in particular the two groups with the highest driving speed that contribute to the reduction. If all those driving at a speed of >90 km/h adapt their speed, the figure shows an expected reduction in accidents of 20.6%. The >100 km/h group alone will contribute an accident reduction that corresponds to 10.6%.

# 9. Summary and conclusion

**ASSC has a speed-reducing effect. At the same time as the average speed declines, high speeds become almost non-existent. The effects are as significant and as clear as those for roads in open air.**

Like the summary of the results from ASSC on roads in open air (shown in Table 1), a similar summary of ASSC in tunnels to some extent reveals substantial effects of these cameras on driving speeds measured before and after their installation.

Table 13 shows the effects measured in the seven separate ASSC systems that we have presented in this report from four different road tunnels. The total results from two subsequent systems in Eiksund are also presented.

| Tunnel name | County | Road no. | Length m | AADT 2010 vhcl/day | Speed limit km/h | Driving speed km/h Before ASSC | After ASSC | Reduction km/h | Estimated acc. red. % |
|---|---|---|---|---|---|---|---|---|---|
| Hell | Trøndelag | E6 | 4180 | 15000 | 80 | 77.9 | 75.3 | 2.6 | 11.4 |
| Eiksund | M& Romsdal | FV653 | 7840 | 2030 | 80 | 81.1 | 74.5 | 6.6 | 20.5 |
| S1 | | | | | | 84.4 | 75.2 | 9.2 | 26.9 |
| S2 | | | | | | 77.9 | 74.3 | 3.6 | 11.3 |
| S3 | | | | | | 80.6 | 75.3 | 5.3 | 16.5 |
| Tromsøysund T | Troms | E8 | 2021 | 5030 | 80 | 80.3 | 73.6 | 6.7 | 20.4 |
| Tromsøysund T2 | | | 2016 | 4860 | | 79.6 | 73.7 | 5.9 | 18.2 |
| Hvaler dir. 2 | Østfold | Fv108 | 3887 | 2000 | 80 | 77.8 | 68.8 | 9.0 | 26.4 |

*Table 13. Summary of results from the evaluation of ASSC in tunnels.*
*Name, county, road no., length, AADT, speed limit and measured driving speed before and after ASSC, estimated change in speed (km/h) and estimated accident reduction (in percentage).*

The greatest reduction of 9.2 km/h was measured in the Eiksund tunnel, FV 653, Møre og Romsdal. Here the speed before the installation of ASSC was highest, with an average of 84.4 km/h. The results are based on spot measurements on the downhill section from Eiksund (km1580) in the direction from Ørsta in the before situation, and on the ASSC section S1 in the same direction with the points A1 and M.

The smallest change in driving speed, 2.6 km/h, was measured in the Hell tunnel, E6, Trøndelag. The before speed here was among the lower speeds measured. ASC were previously installed in this tunnel. The speed in the after situation in the Hvaler tunnel is reflected by the speed after ASSC at S3 (Table 8).
Comments on the column “Estimated accident reduction” will be given later.

**At least 90% of motorists keep to the speed limit in the after situation, almost regardless of the before situation. The speed-reducing effect is thus greatest where the speed level is high in the before situation – as is also the case for surface roads.**

Similar to ASSC on roads in open air, there is a correlation between measured speed before ASSC and the change (reduction) in speed from before until after. In Figure 26 this change for roads in open air and for roads in tunnels is presented in a diagram where a trend line has also been drawn. A linear trend line has been chosen to simplify the diagram.

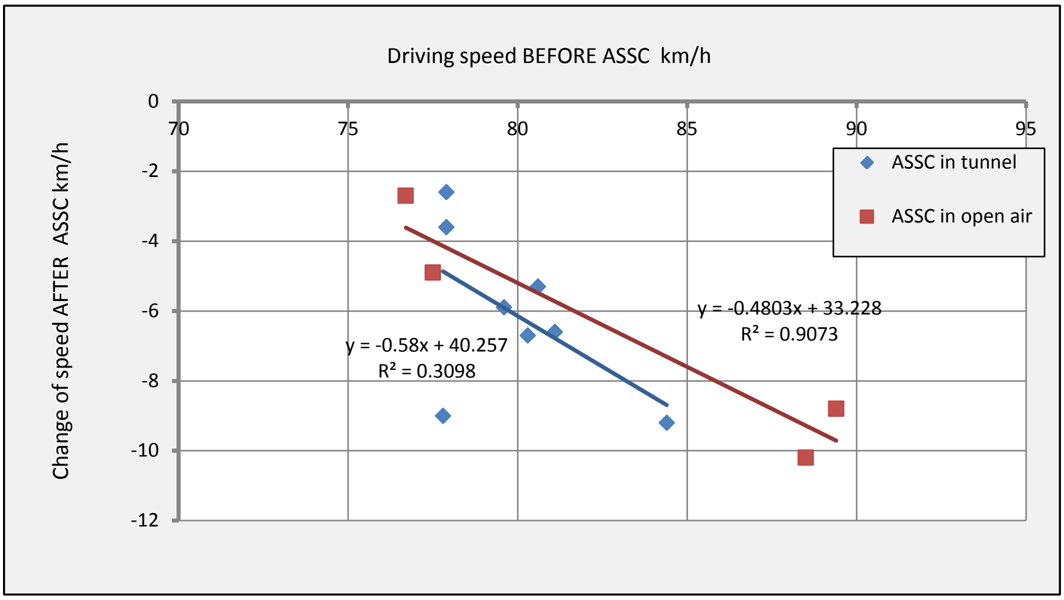



*Figure 26: Correlation between measured driving speed before ASSC and change in driving speed from before to after for roads in open air and roads in tunnels. Km/h.*

The figure shows that the correlations for the two trend lines are somewhat different. However, both lines show a correlation between the speed before the installation of ASSC and the speed reduction that is achieved. Dependence on the before speed is approximately the same for roads in open air as it is for roads in tunnels. This must not be over-interpreted in any way, but we can make a conservative assertion that the correlation is described by a factor with a uniform negative sign for both sets of data. The area of definition is somewhat larger for roads in open air than is the case for tunnels.

In general, the trials show that ASSC in tunnels constitute an effective instrument for reducing driving speed, and that the speed reduction is at least as great as that for roads in open air.

**The positions selected for the cameras (ASSC posts) have been successful.**
The risk zones at the mouths of the tunnel should if possible be avoided when the cameras are positioned.

In flat two-lane tunnels it is an advantage to use two cameras placed on the outside of the tunnel mouths, as was the case in the Hell tunnel.

The trial in Eiksund showed that it can be an advantage to convert an existing ASC system at the bottom of subsea road tunnels into a complete ASSC system with three cameras in each direction. The "old" cameras at the bottom then function as both the first and last point in each ASSC system. The results from this tunnel showed a very sound reduction in driving speed that is guaranteed to apply to the entire tunnel. Unfortunately there are no measurements for the incline in direction 2 from Ørsta to Eiksund after ASSC were installed. There are no grounds to claim that the speed reduction at the ASSC cameras at the bottom is greater if these are ASC cameras.

However, the results from Hvaler showed that two cameras, one at each tunnel mouth, at the top of a subsea road tunnel generate a considerable reduction in driving speed through the entire tunnel – uphill, downhill and at the bottom. This can thus be both an appropriate and a simplified way of restricting high driving speeds. It must be made clear that the motorists in direction 2, who are exposed to the two cameras, one at each tunnel portal, also see the "back" of an camera at the bottom of the tunnel. The speed at the bottom may be affected by this, while at the same time the percentage of heavy vehicles in the tunnel is relatively low.

**There is no clear connection between speed reduction and vertical geometry.**
There is no clear proven connection between vertical geometry and the speed reduction achieved. It seems as if the effect (speed reduction) has a connection with the speed before the installation of ASSC more than with the actual geometry. In addition there does not appear to be any clear connection between the driving speed upwards and downwards on the same incline or the steepness of the gradient. This can be interpreted as the speed resources of light vehicles being sufficiently large to allow choice of speed to be unaffected by geometry.

**ASSC that cover several lanes in the same direction (single-tube tunnels) function well.**
The trial in Tromsøysund shows that ASSC can successfully be used in tunnels with two tubes and with several lanes in the same direction.

**Estimating risk reduction and risk profiles gives us insight into risk contribution in speed intervals.**
The reassessment of the power model shows that the correlation between driving speed and contribution to risk can be greater than previously assumed, i.e. driving at a high speed has even greater impact on the risk than that previously indicated by the power model. In the new system an groving model is used to explain the correlation between speed and risk. In addition to developing faster than the power model, the exponential model uses a type of mathematics that makes it possible to calculate the contributions of different speed intervals to the total risk. This means that the estimated total risk reduction due to ASSC can be divided into two groups: motorists who before the installation drive at a speed of <=80 km/h and those who drive at >80 km/h (when the speed limit is 80 km/h). The examples show that both groups reduce their driving speed when ASSC are installed, thus contributing to the total reduction in risk. Paradoxically, this means that both the group who at the outset drove at a legal driving speed under the speed limit and those who drove at a speed higher than the speed limit contribute to the total risk reduction. ASSC, which represent a tool for sanctions against those who choose a driving speed over the speed limit, nonetheless also influence the speed of those who drive at a speed under the speed limit. The risk reduction this produces must then be interpreted as a sort of "unintended" positive bonus in the use of ASSC. However, it must be emphasised that this bonus must not be too great in relation to the risk reduction that the group driving at a speed of >80 km/h contributes. In practice this means that the driving speed before ASSC is installed must be at a certain level and that the speed after the installation should not be too low. The results from Nesbyen, RV7, Hallingdal indicate that this may be a problem at some sites. The driving speed here after the installation of ASSC is approximately

65 km/h at the cameras, and three-quarters of the estimated risk reduction can be traced back to the group driving at a speed of <=80 km/h in the before situation.

**The estimated risk reductions on the sections vary from 10% to 25%.**
Table 13 shows the estimated accident reduction in percentages for the situation before the installation of ASSC for each of the individual ASSC systems. The estimated reductions are total reductions and contain all contributions from speed intervals to reductions. The reductions become somewhat greater when estimated with the new exponential model than a similar calculation with the power Model would have shown. The estimated reduction has a clear correlation with the size of the reduction in speed.

As with the power model, there is reason to believe that the percentage change in fatalities or seriously injured persons would have been higher than that for accidents in general. A direct calculation of changes in the number of fatalities and seriously injured persons cannot yet be made using the exponential model.

**Proactive use of ASSC in tunnels should be considered.**
The calculations made show a considerable reduction in risk when ASSC is used in general and in particular in tunnels. The system of concepts developed appears to be well adapted for further use in the formulating of new criteria for when ASC and ASSC can be used in various contexts.

This should be an appropriate approach for making a more proactive use of ASSC in general and particularly in tunnels where the potential for disaster is high and where the criteria are largely based on driving speed and to a lesser extent also on accidents that have occurred.

**The total evaluation shows that the trials using ASSC in tunnels have produced extremely positive results. The speed reductions are at least as large as those for roads in open air, and using the system in tunnels can therefore represent a substantial contribution to the reduction in both speed and accidents.**

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ISSN: 1893-1162