

INTELLIGENT SPEED ADAPTATION (ISA) AND ROAD SAFETY*

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An ISA system consists of GPS to determine the car's position, a CD-ROM in the car containing information of a road network including the prevailing speed limit of each road section, and feedback to the driver. Experiments in Sweden are testing several options, from warning the driver to a resisting force exerted by the accelerator pedal that can be countered by the driver. In the Netherlands the system intervenes so the limit cannot be exceeded. Experiments in Sweden have recently been concluded and an evaluation is in progress. In the Netherlands the project was concluded early 2001. The field experiments so far mainly concern the measure of acceptance of the system(s) by the public. Several simulation studies have also been conducted. Little is known as yet from practical research of the effects of ISA on road safety, though a large safety potential is assumed. For the Dutch situation, based on the assumption that all passenger cars are fitted with ISA and an assumed speed distribution as the result of ISA, a theoretical calculation is made of the effects of ISA on speed and safety. The result is an estimated reduction of road casualties of 25 to 30%. Further, the assumed speed distribution is validated with field measurements of the experiment in the city of Tilburg. The result is that the measured average speed of the speed distribution fits quite well with the calculated average speed.

Key Words: Intelligent Speed Adaptation (ISA), Speed behaviour, Safety effect

1. INTRODUCTION

The result of a literature review and research by Transportation Research Laboratory was the report 'The effect of driver's speed on the frequency of road accidents'². The research encompassed road based and driver based studies. 'The evidence is compelling that in a given set of road and traffic conditions the frequency of accidents increases with the speed of traffic, and the higher the speed the more rapidly does accident frequency rise with increases in speed.'

In many countries within Europe accidents and casualties related to speeding are a manifest problem. The police lack the manpower to contain this problem, other than incidentally and periodically. Infrastructure measures are unpopular, costly and time consuming.

So other types of measures that are effective need to be reviewed. The ADVISORS project (funded by the European Commission) deals with Advanced Driver Assisting Systems³. Some car producers have introduced a speed limiting system to be adjusted manually. Overruling in case of an emergency is possible by kick-down. This system is rather cumbersome, because every change

in speed limit necessitates manual adjustment. With the introduction of navigation systems, the expectation is that the next step will be that speed limits will be added to the road network software. Then ISA can be switched on or off. When switched on, the system can function autonomously (no need for manual adjustment) again with the possibility of overruling. Other possibilities are ISA giving a warning only or discouraging the driver by a counteracting force in the accelerator pedal, so more force is needed to speed. The strictest type is mandatory ISA.

Several countries in Europe have been conducting research on ISA, from simulation studies to large scale testing in the field.

The calculation in this article is based on the assumption that all passenger cars are equipped with mandatory ISA, i.e., 100% penetration rate.

2. OBJECTIVES

The main objective of the report¹ on which this article is based, is to provide policy makers with information regarding the potential savings in safety of ISA. This information is important for policy makers in their decision making regarding the continuation of research in the field of ISA.

*This article is based on the report 'Safety Consequences of Intelligent Speed Adaptation ISA'¹.

The main objective of ISA is to reduce speeding on the whole urban and rural road network and so to reduce speed and speed differences.

The ultimate goal is a reduction in the number of road accidents and casualties.

3. DESCRIPTION OF ISA

An ISA system consists of a GPS receiver in the car that determines the position of the car on a road network. For ISA the speed limit information of every road section is added to the road network information. So the in-car system knows its position on the road network and the prevailing speed limit. The driver receives feedback about impending speeding. This feedback can be given in several forms: an auditory and/or visual warning or a counter force by the accelerator pedal or prevention of speeding by regulation of the fuel/braking system.

As a navigation system also comprises a GPS receiver and road network software, ISA and navigation will be integrated.

The acceptance of a future mandatory system as yet is poor – the car industry is against such a system. So ISA has to be voluntary for years after introduction, where the driver has the possibility to switch ISA off.

The most sophisticated ISA will also encompass the safe maximum speed at the approach of dangerous locations and under unfavourable road, traffic and weather conditions.

4. ISA IN EUROPEAN COUNTRIES

Research on ISA has been conducted in several European countries, such as Sweden, United Kingdom and the Netherlands. ISA has also been researched by EU countries, e.g., in the projects MASTER⁴ and ADVISORS³, where the countries directly involved participated with other countries in consortia.

4.1 ISA experiments in Sweden

In the period 1999–2001 large scale experiments were conducted with ISA in four Swedish towns⁵. The objective was to advise the government which ISA system to select. The type of ISA being tested varied in the four towns, but all were voluntary ISA systems. In total several thousand cars were involved, next to passenger

cars, also buses, taxis and commercial vehicles. Speeds of ISA and non-ISA vehicles were measured on road stretches and at the approach of intersections. The attitude of drivers involved, the acceptance by drivers and the general public as well as the experiences of the drivers with ISA were ascertained by surveys. The behaviour of drivers was also to be determined. An accident analysis will be conducted.

It is estimated that the reduction in injury accidents as a result of ISA installed in all vehicles in built up areas will vary between 10% with a voluntary system and 20 to 40% with a mandatory dynamic system.

Preliminary results of the experiments in Lund⁶ and Umeå⁷ have been published. In Lund 225 cars have been equipped with an active gas pedal during 10 months. The driving data of all equipped vehicles is logged with regard to time and speed, both before and after activating the system. Driver behaviour and workload is studied with the help of an instrumented vehicle. Possible system effects, such as speeds, interactions with other road-users (with cars without ISA, with pedestrians and cyclists) and driving through red light are studied in the field. Also accident statistics are analysed. Possible changes in driver attitudes and acceptance are studied by interviews. Only some before measurements were given. In the before period the speed limit has been exceeded to a large extent.

Two thirds of the area of Umeå was allocated as the field trial area. The speed limits in the field trial area are 30, 50, 70 and 90km/h. Four thousand vehicles were installed with ISA, using 200 beacons to transmit the speed limit information to the vehicle. In the vehicle a flashing red light and increasing beeps (Smart Speed system) that signal to the driver that he is speeding was installed.

Surveys were conducted among professional drivers and the general public. Traffic flow measurements were conducted at 106 spots in three periods. Traffic conflict studies were used to analyse traffic safety. Early results show that 67% of the respondents claim that they have totally avoided continued speeding after a system alarm, while those 33% that have continued speeding say they were in a hurry. It was found that it has become easier to adhere to the speed limit and it was experienced that the overall speed in the road network has decreased. The respondents also claim to be more alert to vulnerable road users. Less positive results were that driving pleasure has decreased, frustration because of driving at low speeds, increased travel times, though no compensation by speeding outside the trial area was mentioned. The acceptance is high: 88% supported the equipment in-

stalled. A decrease in speed and speed distribution was found.

4.2 University of Leeds

As part of the MASTER project a literature review was conducted where Advanced Transport Telematics ATT and traditional methods (non-ATT) of reducing driver speed were evaluated⁸. It was concluded that traditional methods such as traffic calming can be effective at reducing driver speed at isolated sites. The most successful measures appear to be those which require drivers physically to lower their speed (e.g., road humps) or alter the way in which drivers perceive the road (e.g., perceptual counter measures). Technologically innovative methods offer opportunities of providing feedback to individual drivers, of implementing variable speed limits to maintain traffic flow and of automating longitudinal control by means of speed limiters and adaptive cruise control. It was concluded that informative or advisory systems may have less potential negative safety effects than intervening systems which automate part of the driving task.

Further, the most promising speed management strategies were evaluated in a driving simulator. Drivers encountered curves in a simulated road network that were either treated with one of four implementations or untreated. The four systems employed ranged from information systems (either using traditional methods such as transverse striping on the road, or an in-car advice system), to one which conveyed the threat of punishment (using a variable message sign) to a fully automated system. It was hypothesised that by providing information and speed advice to the driver, speed would be reduced on the treated curves. It was also hypothesised that the different systems would have differing effects in terms of their effectiveness. The results suggest that the provision

of speed advice to drivers does result in reduced speeds on the approach and negotiation to curves. It seems to matter little exactly in what mode this advice is given. As would be expected optimal performance is attained with an automatic system although further research should evaluate long-term benefits and behavioural adaptation issues.

In a simulation study by the University of Leeds and the Motor Industry Research Organisation Association⁹, three types of ISA and three types of speed limiters were related to reduction of casualty and fatal accidents. The three ISA types were:

- Advisory type – display of the limit and a warning is given to the driver when speeding;
- Driver select – the driver can select by pressing a push button: ‘ISA IN’ or ‘ISA OUT’; and
- Mandatory type – speeding is not possible.

The option of discouraging the driver to speed by asserting a counter force to the accelerator pedal (half open type) was not considered here.

The limiter types considered were:

- Fixed – the general speed limit per road section;
- Variable – specific speed limit depending on road situation: e.g., pedestrian crossing; and
- Dynamic – a specific speed limit depending on prevailing conditions of weather, traffic and light.

The best estimates were based on a literature review. For advisory ISA each 1km/h change in mean speed the best estimate of the change in accident risk was 3%. For mandatory ISA an additional element was introduced, because the speed distribution is transformed as all speeds above the limit are cut off. A formula applied for the relationship between speed variance and risk was used here. The results are shown in Table 1.

Table 1 Best estimates of accident savings by ISA type and severity

ISA type	Speed limit type	Best estimate of injury accident reduction	Best estimate of fatal and serious accident reduction	Best estimate of fatal accident reduction
Advisory	Fixed	10%	14%	18%
	Variable	10%	14%	19%
	Dynamic	13%	18%	24%
Driver select	Fixed	10%	15%	19%
	Variable	11%	16%	20%
	Dynamic	18%	26%	32%
Mandatory	Fixed	20%	29%	37%
	Variable	22%	31%	39%
	Dynamic	36%	48%	59%

The arguments against ISA and the counter arguments are:

- Drivers will switch off ISA, so the authors plead for dynamic ISA. Another possibility to encourage ISA is, for example, to reduce the car insurance premium;
- Drivers need to be able to accelerate out of danger. The article mentions that the need for this was 0.5%. A possibility is the 'kick-down' escape;
- Short following distances where the car in front is driving slowly. As stated elsewhere in this presentation the expectation is that in future several functions such as ISA, navigation system and ACC will be integrated, so such a system will prevent this.

A path to full implementation as outlined in this article puts this in the year 2019. The effect of ISA on speed behaviour and safety might already be achieved with much less than 100% penetration of ISA, so most of the effect might be achieved at a much earlier stage.

In the period up to 2005 the University of Leeds¹⁰ has planned to conduct follow-on research regarding External Vehicle Speed Control, encompassing building a prototype ISA car for field tests, simulator behaviour studies, preparing an ISA design for motorcycles and heavy vehicles, and investigate costs and benefits of ISA.

4.3 Field tests in three countries

Field tests were conducted¹¹, as part of the MASTER project, with static ISA in Sweden, the Netherlands and Spain. Measurements were conducted in real traffic using an unobtrusive instrumented vehicle. The subjects (20–24) drove with and without ISA on all types of roads with a total length of 20 to 30km. Excessive speeds were reduced as well as the average speed especially in built-up areas. No significant changes could be found on 80–90km/h roads and motorways, where heavy traffic slowed down the speed level below the prevailing speed limit. Speed variance decreased and a more adjusted approach speed of roundabouts, intersections and bends was found. Travel time increased slightly as well as frustration, car-following behaviour became less safe in the speed interval 70–90km/h. The headway was also reduced, raising concerns of possible higher rates of rear-end collisions.

4.4 Speed enforcement as an alternative for ISA

For comparison, speed enforcement as a speed management tool is also considered here.

The speed reducing effect of ISA can in principle also be achieved by conventional methods, such as speed enforcement. The question is how this can be achieved.

Automatic enforcement, i.e., using speed cameras is needed, because of the limited manpower of the traffic police. During speed enforcement experiments in the Netherlands¹², drivers were questioned what their speed behaviour would be when they would encounter speed checks respectively: never, once a month or once a week. The percentages of drivers who contended they will comply to the speed limit were: no enforcement: 50%, once a month: 80%, once a week: almost 100%. So to have a comparable effect as ISA, the enforcement frequency per road stretch should be at least once a week, or 12 hours per week per road stretch (enforcement during daytime only). This enforcement frequency is far beyond the capacity of the Dutch traffic police force.

5. ISA IN THE NETHERLANDS

The estimate of the Dutch Ministry of Transport¹³ of a 100% observance of the speed limits on road safety is that road fatalities will be reduced by 200 (20%) and hospitalised wounded by 3,000 (15%). Fuel consumption and carbon dioxide emission will be reduced by 11% each.

A theoretical calculation was made regarding the effect of ISA on speed and road safety, assuming that all vehicles are equipped with mandatory ISA.

5.1 Field experiment in the city of Tilburg

A field experiment with ISA – speeding was impossible except when the emergency button was pushed – was conducted in a district of the city of Tilburg. The roads in this district have a speed limit of respectively 80, 50 and 30km/h. Twenty vehicles were equipped with ISA and 120 inhabitants of the district joined the test, each for 8 weeks. The ISA system was an in-car system, no road beacons were used. Position of the car was determined by differential GPS (dGPS). The objective was to learn about the behaviour of the test drivers and the acceptance of ISA by these drivers as well as others (and an evaluation of the technical operation).

5.1.1 Acceptance of ISA

It is remarkable that the acceptance of ISA is higher before the test than during the test. For test drivers 64 -> 49%, and for other drivers 55 -> 40%. The acceptance of test drivers is largest for residential roads: 66%; for provincial roads the acceptance is 47%. Experience can have a positive effect: 16% of the test drivers are against

mandatory ISA, while of the sample of drivers taken from the province Noord-Brabant (in which Tilburg is situated) this percentage is 45. The majority of the bus drivers experience driving with ISA as more comfortable.

5.1.2 Effect on behaviour

The average speed is lowered, especially by eliminating excessive speeds, and as a result the standard deviation is also lowered and overtaking is reduced. The expectation is that ISA will improve road safety. Though irritations have occurred on the part of drivers without ISA towards drivers in front with ISA.

5.2 Effect of ISA on speed and road safety in the Netherlands

The theoretical calculation was based on measured data of vehicle speed and the number of casualties differentiated according to road type/speed limit in the Netherlands. It is assumed that speeds follow a normal distribution and that ISA will result in the following changes to the speed distribution (Figure 1):

- The right tail of the speed distribution (striped) will change to a peak at the speed limit (δ function) – all speeding vehicles will then drive at the limit speed;
 - Drivers driving with lower speeds do not change their speed behaviour;
 - The average speed H of speeders can be derived from the normal distribution;
 - The average speed will be lowered from G to Z.
- $$Z = G - P * (H - L)$$
- L = speed limit, P = % speeders, H = average speed of speeders, G = average speed without ISA, Z = average speed with ISA;

- The effect of ISA will extend only to accidents/casualties where at least one motor vehicle is involved.

The reduction in accidents, wounded victims and fatalities differentiated to road type is calculated using the empirical Swedish formula¹⁴. The percentage of reduction will be: $100 \times [1 - (Z/G)^3]$ for wounded victims and to the 4th power for fatalities.

The Dutch Ministry of Transport¹⁵ conducted a detailed speed evaluation comparing the theoretically calculated reduction in speed with the achieved speed reduction with ISA at Tilburg. The general conclusion is that ISA is a viable option.

Table 2 shows that the calculated reduction (in parentheses) in average speed is in accordance with the measured average speed reduction, only on 30km/h roads the measured reduction was greater than the calculated reduction.

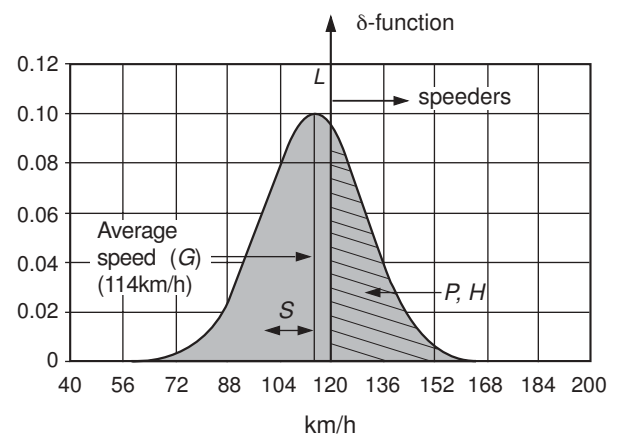


Fig. 1 Changes to the speed distribution when all cars are equipped with ISA

Table 2 Validation of the calculated reduction in average speed with field measurements on streets with and without speed humps

Speed limit km/h	Moments of speed distribution	No speed humps	No speed humps	No speed humps	With speed humps	With speed humps	With speed humps
		No ISA	With ISA	Calculated	No ISA	With ISA	Calculated
30	Average	32.9	24.6 [-25.2%]	27.3 [-17.0%]	28.1	25.4 [-9.6%]	25.1 [-10.7%]
	Standard deviation	10.1	6.6		9.7	7.3	
50	Average	44.7	41.7 [-6.7%]	41.6 [-6.9%]	38.6	37.1 [-3.9%]	37.7 [-2.3%]
	Standard deviation	13.4	10.6		11.2	9.2	
80	Average				63.8	63.4 [-0.6%]	63.4 [-0.6%]
	Standard deviation				11.7	10.9	

5.3 Speed per road type

In Table 3 several characteristics of the speed distribution – average speed, standard deviation and percentage of speeders – are given for three rural road types. The percentage of speeders varies between 36 and 53%.

Table 3 Speed characteristics on rural roads differentiated to road type/speed limit

Road type Speed limit	Average speed G km/h	Standard deviation km/h	% > Speed limit
Motorway 120km/h	114	16	36%
Trunk road 100km/h	91	13	31%
Secondary road 80km/h	82	15	53%

In Table 4 the speed characteristics of the speed distribution for two urban road types are given. The percentage of speeders is respectively 32 and 61%.

Table 4 Speed characteristics on urban roads differentiated to road type

Road type Speed limit	Average speed G km/h	Standard deviation km/h	% > Speed limit
50km/h			
With cycle track	54	12	61%
Without cycle track	46	10	32%

5.4 Casualties per road type

In Table 5 the number of road casualties – from fatality to slightly wounded – is presented on roads with different speed limits during accidents in which at least one motor vehicle is involved (NL–1998).

Table 5 Road casualties (accidents with at least one motor vehicle involved) on roads with different speed limits

Casualty type	120km/h	100km/h	80km/h	50km/h
Fatality	57	51	503	310
Hospitalised	584	434	3,474	4,972
Slightly wounded	1,405	1,305	6,468	20,015

5.4.1 Effect of ISA on reduction in casualties per road type

In Table 6 the calculated estimation of a reduction in casualties is given for four road types, using the Swedish empirical formula relating change of average speed

and change in accident/casualty rate.

Table 6 The calculated reduction in fatalities and wounded victims in NL differentiated to road type when all vehicles are equipped with ISA

Reduction in	Motorway	Trunk road	Secondary road	Urban road
Fatalities	7	4	151	119
Wounded victims	199	104	2,386	7,496

The Dutch Ministry of Transport¹⁶ has formulated a policy regarding ITS. Stimulation of the fitting of ITS systems in cars is done by tax exemptions e.g., for cruise control systems and in-car computers. In consideration for such exemptions are for example ACC.

Preparation for testing Lane Departure Warning Assisting Systems has been started in 2001.

In extension to the successful field test of ISA, a plan for action will be formulated. It is intended to conduct tests with an Autonomous Speed Assistant (ASA) by providing the driver with intelligent speed advice with ACC technology. Decisions have to be made by the recently formed new coalition government regarding the ITS plans.

6. POSSIBLE FUTURE DEVELOPMENTS

New cars in the higher price range nowadays often have ISA installed as a standard by the factory. The driver can manually adjust the speed limit. Speeding is not possible except when 'kick-down' is applied in case of an emergency.

The fitting of navigation systems in new cars shows a tremendous growth in the Netherlands. Geographical location of the vehicle is determined by GPS and road network data stored on a CD-ROM or DVD.

The next step is the addition of speed limit information to the software of the navigation system, so the speed limit is known at any time. Coupling this information with the ISA speed management system in the car will result that speeding belongs to the past. The only thing that is needed to achieve this is that the driver pushes the button: 'ISA IN'.

Further possible developments are that the safe maximum approach speeds of dangerous sharp bends, intersections, a pedestrian crossing or slippery road surfaces are imposed by the system.

It is not needed that all cars be equipped with ISA

to have a considerable effect on speed and accidents. It is not known as yet how the relation between penetration level and speed distribution looks like. But it is not improbable that a rather low penetration level will already have a noticeable effect on speed behaviour, especially on urban and 2-lane rural roads.

The costs of such an ISA might be rather low, if the vehicle has been pre-installed with a navigation system and a speed management system. Further it is expected that systems like navigation, ISA and advanced cruise control (ACC) will be integrated in future.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Simulator studies showed a significant reduction in speed and speed variation on urban roads. A negative effect was the shortening of headways and a possible lowered attention.

Field trials with an instrumented vehicle showed a substantial reduction of speed and standard deviation, especially on urban roads. Another improvement, i.e., lowered approach speed at critical locations was found.

Validation of the calculated average speed reduction with field trial measurements showed great correspondence.

On the premise that all cars are fitted with ISA in the Netherlands, a substantial reduction in casualties between 25 and 30% may be expected.

7.2 Recommendations

More computer simulation studies are recommended to ascertain the relationship between penetration rate and speed behaviour.

More large scale field research is needed before final conclusions can be drawn for the Netherlands. Such a field test could be conducted using existing cars fitted with a navigation system and manual ISA. The software should be expanded with speed limit information for roads, e.g., in a province where the test will be conducted. The speed limit information should be connected to the fuel and brake feedback system. A data-recorder in the car will send periodically the information to a centre for data-analysis.

Research regarding the maximum safe speed at the approach of specific locations such as bends, intersections, pedestrian crossings, schools, etc. is needed. Results of this research can be used to supplement the

software of an ISA/navigation system (next to the road network and speed limit information).

Research is needed regarding the integration of the systems navigation, ISA and ACC, in technical, informational and human machine interface sense.

REFERENCES

- Oei, H. L. Safety Consequences of Intelligent Speed Adaptation ISA. R-2001-11. SWOV Institute for Road Safety Research, Leidschendam. (2001). [In Dutch].
- Taylor, M. C., Lynam, D. A. & Baruya, A. The effects of drivers' speed on the frequency of road accidents. TRL Report 421. Transport Research Laboratory. (2000).
- ADVISORS Project. Problem Identification, User Needs, and Inventory of ADAS. Chapter 3: State of the art on ADA systems, user needs their evaluation results and current implementation trends. ADVISORS, Deliverable D1/2.1 V4. January 2001. Project funded by the European Commission. (2001).
- MASTER Project. Managing Speeds of Traffic on European Roads. MASTER Final Report. VTT Technical Research Centre of Finland, Communities and Infrastructure. Espoo, Finland. Project funded by the European Commission. (1998).
- Lind, G., Lindkvist, A. & Carlsson, A. Intelligent Speed Adaptation in Sweden (summary). Draft report. 7th December 1999. Swedish National Road Administration SNRA – Vägverket, Borlänge. (1999).
- Várhelyi, A., Hydén, Chr., Hjälm Dahl, M., Almqvist, S., Ashouri, H., Draskóczy, M. & Rissler, R. Preliminary results from a large scale trial with intelligent speed adaptation in Lund, Sweden. Paper presented at the 8th World Congress on Intelligent Transport Systems, 30th September – 4th October 2001, Sydney. (2001).
- Sundberg, J. Smart speed – Results from the large scale field trial on intelligent speed adaptation in Umeå, Sweden. Paper presented at the 8th World Congress on Intelligent Transport Systems, 30th September – 4th October, 2001, Sydney. (2001).
- Comte, S. & Jamson, H. The effects of ATT and non-ATT systems and treatments on speed adaptation behaviour. Part of MASTER project. (1998).
- Carsten, O., Fowkes, M. & Tate, F. Implementing intelligent speed adaptation in the UK: recommendations of the EVSC (external vehicle speed control) project. Paper presented at the 7th World Congress on Intelligent Transportation Systems, November 2000 at Turin. (2000).
- Traffic Engineering & Control, March 2002. Supplement: British Universities' Transport Research Projects 2001. (2002).
- Várhelyi, A., Comte, S. & Mäkinen, T. Evaluation of in-car speed limiters. Final report. Part of the MASTER project, funded by the European Commission. (1998).
- Oei, H. L. The effect of enforcement on speed behaviour. A literature study. Part of the MASTER project. Project funded by the European Commission. D-98-8 SWOV, Leidschendam. June 1998. (1998).
- Ministry of Transport. ISA Tilburg. Final Report. Field Experiment Intelligent Speed Adaptation. Rotterdam, February 2001. (2001). [In Dutch].
- Nilsson, G. The effects of speed limits on traffic accidents. In: OECD Proceedings, Dublin, 1981. (1981).
- Dutch Ministry of Transport. Methodology ISA 2nd phase. Rotterdam, September 17, 2001. (2001). [In Dutch].
- Dutch Ministry of Transport. A framework for automatic vehicle guidance 2001-2006. The Hague, November 2001. (2001). [In Dutch].